Spine

SPINE Volume 43, Number 13, pp E773–E781

DEFORMITY

Analysis of Successful *Versus* Failed Radiographic Outcomes After Cervical Deformity Surgery

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Study Design. Prospective multicenter cohort study with consecutive enrollment.

Objective. To evaluate preoperative alignment and surgical factors associated with suboptimal early postoperative radiographic outcomes after surgery for cervical deformity.

Summary of Background Data. Recent studies have demonstrated correlation between cervical sagittal alignment and patient-reported outcomes. Few studies have explored cervical deformity correction prospectively, and the factors that result in successful *versus* failed cervical alignment corrections remain unclear.

Methods. Patients with adult cervical deformity (ACD) included with either cervical kyphosis more than 10°, C2-C7 sagittal vertical axis (cSVA) of more than 4 cm, or chin-brow vertical angle of more than 25°. Patients were categorized into failed outcomes group if cSVA of more than 4 cm or T1 slope and cervical lordosis (TS-CL) of more than 20° at 6 months postoperatively.

Results. A total of 71 patients with ACD (mean age 62 yr, 56% women, 41% revisions) were included. Fourty-five had primary cervical deformities and 26 at the cervico-thoracic junction junction. Thirty-three (46.4%) had failed radiographic outcomes by cSVA and 46 (64.7%) by TS-CL. Failure to restore cSVA was associated with worse preoperative C2 pelvic tilt angle (CPT: 64.4° *vs.* 47.8°, $P=0.01$), worse postoperative C2 slope (35.0° *vs.* 23.8°, $P=0.004$), TS-CL (35.2° *vs.* 24.9°, $P=0.01$), CPT (47.9° *vs.* 28.2°, $P<0.001$), "+" Schwab modifiers ($P=0.007$), revision surgery ($P=0.05$), and failure to address the secondary, thoracolumbar driver of the deformity ($P=0.02$). Failure to correct TS-CL was associated with worse preoperative cervical kyphosis (10.4° *vs.* –2.1°, $P=0.03$), CPT (52.6° *vs.* 39.1°, $P=0.04$), worse postoperative C2 slope (30.2° *vs.* 13.3°, $P<0.001$), cervical lordosis (–3.6° *vs.* –15.1°, $P=0.01$), and CPT (37.7° *vs.* 24.0°, $P<0.001$). Multivariate analysis revealed postoperative distal junctional kyphosis associated with suboptimal outcomes by cSVA (odds ratio 0.06, confidence interval 0.01–0.4, $P=0.004$) and TS-CL (odds ratio 0.15, confidence interval 0.02–0.97, $P=0.05$).

Conclusion. Factors associated with failure to correct the cSVA included revision surgery, worse preoperative CPT, and concurrent thoracolumbar deformity. Failure to correct the TS-CL mismatch was associated with worse preoperative cervical kyphosis and CPT. Occurrence of early postoperative distal junctional kyphosis significantly affects postoperative radiographic outcomes.

Key words: alignment targets, cervical deformity, cervicothoracic junction, deformity correction, deformity driver, distal junctional kyphosis, failed outcomes, radiographic outcomes, sagittal malalignment, surgical planning.

Level of Evidence: 3

Spine 2018;43:E773–E781

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Acknowledgment date: May 17, 2017. First revision date: October 10, 2017. Acceptance date: November 16, 2017.

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

No funds were received in support of this work.

Relevant financial activities outside the submitted work: board membership, consultancy, grants, payment for lecture, stocks.

