JNS SPINE

CLINICAL ARTICLE

J Neurosurg Spine 36:616–623, 2022

When can we expect global sagittal alignment to reach a stable value following cervical deformity surgery?

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OBJECTIVE Cervical deformity (CD) is a complex condition with a clear impact on patient quality of life, which can be improved with surgical treatment. Previous study following thoracolumbar surgery demonstrated a spontaneous and maintained improvement in cervical alignment following lumbar pedicle subtraction osteotomy (PSO). In this study the authors aimed to investigate the complementary questions of whether cervical alignment induces a change in global alignment and whether this change stabilizes over time.

METHODS To analyze spontaneous changes, this study included only patients with at least 5 levels remaining unfused following surgery. After data were obtained for the entire cohort, repeated-measures analyses were conducted between preoperative baseline and 3-month and 1-year follow-ups with a post hoc analysis and Bonferroni correction. A subanalysis of patients with 2-year follow-up was performed.

RESULTS One-year follow-up data were available for 121 of 168 patients (72%), and 89 patients had at least 5 levels remaining unfused following surgery. Preoperatively there was a moderate anterior cervical alignment (C2–7, −7.7° [kyphosis]; T1 slope minus cervical lordosis, 37.1°; cervical sagittal vertebral axis [cSVA], 37 mm) combined with a posterior global alignment (SVA, −8 mm) with lumbar hyperextension (pelvic incidence [PI] minus lumbar lordosis [LL] mismatch [PI-LL], −0.6°). Patients underwent a significant correction of the cervical alignment (median ΔC2–7, 13.6°). Simultaneously, PI-LL, T1 pelvic angle (TPA), and SVA increased significantly (all $p < 0.05$) between baseline and 3-month and 1-year follow-ups. Post hoc analysis demonstrated that all of the changes occurred between baseline and 3 months. Subanalysis of patients with complete 2-year follow-up demonstrated similar results, with stable postoperative thoracolumbar alignment achieved at 3 months.

CONCLUSIONS Correction of cervical malalignment can have a significant impact on thoracolumbar regional and global alignment. Peak relaxation of compensatory mechanisms is achieved by the 3-month follow-up and tends to remain stable. Subanalysis with 2-year data further supports this finding. These findings can help to identify when the results of cervical surgery on global alignment can be best evaluated.

https://thejns.org/doi/abs/10.3171/2021.7.SPINE21306

KEYWORDS cervical deformity; reciprocal change; compensation; maintenance of alignment

ABBREVIATIONS ACD = adult CD; CD = cervical deformity; cSVA = cervical SVA; LIV = lowermost instrumented vertebra; LL = lumbar lordosis; PI = pelvic incidence; PI-LL = PI-LL mismatch, measured as PI minus LL; PSO = pedicle subtraction osteotomy; PT = pelvic tilt; SVA = sagittal vertebral axis; TK = thoracic kyphosis; TPA = T1 pelvic angle; TS-CL = thoracic slope minus cervical lordosis.

SUBMITTED February 23, 2021. **ACCEPTED** July 1, 2021.
INCLUDE WHEN CITING Published online November 5, 2021; DOI: 10.3171/2021.7.SPINE21306.

Cervical deformity (CD) of the spine is a broad pathology stemming from a variety of etiologies and encompassing diverse spinal malalignment patterns. The complexity of the cervical spine originates from the strong interplay with the rest of the spine and the wide variation seen in normative alignment. In addition to the wide range of motion provided by the cervical spine, it also supports the weight of the head and aids in maintaining horizontal gaze. CD can have a substantial health impact, with a reported mean EQ-5D of CD below the bottom 25th percentile values of several chronic disease states, such as chronic ischemic heart disease, malignant breast cancer, and prostate cancer.[1,2] In general, the primary goal of CD surgery is to correct and stabilize the deformity while decompressing neural elements. Many studies have shown favorable outcomes of restoring good cervical alignment following surgical management of CD.[3–5]

Historically, surgical planning for treatment of cervical pathology mainly focused on focal correction.[6,7] More recently, deformity surgeons have recognized the importance of a preoperative global spinal assessment. The relationship between cervical and thoracolumbar alignment is evident, and a chain of correlations between adjacent and subadjacent spinal regions from the occiput to the pelvis has been described in the literature.[8] Therefore, optimizing regional and global alignment parameters may be critical for better outcomes and prevention of secondary disorders in the adjacent segments.

