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Proximal and distal reciprocal changes following cervical deformity malalignment correction

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OBJECTIVE Hyperextension of C0–2 is a debilitating compensatory mechanism used to maintain horizontal gaze, analogous to high pelvic tilt in the lumbopelvic complex to maintain an upright posture. This study aims to investigate the impact of cervical deformity (CD) correction on this hyperextension. The authors hypothesize that correction of cervical sagittal malalignment allows for relaxation of C0–2 hyperextension and improved clinical outcomes.

METHODS A retrospective review was conducted of a multicenter database of patients with CD undergoing spinal realignment and fusion caudal to C2 and cephalad to the pelvis. Range of motion (ROM) and reserve of extension (ROE) were calculated across C2–7 and C0–2. The association between C2–7 correction and change in C0–2 ROE was investigated while controlling for horizontal gaze, followed by stratification into ΔC2–7 percentiles.

RESULTS Sixty-five patients were included (mean age 61.8 ± 9.6 years, 68% female). At baseline, patients had cervical kyphosis (C2–7, −11.7° ± 18.2°; T1 slope–cervical lordosis mismatch, 38.6° ± 18.6°), negative global alignment (sagittal vertical axis [SVA] −12.8 ± 71.2 mm), and hyperlordosis at C0–2 (mean 33.2° ± 11.8°). The mean ROM was 25.7° ± 17.7° and 21.3° ± 9.9° at C2–7 and C0–2, respectively, with an ROE of approximately 9° for each segment. Limited C0–2 ROM and ROE correlated with the Neck Disability Index ($r = −0.371$ and $−0.394$, $p < 0.01$). The mean number of levels fused was 7.0 ± 3.1 (24.6% anterior, 43.1% posterior), with 87.7% undergoing at least an osteotomy. At 1 year, mean C2–7 increased to 5.5° ± 13.4°, SVA became neutral (11.5 ± 54.8 mm), C0–2 hyperlordosis decreased to 27.8° ± 11.7°, and thoracic kyphosis (TK) increased to −49.4° ± 18.1° (all $p < 0.001$). Concurrently, mean C0–2 ROM increased to 27.6° ± 8.1° and C2–7 ROM decreased significantly to 9.0° ± 12.3° without a change in ROE. Controlling for horizontal gaze, change in C2–7 lordosis significantly correlated with increased TK ($r = −0.617$, $p < 0.001$), decreased C0–2 ($r = −0.747$, $p < 0.001$), and increased C0–2 ROE ($r = 0.550$, $p = 0.002$).

CONCLUSIONS CD correction can significantly impact cephalad and caudal compensation in the upper cervical and thoracic spine. Restoration of cervical alignment resulted in increased C0–2 ROE and TK and was also associated with improved clinical outcome.

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KEYWORDS cervical deformity; reciprocal change; compensation; relaxation; sagittal alignment

ABBREVIATIONS BMP = bone morphogenetic protein; CCI = Charlson Comorbidity Index; CD = cervical deformity; CL = cervical lordosis; cSVA = cervical SVA; EBL = estimated blood loss; HRQOL = health-related quality of life; IQR = interquartile range; LIV = lowermost instrumented vertebra; LL = lumbar lordosis; LOS = length of stay; MGS = McGregor's slope; mJOA = modified Japanese Orthopaedic Association; NDI = Neck Disability Index; NRS = numeric rating scale; PI = pelvic incidence; PI-LL = PI-LL mismatch; PT = pelvic tilt; ROE = reserve of extension; ROM = range of motion; SVA = sagittal vertical axis; T1S = T1 slope; TK = thoracic kyphosis; TLK = thoracolumbar kyphosis; TPA = T1 pelvic angle; TS-CL = T1S-CL mismatch; UIV = uppermost instrumented vertebra.