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DOI: 10.1097/BRS.0000000000002524

It is well established that adult thoracolumbar deformity results in significant pain and disability.[1–5] There are limited studies reporting on outcomes of adult cervical deformity (ACD) surgery and fewer still that explore the negative health effects of ACD using validated patient-reported outcome measures (PROMs).[6–19] The studies focused on surgery for ACD are limited by the small number of patients included and their retrospective designs.[6–15,19] ACD represents a complex and heterogenous category of spinal deformity and surgeries to address ACD employ a wide variety of techniques with no clear surgeon consensus approach.[20,21] Moreover, surgical correction can be challenging with a high rate of complications and reoperations.[6–15,19]

In an effort to create a more standardized approach to the various techniques employed in these surgeries, Ames *et al*[22] sought to create a comprehensive classification system of osteotomies and soft tissue releases relevant to the correction of cervical deformity to facilitate a common language on the topic. In addition a classification scheme of ACD types has also been proposed using radiographic parameters such as the C2-C7 sagittal vertical axis (cSVA), the mismatch between T1 slope and cervical lordosis (TS-CL), amongst others. However, little is known regarding the factors that contribute to successful realignment of cervical deformities *versus* those that are more likely to result in failed radiographic outcomes.[23]

Using a prospective multicenter collection of ACD surgeries, the purpose of this study was to investigate the postoperative radiographic results of cervical deformity surgery and assess the factors that result in failed outcomes *versus* successful realignment.

MATERIALS AND METHODS

Data Collection

Consecutive patients with ACD were prospectively enrolled at 11 centers throughout the United States with expertise in treating spinal deformity. The enrollment period for the study was from 2013 to 2016. Internal review board approval was obtained from each participating site before enrollment. Inclusion criteria were age 18 years or older, presence of cervical deformity, plan for surgical correction of the deformity, and availability of pre- and early postoperative (minimum follow-up of 3 months) standing full-length anteroposterior and lateral radiographs. Cervical deformity was defined as the presence of at least one of the following: cervical kyphosis (CK, C2–7 lateral Cobb angle >10°), cervical scoliosis (C2-C7 coronal Cobb angle >10°), cSVA more than 4 cm or chin-brow vertical angle of more than 25°. Patients with active tumor or infection, and patients who were pregnant or planning to get pregnant during the study period were excluded from the study.

Outcome Measurements

Standardized data collection forms were used to collect patient demographics, imaging studies, comorbidities, type of deformity, details of the surgical procedures, and radiographic measurements. The radiographic parameters measured in this study (Figure 1A, B) included: upper cervical lordosis (C0-C2 Cobb angle measured by the angle formed by McGregor's line and line passing through upper end plate of C2), C2 slope, chin-brow vertical angle, TS-CL, T2-T12 thoracic kyphosis, lumbar lordosis (LL), pelvic tilt (PT), pelvic incidence minus LL (PI-LL), cSVA, C7 SVA, C2-T3 SVA, and the C2 pelvic tilt angle (CPT) which is the angle formed by the intersection of a line connecting the center of femoral heads and center of the S1 endplate and a line tangent to posterior border of C2 vertebral body (Figure 1).[24] Distal junctional kyphosis (DJK) was defined as a change in kyphosis of more than 10° in the lowest instrumented vertebrae (LIV) to LIV-2 from pre- to postoperatively. Patients with the above criteria were excluded as having DJK if their preoperative angle between their lower