Previous analysis of thoracolumbar deformity patients has demonstrated reciprocal changes in the cervical area following thoracolumbar deformity correction.[9] Adults with positive sagittal spinopelvic malalignment compensate with abnormally increased cervical lordosis in an effort to maintain horizontal gaze. Surgical correction of sagittal malalignment results in an improvement of the abnormal cervical hyperlordosis through reciprocal changes. However, the reverse has not been assessed and little is known regarding whether correction of the CD alone is enough to produce a change in global spinal alignment. We know that cervical changes can trigger regional and global compensation mechanisms. For example, compensation for symptomatic primary cervical kyphosis usually occurs by a posterior shifting of SVA, smaller T1 slope, and larger lumbar lordosis (LL).[10] Furthermore, it has been reported that restoring normal cervical lordosis correlates with improvements in health-related quality of life in patients with thoracolumbar deformity. A possible explanation for these findings is that restoring normal cervical lordosis leads to a direct or a reciprocal compensatory effect on underlying global deformities.[3]

Understanding such reciprocal compensatory mechanisms is important as it may aid in better prediction of global outcomes and possibly avoid unnecessary fusion of extra levels to achieve optimal outcomes. Previous reports of studies of interventions for treatment of CD have not included assessments of the sequelae on global spinal alignment but have focused mainly on local radiographic outcomes like cervical kyphosis. In the current study, we sought to investigate the reciprocal changes of global sagittal alignment following CD surgery and to identify potential time points associated with reaching stable or final global alignment. These data can improve surgical planning for CD correction and provide a quantitative understanding of postoperative alignment. In addition, the resulting findings can help to identify follow-up time points at which more reliable and stable follow-up outcomes can be expected.

Methods

Cohort

This study was a retrospective review of a multicenter prospective database of consecutive CD patients. The enrollment period for this study extended from 2012 to 2015. Institutional review board approval was obtained from each participating site before enrollment. Inclusion criteria were age of 18 years or older and the presence of CD defined by at least one of the following radiographic criteria: cervical scoliosis (C2–7 coronal Cobb angle > 10°), cervical kyphosis (C2–7 lateral Cobb angle > 10°), cervical sagittal vertebral axis (cSVA) more than 4 cm, or chin-brow vertical angle more than 25°. Additional inclusion criteria specific for the current analysis were the availability of at least 1-year follow-up radiographs and having at least 5 vertebral levels remaining unfused in the thoracic or lumbar spine after surgery to allow for reciprocal changes.

Data Collection

Demographic data, including age, sex, and BMI, were collected. Radiographic analysis was conducted at a single center using a validated and dedicated software for spinal alignment analysis.[11,12] Spinal data analyzed included full-length standing spine radiographs with anteroposterior and lateral views and cervical anteroposterior, lateral, and flexion/extension radiographs. Regional cervical parameters included T1 and C2 slope, C2–7 Cobb angle, thoracic slope minus cervical lordosis (TS-CL), C2 slope, and cSVA. Local cervical parameters included maximum focal kyphosis between 2 adjacent segments and number of kyphotic levels greater than 5°. Global radiographic parameters assessed included the sagittal vertebral axis (SVA), T1 pelvic angle (TPA), T2–12 thoracic kyphosis (TK), T10–2 kyphosis, pelvic tilt (PT), pelvic incidence (PI), and the mismatch between PI and LL (PI-LL). All radiographic parameters were obtained preoperatively and at 3-month and 1-year follow-ups.