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Cervical deformity (CD) is a debilitating condition that causes pain and disability and has a negative impact on health-related quality of life (HRQOL).[1] A recent study found that the mean CD EQ-5D index can be grouped along with the bottom 25th percentile values of severe medical conditions, including blindness, emphysema, renal failure, and stroke.[2] In addition to having neurological symptoms and associated comorbidities, patients with severe CD experience difficulty maintaining a horizontal gaze, which necessitates recruitment of several compensatory mechanisms, including C0–2 hyperlordosis.[3] Corrective surgery for CD is often effective in restoring horizontal gaze, correcting sagittal malalignment, relieving neurological symptoms, and improving patient-reported outcomes.[3,4]

The phenomenon of spinal compensation is one of the established concepts in spinal deformity that was described by numerous authors, including Dr. Jean Dubousset. In patients with loss of lumbar lordosis (LL), full-body radiographic studies described compensatory mechanisms that were recruited to maintain an upright posture such as cervical hyperlordosis, thoracic hypokyphosis, pelvic retroversion, and knee flexion.[5] Similarly, studies of patients with cervical kyphotic deformity showed distal compensatory changes such as a posterior thoracolumbar malalignment and lumbar hyperlordosis.[6] On the regional cervical level, a study by Khalil et al. demonstrated that the upper cervical spine compensates for C2–7 cervical kyphosis by recruiting C0–2 hyperlordosis to maintain the patient's horizontal gaze.[7]

If adequately performed, surgical correction of spinal deformity often leads to relaxation of those compensatory mechanisms.[4] Previous studies on thoracolumbar deformities demonstrated the indirect correction of cervical hyperlordosis following lumbar pedicle subtraction osteotomy.[8] It was shown that correction of the sagittal malalignment improved the compensatory cervical hyperlordosis. However, there are limited data on the impact of cervical kyphosis deformity correction on relaxation of upper cervical hyperlordosis and subsequent clinical outcomes. Specifically, in-depth studies on postoperative C0–2 reserve of extension (ROE) remain sparse. This raises the question of whether correction of CD is sufficient to cause indirect correction of global alignment. The objective of this study was to evaluate the reciprocal changes proximal and distal to the correction and their association with patient-reported outcomes.

Methods

Patient Population

This study is a retrospective review of a multicenter, prospective database of patients with CD. IRB approval was obtained for each site prior to data collection. Inclusion criteria for the database included patient age > 18 years and the presence of at least one of the following radiographic criteria for CD: cervical scoliosis > 10°, cervical kyphosis (C2–7) > 10°, cervical plumbline (cervical sagittal vertical axis [cSVA]) > 4 cm, and chin-brow vertical angle > 25°. For the present study, only patients who were surgically treated between 2012 and 2015 were analyzed. Patients must also have had a minimum 1-year follow-up. Those patients who had a fusion procedure extending to the occiput or pelvis were excluded.

Data Collection

Data were collected preoperatively to the 1-year follow-up points. Data included demographic, clinical, surgical, and radiographic information, as well as standardized HRQOL questionnaires. Demographic information consisted of age, sex, BMI, previous cervical spine surgery, and comorbidities, which were used to calculate a Charlson Comorbidity Index (CCI) score.[9] Surgical information included surgical approach, osteotomies performed, use of bone morphogenetic protein (BMP), number of levels treated, number of levels fused, uppermost instrumented vertebra (UIV), lowermost instrumented vertebra (LIV), mean operating time, estimated blood loss (EBL), and mean hospital length of stay (LOS).

Radiographic information collected consisted of both cervical and global alignment parameters. Cervical alignment parameters were T1 slope (T1S), cervical curvature (C2–7), T1S–cervical lordosis (CL) mismatch (TS-CL), C0–2 sagittal Cobb angle (C0–2), and McGregor's slope (MGS), which is a validated measure of horizontal gaze.[10] Global alignment parameters were pelvic incidence (PI), pelvic tilt (PT), PI-LL mismatch (PI-LL), thoracolumbar kyphosis (TLK) measured between T10 and L2 (T10–L2), thoracic kyphosis (TK) between T2 and T12 (T2–12), T1 pelvic angle (TPA), and sagittal vertical axis (SVA). Other radiographic measures obtained were cervical alignments in the flexion, extension, or neutral positions, examined preoperatively and 1 year postoperatively. Range of motion (ROM) of the cervical spine was calculated by subtracting the flexion alignment measurement from the extension alignment measurement (e.g., extension minus flexion). ROE was also calculated by subtracting the neutral alignment measurement from the extension alignment measurement (e.g., extension minus neutral lateral). All measurements were performed at a centralized location using validated and dedicated software for radiographic measurements (Spineview, ENSAM Laboratory of Biomechanics;[11] Fig. 1). Neutral radiographs were obtained in a free-standing position of comfort, with no requirement regarding horizontal gaze.