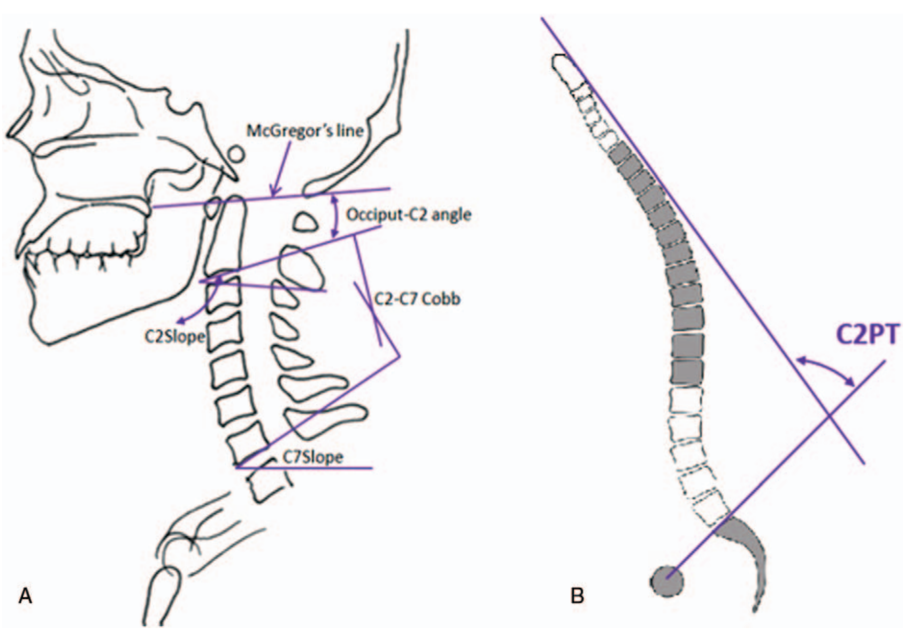

Figure 1. Schematic representation of cervical radiographic parameters. **A**, Upper cervical lordosis is measured by the Cob angle between McGregor line and the line along the endplate of C2. **B**, C2 pelvic tilt (C2PT) is the angle subtended by a line along the posterior vertebral body of C2 and line joining the bicoxofemoral axis and the middle of the S1 endplate.

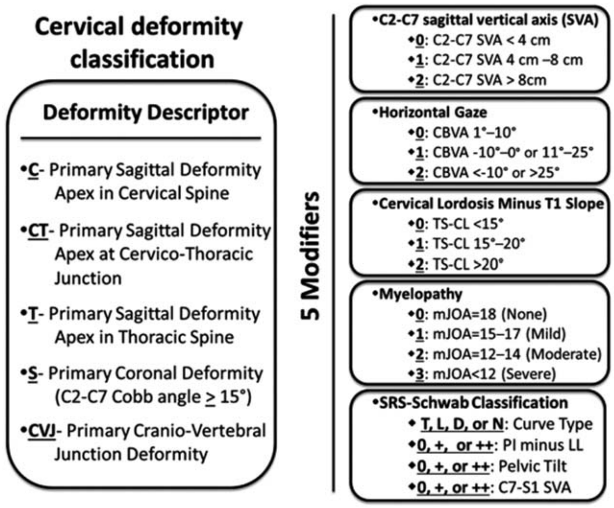

Figure 2. The cervical deformity classification of Ames *et al*[23] includes the deformity descriptor and 5 Modifiers. D indicates double; L, lordosis; N, none; T, thoracic.

instrumented vertebra and the vertebra 2 levels caudal to it (LIV to LIV-2) was less than 0°. All radiographic measurements were performed using a validated software tool SpineView (Laboratory of Biomechanics, ENSAM ParisTech, Paris, France).

Patients were classified based on the apex of the primary cervical deformity using criteria from Ames *et al* (Figure 2).[23] The highest osteotomy grade was defined by Ames *et al*.[22] The cumulative osteotomy grade was calculated by adding all the osteotomy grades performed in a particular patient (Appendix 1, http://links.lww.com/BRS/B328, Figure 3); that is, for a patient who underwent a grade 6 pedicle subtraction osteotomy at T3 and Ponte-type (grade 2) osteotomies at T4–5 and T5–6, the total osteotomy grade would be 10. For each patient, secondary drivers of deformity were identified using full-length standing radiographs and were categorized as: upper thoracic (UT: T1-T4), mid-thoracic (MT: T4-T7), lower thoracic (LT: T7-T10), thoracolumbar (TL: T11-L2), and lumbo-pelvic (LP: L3-S1).

Statistical Analysis

Frequency distributions were determined for demographic and surgical parameters. Statistical comparisons of regional and global preoperative alignment parameters and deformity types were performed in the successful and failed radiographic outcome groups based on cSVA and TS-CL using analysis of variance for continuous variables and Chi-square test for categorical variables. Pre- and early postoperative radiographic parameters were compared using paired *t* tests. The successful and failed radiographic outcome groups were compared with respect to demographic, surgical, and radiographic parameters. The statistical tests were two-tailed, mean values are represented as mean ± standard deviation (SD) and a *P* value of less than 0.05 was considered statistically significant. Multivariate analysis of risk factors for failed correction of the cervical deformity parameters was performed using binary logistic regression. All statistical analyses were performed using SPSS software, version 20.