Statistical Analysis

Cohort frequency distributions were determined for demographic data, associated comorbidities, and past medical history. Radiographic data were described and analyzed at baseline and each follow-up time point. Statistical comparisons of pre- to postcervical and global alignment parameters were performed using a paired t-test. Repeated-measures analysis was conducted between data from the preoperative baseline and 3-month and 1-year follow-ups, with a post hoc analysis and Bonferroni adjustment to analyze maintenance and relaxation of global alignment. The cohorts were further stratified into two groups based on the location of lowermost instrumented

TABLE 1. Preoperative sagittal alignment of the cervical spine

Parameter	Value
cSVA (mm)	37 ± 19
TS-CL (°)	37.1 ± 19.4
C2–7 (°)	−7.7 ± 22.3 (kyphotic)
Max kyphosis (°)	−12.7 ± 8.5
No. of kyphotic levels	1.7 ± 1

Values are presented as mean ± SD.

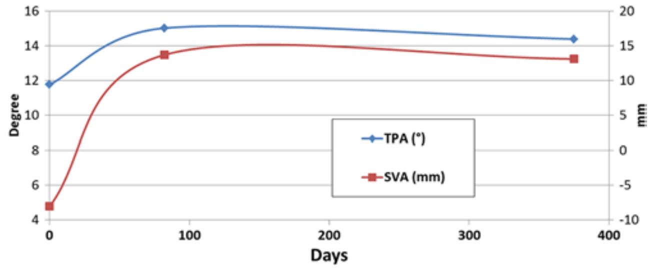

FIG. 1. Evolution of the global alignment (TPA and SVA) between preoperative condition and 3-month and 1-year follow-ups following CD surgery. Figure is available in color online only.

vertebra (LIV) at either T3 and above or and T4 and below. Later, the cohort was stratified based on the magnitude of correction of cervical lordosis using the median as a cutoff value. A subgroup analysis was conducted on patients with 2-year data available. All analysis was performed using SPSS software, and a p value less than 0.05 was considered statistically significant.

Results

Numbers of Patients

Out of 168 patients who underwent surgical correction for CD, 121 (72%) had at least 1 year of follow-up data available, and 102 (60.7%) had complete preoperative, 3-month, and 1-year radiographs. From these, 13 patients (12.7%) had fewer than 5 vertebral levels remaining unfused and were excluded from the analysis. The mean follow-up period for the 89 remaining patients was 82 ± 25 days for the 3-month follow-up, and 390 ± 90 days for the 1-year follow-up.

Cohort Description

The mean age of the patients was 60.8 ± 10.2 years, mean BMI was 28.3 ± 7.1 kg/m^2, and 65.2% of patients were women. Past medical history showed that 36 patients (40.9%) had a history of spine surgery, including anterior cervical discectomy and fusion (n = 18, 20.2%), posterior fusion (n = 14, 15.7%), and laminectomy (n = 6, 6.7%). Thirteen patients (14.6%) also had a history of previous lumbar/thoracolumbar surgery, with 9 patients having fusion of 4 or fewer lumbar vertebrae (L3–S1 fusion).

Baseline Radiographic Assessment

Overall, the cohort exhibited moderate to severe CD (Table 1) associated with a neutral to posterior thoracolumbar alignment and a PI-LL of −0.6° ± 18.8°, a PT of 18.3° ± 11.1°, and an SVA of −8 ± 70 mm.

Correction, Maintenance, and Relaxation

The pre- to postoperative analysis demonstrated a significant correction of the cervical alignment at 1 year (all $p < 0.005$), with a mean C2–7 (cervical lordosis) correction of 15.3° ± 21.1° (median 13.6°). Assessment of thoracolumbar alignment across time demonstrated a significant difference in every sagittal parameter between preoperative baseline and 3-month and 1-year follow-ups (all $p < 0.05$), except for PT ($p = 0.052$) (Table 2). Post hoc analysis revealed significant changes in alignment between preoperative and postoperative follow-ups, as illustrated by an increase in PI-LL, TK, T10–L2, TPA, and SVA. Comparison between 3 months and 1 year showed no significant difference in thoracolumbar alignment (all $p > 0.1$) (Fig. 1). Interestingly, a more in-depth look at the distribution revealed that the percentage of patients deteriorating (approximately 20%) by more than 5° in either PI-LL or TK was counterbalanced by the percentage of patients improving (approximately 20%) by more than 5°.