Standardized HRQOL questionnaires included the Neck Disability Index (NDI),[12,13] numeric rating scale (NRS) for the back and neck, and modified Japanese Orthopaedic Association (mJOA) score for myelopathy.[14] The NDI was scored from 0 to 100 points, and an NDI > 40 points was considered severe disability.[15] The mJOA has a score ranging from 0 to 18 points: severe myelopathy was defined as mJOA score < 11, moderate myelopathy as 12–14, and mild myelopathy as 15–17.[14]

Statistical Analysis

Descriptive analyses were used to summarize the patient cohort. Analyses pertained to patient demographics, past medical history, comorbidities, and previous surgical treatment. Associations between preoperative sagittal alignment of the cervical spine and patient-reported outcomes were determined using bivariate Pearson's cor-

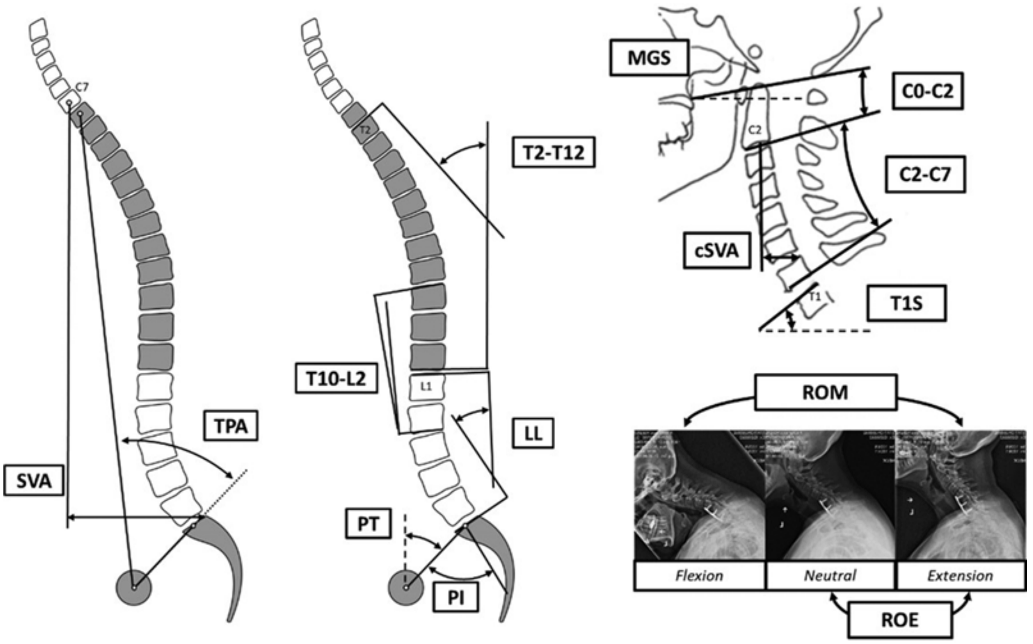


FIG. 1. Radiographic parameters collected: PI, PT, LL, PI-LL, TLK (T10–L2), TK (T2–12), TPA, SVA, T1S, cervical curvature (C2–7), TS-CL, cSVA, C0–2 sagittal Cobb angle (C0–2), and MGS. ROE = the difference between neutral and extension alignment; ROM = the difference between flexion and extension alignment.

relations. The changes in cervical and global alignment parameters from the pre- to postoperative period were assessed by using paired t-tests or the Wilcoxon rank-sum test as appropriate. The association between cervical correction and change in sagittal alignment was determined using multilinear regression to predict relaxation associated with a given cervical correction while controlling for the horizontal gaze alignment. All statistical analyses were performed using IBM SPSS (version 20.0, IBM Corp.). A p value ≤ 0.05 was considered statistically significant.