Stratification by LIV Position

Stratification by LIV identified 54 patients (60.7%) with

TABLE 2. Comparison of thoracolumbar alignment preoperatively, 3 months postoperatively, and 1 year postoperatively, including pairwise comparison between follow-up results

	Preop		Postop 3 mos		Postop 1 yr		Overall	Multiple Bonferroni		
	Mean	SD	Mean	SD	Mean	SD	p Value	Preop vs 3 mos	Preop vs 1 yr	3 mos vs 1 yr
PI (°)	52.89	11.57	53.02	11.88	53.08	11.88	0.651	1.000	1.000	1.000
PT (°)	18.29	11.13	19.72	11.72	19.47	11.21	0.052	0.103	0.220	1.000
PI-LL (°)	−0.65	18.85	1.95	19.34	1.43	17.71	0.028*	0.036	0.212	1.000
T10–L2 (°)	−6.39	13.40	−10.19	15.35	−10.84	16.37	0.000*	0.000	0.000	1.000
T2–12 (°)	−46.51	19.74	−50.68	18.23	−50.93	17.94	0.003*	0.059	0.016	0.706
TPA (°)	11.76	12.49	15.01	13.47	14.38	12.56	0.000*	0.000	0.008	1.000
SVA (mm)	−8.03	70.49	13.68	68.74	13.09	65.65	0.000*	0.001	0.007	1.000

* Statistically significant.

TABLE 3. Comparison of thoracolumbar alignment preoperatively, 3 months postoperatively, and 1 year postoperatively, including pairwise comparison between follow-ups after stratification by LIV position

	Preop		Postop				Overall p Value
			3 mos		1 yr		
	Mean	SD	Mean	SD	Mean	SD	
LIV: T3 & above							
PI (°)	52.17	11.91	52.75	12.25	52.54	12.20	0.121
PT (°)	18.30	9.89	19.42	10.84	18.34	10.20	0.230
PI-LL (°)	1.54	17.74	2.52	18.61	1.82	16.50	0.703
T10–L2 (°)	−7.33	13.15	−8.76	14.31	−10.04	14.76	0.000*
T2–12 (°)	−39.99	14.30	−44.42	14.99	−45.48	15.18	0.000*
TPA (°)	13.05	11.82	14.93	12.74	14.07	11.81	0.172
SVA (mm)	1.48	68.40	12.47	62.41	18.28	60.72	0.158
LIV: T4 & below							
PI (°)	53.99	11.11	53.45	11.44	53.92	11.49	0.164
PT (°)	18.27	12.97	20.18	13.11	21.22	12.57	0.028*
PI-LL (°)	−4.01	20.25	1.07	20.66	0.82	19.65	0.007*
T10–L2 (°)	−4.96	13.83	−12.39	16.80	−12.07	18.74	0.000*
T2–12 (°)	−56.87	22.79	−59.99	18.82	−58.95	18.86	0.845
TPA (°)	9.71	13.40	15.13	14.63	14.83	13.73	0.000*
SVA (mm)	−23.13	72.14	15.40	77.82	5.62	72.45	0.000*

* Statistically significant.

a short cervical fusion (LIV at or above T3), and 35 patients (39.3%) with a long cervical fusion (LIV at T4 and below). There was no significant difference in C2–7 correction between the 2 LIV groups (15.7° ± 12.8° vs 14.6° ± 30.1°, $p = 0.840$). Analysis of the evolution of global sagittal alignment demonstrated the following (Table 3): for the short cervical fusion group, only T10–L2 and T2–12 kyphosis significantly increased from preoperatively to the 3-month follow-up, without further changes from 3 months to 1 year. For the long cervical fusion group, significant increases were seen in almost every sagittal parameter (PT, PI-LL, T10–L2, TPA, and SVA), and only TK (T2–12) remained unchanged. Post hoc analysis showed no significant difference in alignment between 3 months and 1 year (all $p > 0.5$).