Results

Patient Information

Sixty-five patients had sufficient data to meet eligibility criteria and were included in the analysis. Preoperative data showed that 67.7% of patients were female, the mean (± SD) age was 61.8 ± 9.6 years, the mean BMI was 28.5 ± 7.2 kg/m^2, the median CCI was 1 (interquartile range [IQR] 0–2), and 28 patients (43.1%) had previous cervical spine surgery (Table 1). Of the patients who had previously undergone cervical spine surgery, 13 had an anterior fusion, 5 had a laminectomy, and 11 had a posterior fusion; none of those fusions extended cephalad to C2 or caudal to L5. Preoperative HRQOL questionnaires included the NDI, NRS-back, NRS-neck, and mJOA. The mean NDI score was 48.5 ± 16.6 and 67.7% of the patients had an NDI score that was above the threshold for severe disability. The NRS-back and -neck scores were 5.0 ± 3.0 and 6.8 ± 2.4, respectively. The mean mJOA score was 13.8 ± 2.5, indicating moderate myelopathy symptoms for the group (Table 1). The mJOA scores in 32.3% of patients showed moderate myelopathy symptoms, while 15.4% had mJOA scores suggesting severe myelopathy symptoms.

Surgical Data

All included patients underwent surgical correction for CD: 24.6% had an anterior approach only, 43.1% had a posterior approach only, and 32.3% had a combination of anterior and posterior surgical approaches (Table 2). Patients underwent at least one osteotomy in 87.7% of cases. The breakdown by type of osteotomy was as follows: 53.8% had some anterior osteotomy, 49.2% had some posterior osteotomy, and 16.9% had a grade 6 or 7 osteotomy (3-column osteotomy). Additionally, BMP was used in 26 patients.

The number of spinal levels treated varied greatly and ranged from 2 to 15 levels. The mean number of levels

TABLE 1. Demographic and preoperative patient-reported outcomes (n = 65)

Variable	Value
Mean age ± SD, yrs	61.8 ± 9.6
Females (%)	44 (67.7)
Mean BMI ± SD	28.5 ± 7.2
Median CCI (IQR)	1 (0–2)
History of CS surgery, n (%)	28 (43.1)
Anterior fusion	13 (20.0)
Laminectomy	5 (7.7)
Posterior fusion	11 (16.9)
Mean NDI ± SD	48.5 ± 16.6
Mean NRS-back ± SD	5.0 ± 3.0
Mean NRS-neck ± SD	6.8 ± 2.4
Mean mJOA score ± SD	13.8 ± 2.5

CS = cervical spine.

TABLE 2. Surgical information and complication rates for the entire cohort

Variable	Value
Surgical data	
Approach, %	
Ant only	24.6
Pst only	43.1
Combine ant & pst	32.3
Osteotomy, %	87.7
Ant	53.8
Pst	49.2
3-column	16.9
Mean no. levels treated (range)	7 ± 3 (2–15)
No. of levels fused	
Mean ± SD	8 ± 3.5
Median (IQR)	8 (5–10)
UIV, %	
C2	53.8
C3	24.6
C4	21.5
LIV, %	
Above T2	58.5
Between T3 and T5	30.8
Below T5	10.8
Mean OR time ± SD, mins	370 ± 224
Median EBL (IQR), ml	500 (200–975)
Mean LOS ± SD, days	5.5 ± 3.1
Complication rates, n (%)	
Any complication	33 (50.8)
Major complication	18 (27.7)
Needing a reop	5 (7.7)
Minor complication	20 (30.8)
Cardiopulmonary	5 (7.7)
Dysphagia	7 (10.8)
Dysphonia	3 (4.6)
GI	1 (1.5)
Infection	6 (9.2)
Instrumentation	2 (3.1)
Neurological	13 (20)
Operative	7 (10.8)
Radiographic	3 (4.6)
Renal	0 (0)
Vascular	3 (4.6)
Wound	1 (1.5)

ant = anterior; GI = gastrointestinal; OR = operating room; pst = posterior.