Stratification by Cervical Lordosis Correction

After stratification by the median amount of C2–7 correction (i.e., 13.6°), the analysis revealed no change in thoracolumbar alignment for patients who sustained a small correction of C2–7 lordosis (with the exception of a small increase in thoracolumbar kyphosis), while those undergoing a correction greater than 13.6° exhibited a significant increase in thoracic alignment (T10–L2 and T2–12) and global alignment (TPA and SVA) but lacked significant change in LL or PT (Table 4).

Stratification by Demographic Data

After stratification by mean age (i.e., 60 years), the analysis revealed no significant changes in thoracolumbar alignment in patients younger than 60 years. Patients older than 60 years demonstrated a significant change in every sagittal parameter (except PI) (all $p < 0.05$). These changes were maintained between 3 months and 1 year (all $p > 0.5$). Patients older than 60 years demonstrated a larger correction between C2 and C7 (20.7° ± 22.6° vs 10.3° ± 18.2°, $p = 0.023$).

Comparison of pre- to postoperative changes in multiple patients showed a significant increase in TK but no significant change in other sagittal alignment parameters for patients with a BMI above 30. Those with a BMI below 30 showed a significant change in every sagittal parameter.

Subanalysis on Patients With 2 Years of Data Available

Forty-five patients (50.6%) had a 2-year radiographic follow-up available at the time of the investigation. Comparison of the thoracolumbar alignment between preoperatively and 3-month, 1-year, and 2-year follow-ups demonstrated similar results, with significant changes occurring between pre- and postoperative follow-ups and a stable alignment between 3-month, 1-year, and 2-year follow-ups (Table 5 and Fig. 2).

Discussion

This present study, to our knowledge, is the first to provide a comprehensive analysis of the distal and global effects of CD correction. Results showed that postoperative cervical alignment can affect thoracolumbar alignment, PI-LL, TPA, and SVA. All of the previous parameters increased significantly (all $p < 0.05$) between preoperative baseline and 3-month and 1-year follow-ups (Fig. 3). These results suggest that the preoperative posterior thoracolumbar compensatory alignment has dissipated

TABLE 4. Comparison of thoracolumbar alignment preoperatively, 3 months postoperatively, and 1 year postoperatively, including pairwise comparison between follow-up after stratification by the amount of cervical correction

	Preop		Postop				Overall p Value
			3 mos		1 yr		
	Mean	SD	Mean	SD	Mean	SD	
Cervical correction ≤13.6°							
PI (°)	53.23	10.50	53.32	10.99	53.05	10.78	0.643
PT (°)	17.70	10.96	19.06	10.92	18.60	9.38	0.362
PI-LL (°)	1.07	19.83	2.82	20.13	2.34	17.61	0.559
T10–L2 (°)	−5.33	10.58	−8.14	12.25	−9.49	12.40	0.007*
T2–12 (°)	−48.66	22.37	−47.18	19.08	−48.24	17.54	0.578
TPA (°)	12.33	13.30	14.69	13.54	14.03	12.20	0.122
SVA (mm)	4.43	71.03	16.10	69.68	16.37	75.09	0.491
Cervical correction >13.6°							
PI (°)	51.34	12.05	51.32	12.15	51.70	12.21	0.423
PT (°)	17.93	10.63	18.96	11.40	19.20	11.65	0.320
PI-LL (°)	−3.33	17.38	−1.02	17.17	−1.10	16.33	0.125
T10–L2 (°)	−7.83	15.11	−12.85	16.97	−12.77	19.02	0.000*
T2–12 (°)	−44.80	18.06	−54.85	17.97	−54.99	18.90	0.000*
TPA (°)	10.07	10.98	13.81	12.43	13.31	11.65	0.001*
SVA (mm)	−23.64	69.59	8.30	66.94	5.93	51.92	0.000*

* Statistically significant.

and better global spinal alignment has been achieved following surgery. We found that the amount of cervical correction and fusion length both have an impact on the observed global reciprocal changes. A small amount of correction in the cervical spine resulted in minor changes confined to the thoracic region. In contrast, a larger correction had a greater thoracic impact as well as forward shifting of global alignment (TPA, SVA). Also, correction with longer fusion segments created a more distal global impact that involved spinopelvic parameters including pelvic retroversion (PT). However, previous studies have shown that many additional factors can influence the amount of reciprocal changes, such as muscle quality, spine rigidity, and alignment within the fused segment.[13–15] Limited data are presented about these factors in our study, and future studies are needed to assess these factors in greater detail.

In recent years, several studies have examined the chain of correlations from the pelvis to the occipital region, illustrating that adult spinal deformity (ASD) surgeries in the thoracic and lumbar spine can induce compensatory changes in cervical spine alignment.[9,16,17] Smith and colleagues[9] demonstrated that correction of a forward sagittal malalignment using pedicle subtraction osteotomy (PSO) resulted in relaxation of the abnormal compensatory cervical hyperlordosis through reciprocal changes. While the effect of thoracolumbar correction is well studied, there is a growing interest in the impact of cervical correction on regional and global alignment. Passias et al.[18] showed that CD patients undergoing osteotomies in the cervical

TABLE 5. Comparison of thoracolumbar alignment preoperatively and 3 months, 1 year, and 2 years postoperatively

	Preop	Postop			p Value
		3 mo	1 yr	2 yr	
PI (°)	53.1 ± 11	53.3 ± 11.5	53.2 ± 11.3	53.3 ± 11.4	0.976
PT (°)	18.2 ± 12	19.5 ± 11.6	19.7 ± 10.6	20.3 ± 12	0.176
PI-LL (°)	0.3 ± 21	2.2 ± 20.9	2.9 ± 19.2	3.1 ± 18.9	0.107
T10–L2 (°)	−6.1 ± 13.9	−9.7 ± 16.2	−11.2 ± 17.4	−9.5 ± 13.8	0.003*
T2–12 (°)	−42.7 ± 16.7	−48.8 ± 19	−50.3 ± 17.5	−52.2 ± 17.9	0.000*
TPA (°)	12.1 ± 13.6	15.3 ± 13.8	15.2 ± 13	15.4 ± 12.6	0.001*
SVA (mm)	−3.6 ± 66.8	17.7 ± 64.6	20.7 ± 66.2	22.9 ± 60.4	0.004*

* Statistically significant.

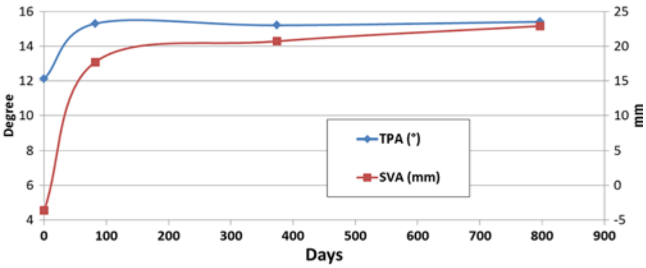

FIG. 2. Evolution of the global alignment (TPA and SVA) between preoperative condition and 3-month, 1-year, and 2-year follow-ups following CD surgery. Figure is available in color online only.

and upper thoracic spine experienced an improvement in TS-CL and C2 slope. They also reported that the type and location of osteotomy had an impact on the adjacent reciprocal changes: in the upper thoracic spine, multiple minor osteotomies achieved similar alignment changes as did major osteotomies at a single level, while a major osteotomy at T2 had the greatest overall impact in cervicothoracic and global alignment in CD patients.[18] Furthermore, Smith et al.[19] in a multicenter series of 23 adult CD (ACD) patients treated with a 3-column osteotomy for cervical or cervicothoracic deformity reported a statistically significant increase in C7–S1 SVA following surgery that may reflect a relaxation of compensatory measures.

In an era of rising healthcare costs and a focus on achieving significantly better health outcomes per dollar spent, it is important to determine the value of complex spine interventions. Achieving durable benefit is one of the main priorities of these expensive surgeries. A previous study showed the estimated time to cost-effectiveness to be between 3 and 4.5 years for ASD surgery.[20] Our current results showed maintenance of radiographic outcome between 3-month and 1-year follow-ups. To examine the cost-effectiveness, a longer follow-up is needed to examine the maintenance of gained global radiographic outcomes. Our subanalysis with 2-year data results showed nonsignificant changes between 1 and 2 years, which allows us to extrapolate the demonstrated benefit.