TABLE 3. Preoperative and 1 year postoperative alignment

Radiographic Parameter	Preop	1 yr Postop	p Value
Thoracolumbar alignment			
PI, °	52 ± 12.4	52 ± 12.6	0.914
PT, °	18 ± 11.2	18.3 ± 10.9	0.664
PI-LL, °	−0.5 ± 19.1	0.4 ± 16.5	0.430
T10–L2 (TLK), °	−6.4 ± 14.3	−11.1 ± 17.9	**0.001**
T2–12 (TK), °	−43.4 ± 18.2	−49.4 ± 18.1	**0.000**
TPA,°	11.2 ± 12.6	13.4 ± 11.3	**0.034**
SVA, mm	−12.8 ± 71.2	11.5 ± 54.8	**0.001**
Cervical alignment			
T1S, °	26.9 ± 15.2	34.5 ± 13.2	**0.000**
C2–7, °	−11.7 ± 18.2	5.5 ± 13.4	**0.000**
TS-CL, °	38.6 ± 18.6	29 ± 13.6	**0.000**
cSVA, mm	36.3 ± 20.3	32.9 ± 15.5	**0.033**
C0–2, °	33.2 ± 11.8	27.8 ± 11.7	**0.000**
MGS, °	4.5 ± 13.3	−0.5 ± 9.3	**0.003**
Dynamic alignment, °			
C2–7 ROM	25.7 ± 17.7	9 ± 12.3	**0.000**
C0–2 ROM	21.3 ± 9.9	27.6 ± 8.1	**0.006**
C2–7 ROE	9.7 ± 10.2	3.8 ± 8.5	**0.000**
C0–2 ROE	9 ± 10.3	13.2 ± 11	0.352

Values are presented as mean ± SD unless otherwise indicated. Boldface type indicates statistical significance.

treated was 7 ± 3. Of the levels treated, some were previously fused, and the mean levels fused (combination of treated and any existing fusion) was 8 ± 3.5, with a median of 8 levels (IQR 5–10 levels). Most patients had a UIV at C2 (53.8%), while 24.6% had a UIV at C3 and 21.5% had a UIV at C4. The position of the LIV was above T2 in most patients (58.5%); 30.8% of patients had an LIV between T3 and T5 while 10.8% of patients had an LIV below T5 (Table 2).

Other hospital metrics related to the operation were also gathered. The mean operating duration was 370 ± 224 minutes, and the median EBL was 500 ml (IQR 200–975 ml). EBL was then stratified by surgical approach. The mean EBL was 90 ± 85.6 ml for the anterior-only approach, 630 ± 398 ml for the posterior-only approach, and 1124 ± 899 ml for the combined anterior and posterior approach, showing a significant difference between the approaches ($p < 0.001$). The mean hospital LOS was 5.5 ± 3.1 days. At least one complication was experienced by 50.8% of the patients, and 27.7% had at least one major complication, with 7.7% leading to a reoperation/revision. A breakdown according to severity and type of complication is reported in Table 2.

Sagittal Alignment

Radiographic parameters of static (neutral) alignment were measured preoperatively (Table 3). Measures of posterior global alignment included SVA and TPA, which were −12.8 ± 71.2 mm and 11.2° ± 12.6°, respectively. TS-CL and cSVA, measures of anterior cervical alignment, were 38.6° ± 18.6° and 36.3 ± 20.3 mm, respectively. Horizontal gaze was maintained, as suggested by an MGS of 4.5° ± 13.3°.[10,16]

Dynamic alignment was analyzed using ROM and ROE. ROM was calculated by the extension alignment minus the flexion alignment (extension minus flexion) measurements (Table 3). C2–7 ROM was 25.7° ± 17.7° and

TABLE 4. Correlation between preoperative patient-reported outcomes and preoperative sagittal alignment of the cervical spine

Variable	NRS-Back	NRS-Neck	NDI	mJOA
T1S				
r value	−0.109	0.152	0.057	−0.049
p value	0.391	0.230	0.649	0.722
C2–7				
r value	0.034	−0.035	−0.053	0.171
p value	0.789	0.783	0.676	0.207
TS-CL				
r value	−0.120	0.156	0.099	−0.203
p value	0.344	0.218	0.434	0.133
cSVA				
r value	−0.097	0.200	0.137	0.006
p value	0.446	0.113	0.275	0.962
C0–2				
r value	0.002	0.043	0.166	−0.128
p value	0.990	0.737	0.186	0.349
C2–7 ROM				
r value	0.094	−0.112	−0.100	0.278
p value	0.488	0.407	0.455	0.051
C0–2 ROM				
r value	0.100	−0.189	**−0.371**	0.194
p value	0.494	0.192	**0.008**	0.207
C2–7 ROE				
r value	0.187	0.125	0.090	0.205
p value	0.161	0.349	0.498	0.149
C0–2 ROE				
r value	0.009	−0.215	**−0.394**	0.229
p value	0.949	0.118	**0.003**	0.118

Boldface type indicates statistical significance.