In this study, the overall patient group demonstrated stable alignment between 3 months and 1 year. However, a group effect does not necessarily mean that every patient will remain stable. A deeper look into the cohort showed that 20% of the patients deteriorated in TK by more than 5°, with a primary reason relating to distal junctional kyphosis (DJK).[21] Also, 20% of the patients continued to improve beyond 3 months. This is similar to previous results analyzing cervical reciprocal changes following TL surgery where time to reach relaxation can occur up to 6 months.

The effect of demographic parameters on patient capacity to compensate was previously demonstrated in the setting of thoracolumbar deformity. Older patients tend to recruit less thoracic hyperextension to compensate for anterior malalignment.[22] In the current study, we found a significant change in sagittal alignment only for patients older than 60 years. This difference between younger and

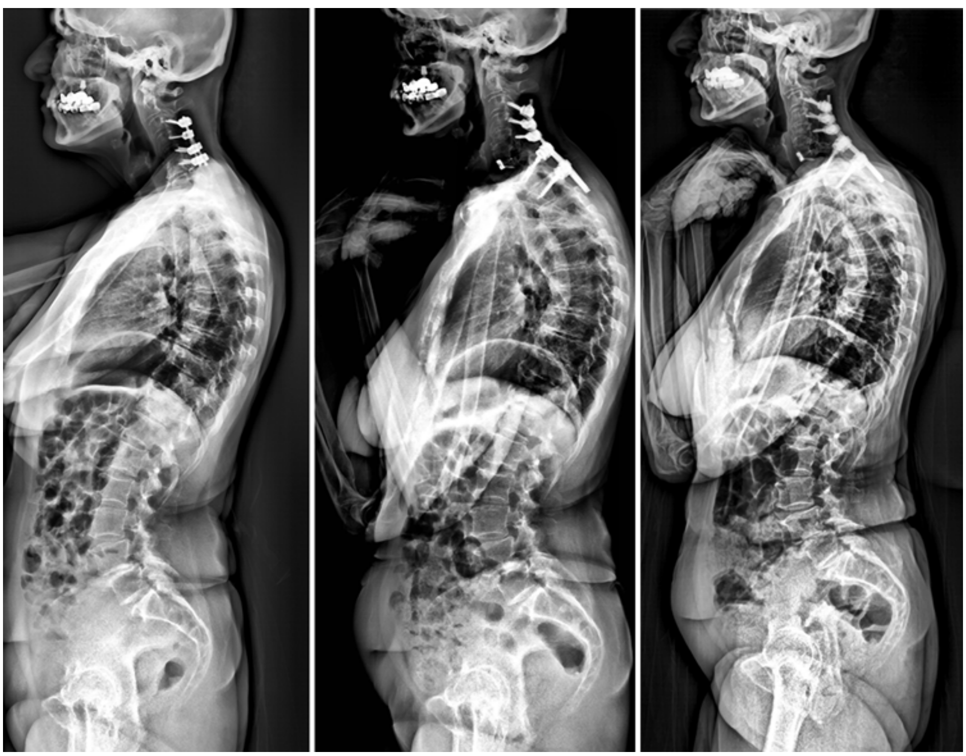

FIG. 3. Radiographs of a patient surgically treated with a posterior fusion between C3 and T2. Cervical lordosis improved from −3° (kyphosis) preoperatively (*left*) to +29° (lordosis; *right*). In the meantime, PI-LL increased by 8°, TK by 11°, and TPA by 3°. Regional and global alignment was maintained between 3 months (*center*) and 1-year (*right*).

older CD patients was probably confounded by the larger correction sustained by this group compared to younger patients. BMI was also associated with a different mechanism of compensation, especially at the lower-extremity level.[23] In this cohort, patients with larger BMI did not experience a significant change in global sagittal alignment despite the change in thoracic alignment. These patients may need a larger change in regional alignment to warrant a significant change in the center of gravity position, which will lead to significant reciprocal change.[24]

This study was not without limitations. First, the limited sample size does not allow for deeper analysis of the patient profile with regard to deterioration versus improvement in sagittal alignment after 3 months. Also, a potential confounding effect between fusion length and amount of correction on the reciprocal change was observed. Finally, this study is limited by the heterogeneity of the cohort, since CD patients have different profiles and deformity types that often necessitate very different surgical approaches.