C0–2 ROM was 21.3° ± 9.9°. ROE was calculated by the extension alignment minus the neutral alignment (extension minus neutral) measurements. C2–7 ROE was 9.7° ± 10.2° while C0–2 ROE was 9.0° ± 10.3°.

Association Between Change in Cervical Alignment and Compensatory Mechanism Relaxation

Mean C2–7 correction was an increase by 17.2° ± 18.6°. Bivariate correlations between cervical alignment and patient-reported outcomes are shown in Table 4. When controlling for change in horizontal gaze alignment, a significant association was seen between an increase in C2–7 and an increase in T2–12 (the coefficient correlation [r] is negative as kyphosis is negative), increase in SVA, increase in T1S, decrease in TS-CL, decrease in C0–2, and increase in C0–2 ROE (Table 5). There was no significant association with pelvic parameters, cSVA, or changes in cervical ROM.

Multilinear regression between change in alignment and ΔC2–7 while controlling for changes in horizontal gaze demonstrated similar results (Table 6). These results support the prediction that relaxation was associated with a 10° correction between C2–7, while maintaining the same horizontal gaze (ΔMGS = 0) will lead to a 5.6° decrease in TK, 7.7° increase in T1S, 3.2° decrease in C0–2, and a 0.6° increase in C0–2 ROE. For a 20° correction between C2–7, there would be a predicted 9.8° decrease in TK, 12.4° increase in T1S, 7.7° decrease in C0–2, and a 3.3° increase in C0–2 ROE.

TABLE 5. Partial correlation between change in C2–7 curvature (correction) and change in sagittal alignment, while controlling for the change in horizontal gaze acquisition

Parameter	r Value	p Value
ΔPT	0.187	0.331
ΔPI-LL	0.158	0.413
ΔT10–L2	−0.225	0.240
ΔT2–12	−0.617	**0.000**
ΔTPA	0.332	0.078
ΔSVA	0.382	**0.041**
ΔT1S	0.668	**0.000**
ΔTS-CL	−0.751	**0.000**
ΔcSVA	0.098	0.613
ΔC0–2	−0.747	**0.000**
ΔC2–7 ROM	0.270	0.157
ΔC0–2 ROM	0.058	0.763
ΔC2–7 ROE	0.033	0.866
ΔC0–2 ROE	0.550	**0.002**

Boldface type indicates statistical significance.

Discussion

This study showed that correction of sagittal CD led to reciprocal relaxation of the established CD compensatory mechanisms such as C0–2 hyperlordosis and thoracic hypokyphosis. In addition, CD correction improved ROM and increased the ROE of the upper cervical spine. Deformity correction and compensatory mechanism relaxation were found to be associated with improvement in patients' reported clinical outcomes (Fig. 2).

Preoperatively, patients had severe disability and pain as evident by their HRQOL questionnaire responses. Mean NDI and mJOA scores were categorized as severe and moderate, respectively. Patients also exhibited compensation for their cervical malalignment by posterior global thoracolumbar alignment, reduction of T1S, and upper cervical hyperextension. After correcting for their CD, patients showed significant improvement in subaxial cervical sagittal alignment as a driver of deformity, as well as a relaxation in the global chain of compensation. The amount of correction was proportional to the associated relaxation, so a larger correction was associated with a larger amount of relaxation. And, while controlling for changes in horizontal gaze, a large correction also increased the upper cervical ROE. This study also established formulas to predict the relaxation of compensation, allowing spine care providers to estimate the indirect effect of the corrections on adjacent segments while con-

TABLE 6. Multilinear stepwise regression predicting the change in alignment using ∆C2–7 and ∆MGS as independent predictors

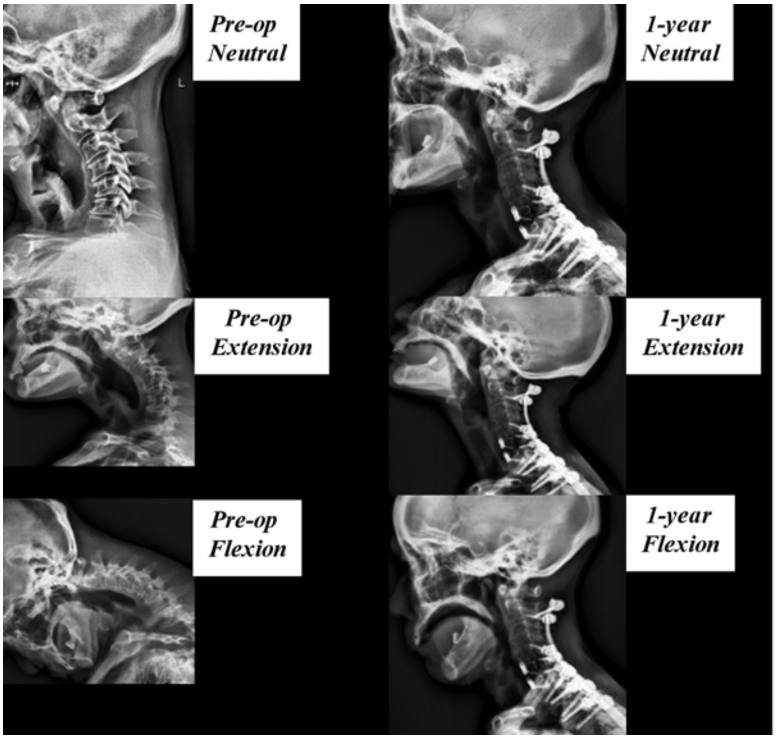
Change in Alignment	Mutilinear Regression		Predicted Values	
	R (R^2)	Coefficients	∆C2–7 = 10°	∆C2–7 = 20°
∆T2–12	0.568 (0.323)	–1.350 – 0.524 × ∆MGS – 0.424 × ∆C2–7	–5.6°	–9.8°
∆T1S	0.755 (0.570)	2.944 + 0.693 × ∆MGS + 0.471 × ∆C2–7	7.7°	12.4°
∆C0–2	0.730 (0.533)	1.298 – 0.199 × ∆MGS – 0.450 × ∆C2–7	–3.2°	–7.7°
∆C0–2 ROE	0.364 (0.132)	–2.188 + 0.230 × ∆MGS + 0.275 × ∆C2–7	0.6°	3.3°

For reference purposes, prediction of the change in alignment associated with a correction at C2–7 of 10° and 20° while maintaining horizontal gaze (∆MGS = 0) is reported.

trolling for horizontal gaze output. We found that a 20° correction would drive a relaxation of about 10° in TK and T1S, 7° in C0–2, and an increase of 3° in C0–2 ROE. These estimations assume homogenous correction of each parameter. However, they do not account for the potential nonlinear answer for some parameters.

Our study demonstrated a lack of correlation between classic parameters of sagittal alignment of the cervical spine and typical HRQOL questionnaires preoperatively (Table 4). In the current literature, most of the correlations found have used postoperative data.[15,17] This may suggest that the parameters we analyzed to describe sagittal alignment of the cervical spine may not be as helpful in understanding our patients' pain and disability prior to surgery. There may be a few potential reasons for the lack of association. One reason was that patient-reported outcome measures were not specific to or appropriate for CD, thus, there is a need for a dedicated HRQOL measure for CD.[18] Another potential explanation was that there was interplay between CD and compensatory mechanisms of global alignment. To maintain alignment and horizontal gaze, the body may compensate by rearranging alignment of other body parts.[6] Likewise, change in cervical alignment can be compensatory for thoracolumbar deformity, which can lead to its own impact on pain scores and disability.[18]

While the static parameters investigated were not associated with patient-reported outcomes preoperatively, parameters of dynamic alignment did show association with an HRQOL measure. The NDI had a significant negative correlation with C0–2 ROM and C0–2 ROE. A previous paper that investigated dynamic alignment and HRQOL showed similar results.[19] We also note that CD was mainly associated with its alignment in extension. This may be because the alignment in extension was more associated