Conclusions

Cervical deformity (CD) can significantly impact thoracolumbar alignment. A large CD correction is associated with a larger reciprocal change in the thoracic spine as well as in global alignment. Despite its close proximity to the surgery, a 3-month follow-up can be used to evaluate the overall results of the surgical treatment based on the sagittal alignment. Future studies should investigate risk factors associated with deterioration between 3-month and 1-year follow-ups.

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Disclosures

The International Spine Study Group (ISSG) is funded through research grants from DePuy Synthes (current), NuVasive (current), K2M (current), Innovasis (past), Biomet (past), and individual donations. Authors reported the following. Renaud Lafage: ownership of Nemaris. Justin S. Smith: consultant for Zimmer Biomet, NuVasive, Stryker, DePuy Synthes, Cerapedics, Carlsmed; royalties from Zimmer Biomet, NuVasive, Thieme; direct stock ownership in Alphatec, NuVasive; receiving support of non–study-related clinical or research effort overseen by author from DePuy Synthes, ISSG, AO Spine, NuVasive, Stryker; clinical or research support for study described (includes equipment or material) from DePuy Synthes/ISSGF; fellowship funding from AO Spine; editorial board membership in *Neurosurgery*, *Operative Neurosurgery*, *Journal of Neurosurgery Spine*; board of directors membership in the Scoliosis Research Society. Christopher Ames: employee of UCSF; royalties from Stryker, Biomet Zimmer Spine, NuVasive, DePuy Synthes, Next Orthosurgical, K2M, Medicrea; consultant for DePuy Synthes, Medtronic, Medicrea, K2M; research for Titan Spine, DePuy Synthes, ISSG; editorial board member of *Operative Neurosurgery*; grant funding from SRS; executive committee member of ISSG; director of Global Spinal Analytics. Peter G. Passias: consultant for Globus, Royal Biologics, Spine Wave. Christopher I. Shaffrey: consultant for Medtronic, NuVasive, SI Bone; direct stock ownership in NuVasive; patent holder in Medtronic, NuVasive, Zimmer Biomet; royalties from Medtronic, NuVasive. Gregory Mundis Jr.: consultant for NuVasive, Viseon, SeaSpine, Carlsmed; direct stock ownership in Alphatec, SeaSpine; patent holder in Stryker, SeaSpine. Themistocles S. Protopsaltis: consultant for Globus, Stryker K2M, NuVasive, Medicrea, Medtronic; royalties from Altus; stock options in SpineAlign. Munish Gupta: consultant for DePuy, Globus, Medtronic; royalties from Innomed, DePuy, Globus; honoraria from AO Spine; direct stock ownership in J&J, P&G; travel reimbursement from Scoliosis Research Society, DePuy, Globus, Medtronic, AO Spine. Eric Klineberg: consultant for Depuy Synthes, Stryker, Medicrea/Medtronic; honoraria from AO Spine; fellowship grant from AO Spine. Shay Bess: consultant for K2M Stryker, Mirus; patent holder in K2M, Stryker, NuVasive; clinical or research support for study described (includes equipment or material) from K2M Stryker, NuVasive, ISSGF, DePuy Synthes; support of non–study-related clinical or research effort overseen by author from Medtronic, Globus, ISSGF, SI Bone, SeaSpine; speakers bureau for K2M, Stryker; royalties from K2M, Stryker, NuVasive. Frank Schwab: consultant for MSD, Zimmer Biomet; royalties from Zimmer Biomet, Medtronic; ownership in VFT Solutions, SeaSpine; executive committee of International Spine Study Group. Virginie Lafage: consultant for Globus Medical; royalties from NuVasive; honoraria from Depuy Synthes, Implanet.

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