Pre-operative alignment:
- **C2-C7:** 32° kyphosis
- **TS-CL:** 62° mismatch
- **C0-C2:** 57° lordosis
- **McGregor's Slope:**11°
- **ROM C0-C2:** 15° between flexion and extension
- **ROE C0-C2:** 5° between neutral and extension

1-year alignment:
- **C2-C7:** 11° lordosis
- **TS-CL:** 33° mismatch
- **C0-C2:** 28° lordosis
- **McGregor's Slope:**3°
- **ROM C0-C2:** 33° between flexion and extension
- **ROE C0-C2:** 14° between neutral and extension

FIG. 2. Case example. After increased C2–7 correction we can see decreased (C0–2) Cobb angle and increased C0–2 ROM and ROE.

with patients' clinical presentation than arbitrary parameters, as evident by the correlation with HRQOL questionnaire scores.

Spinal deformity is a challenging spectrum of concomitant pathologies. The cervical spine remains among the least understood and most understudied parts of the spine. Identifying the drivers of CD and every compensatory mechanism associated with it are crucial to allow spine surgeons to accurately address the regional drivers of the deformities. This study adds to the literature by supporting full-spine analysis for every patient with deformity; taking the compensatory C0–2 hyperlordosis, posterior thoracolumbar malalignment, or thoracic hypokyphosis in isolation can be misunderstood as perhaps a deformity driver or an indication for surgery. Furthermore, predicting compensatory relaxation of adjacent segments has been a challenging task for spine surgeons and researchers. Expanding our ability to not only simulate postoperative alignment of the fused segments but also methodically and systematically predict reciprocal changes in the unfused segments is important for improving surgical outcomes and decreasing mechanical complications.

In the setting of spinal deformity at any focal or regional level, initial compensatory mechanisms are usually adjacent to the deformity. After the adjacent compensation has been exhausted, the next adjacent segments will be progressively recruited in an attempt to maintain an erect posture in order to prevent patients from falling and to decrease the use of assistive devices.[20] In the case of CD, patients recruit additional compensation from the upper cervical segments to maintain alignment. The upper cervical segment is among the most mobile in the cervical spine, so compensation at that level would allow a patient to maintain a horizontal gaze.[21] Correcting the driver of the CD will indirectly affect the established compensatory mechanism. After surgically correcting for patient C2–7 reach, there is an indirect release of TK hyperextension as well as reduced upper cervical compensation to achieve a neutral global alignment.[22] Although surgery can aid with correcting CD and relaxing compensatory mechanisms, there are some side effects. One notable effect is the increase in C0–2 mobility to compensate for the fusion, which was previously demonstrated in degenerative surgery.[23] This phenomenon is independent of the correction but linked to the biomechanics of the fusion construct. In addition, patients with fusion extended to the mid- or lower thoracic spine may have less room for the relaxation to occur and require surgery to include this relaxation within the fusion (surgically recreate some curvature).

Study Limitations

Although this study provides important findings, it does have limitations. First, the sample size was small and the follow-up of 1 year was relatively short. Even if the alignment stabilized 1 year after surgery, the time frame does not allow for the evaluation of long-term changes,[24] which would not be conducive for a deeper analysis. Second, there is a lack of standardization in obtaining flexion and extension images across sites. Third, this study examines different types of CDs. The patients with CD were included if the cervical spine was fused to account for the location of the correction for the CD. A future study with a larger sample size will allow us to study the relationships between and within each type of deformity.[25] It will also allow a more in-depth analysis of the parameters affecting postoperative outcomes following CD surgery. Finally, due to the lack of advanced imaging, the impact of degeneration severity on reciprocal change could not be evaluated.

Conclusions

CD is a complex pathology. Its effects impact the entire spine from upper cervical segments to global spinopelvic alignment. A correction of the driver of cervical malalignment leads to a relaxation of the proximal and distal compensatory mechanisms. Relaxation was proportional to the amount of correction. Upper cervical motion and ROE, one of the only parameters associated with patient-reported outcomes, were significantly associated with correction of the deformity. Inclusion of these aspects during patient evaluation can help to better understand this complex condition.

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Supplemental Information

Previous Presentations

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