RESULTS

Demographic and Surgical Parameters

Out of 125 consecutive patients who were enrolled in the database, 71 patients had a minimum of 6 months of follow-up and were included in this study. Fifty-four patients were excluded from the study because they did not meet the minimum follow-up time of 6 months. The mean age of the study cohort was 60.5 ± 10.8 years and included 36 women (57%). Twenty-five patients (37.3%) had previous fusion: 16 (23.8%) cervical, 1 (1.4%) thoracic, 1 (1.4%) thoracolumbar, and 7 (10.4%) lumbar. The diagnostic categories included degenerative kyphosis 29 (43.2%), iatrogenic kyphosis 6 (8.9%), traumatic kyphosis 2 (2.9%), congenital kyphosis 2 (2.9%), cervical scoliosis 2 (2.9%), and others 26 (38.8%) including kyphoscoliosis and myopathic dropped head syndrome. Forty-six patients (68.6%) had a deformity apex in the cervical spine and 21 patients (31.3%) had the apex of deformity in the cervico-thoracic region.

Analysis of Successful and Failed Restoration of C2-C7 Sagittal Vertical Axis

Overall 33 (46.4%) had failed radiographic outcomes with regard to correction of the cSVA. Table 1 compares demographic and surgical parameters in the patients with successful *versus* failed corrections of cSVA at 3 months

Osteotomy Grade	Resection	Description	Surgical Approach
1	partial facet joint resection	anterior cervical discectomy including partial uncovertebral joint resection, posterior facet capsule resection, or partial facet resection	A, P, AP, PA, APA, PAP
2	complete facet joint/Ponte osteotomy	both superior & inferior facets at a given segment are resected; other posterior elements of vertebra including lamina & spinous processes may also be resected	P, AP, PA, APA, PAP
3	partial or complete corpectomy	partial or complete corpectomy, including discs above & below	A, AP, PA, APA, PAP
4	complete uncovertebral joint resection to transverse foramen	anterior osteotomy through lat body & uncovertebral joints & into transverse foramen	A, PA, AP, APA, PAP
5	opening wedge osteotomy	complete posterior element resection w/ osteoclastic fracture & open wedge creation	P, PA, AP, APA, PAP
6	closing wedge osteotomy	complete posterior element resection & pedicle resection w/ closing wedge creation	P, PA, AP, APA, PAP
7	complete vertebral column resection	resection of 1 or more entire vertebral bodies & discs including complete uncovertebral joint & posterior lamina and facets	AP, PA, APA, PAP

* A = anterior; AP = anterior-posterior; APA = anterior-posterior-anterior; P = posterior; PA = posterior-anterior; PAP = posterior-anterior-posterior.

Figure 3. Nomenclature for cervical spine soft-tissue release and osteotomy for deformity correction per Ames *et al*.[25]

TABLE 1. Comparison of Demographic and Surgical Parameters in Successful *Versus* Failed Radiographic Outcomes on the Basis of C2-C7 Sagittal Vertical Axis at 3 Months Postoperatively After Surgery for Adult Cervical Deformity

Parameters	cSVA (mm) at 3 Months Postoperative Interval		
	Successful (cSVA < 40) (N = 59)	Failed (cSVA > 40) (N = 30)	*P*
Demographic			
Age (yr)	61.8 ± 7.5	62.9 ± 12.1	0.67
BMI	28.8 ± 7.3	29.9 ± 8.4	0.57
CCI	0.8 ± 1.3	0.6 ± 0.8	0.43
Female (%)	23 (69.7)	20 (56)	0.16
Previous fusion (%)	12 (36.4)	21 (58.3)	0.05
Smoker (%)	2 (6.1)	3 (8.6)	0.52
Surgical			
EBL (mL)	500 ± 518	1246 ± 1044	**<0.001**
OP time (min)	387 ± 283	428 ± 296	0.54
Fusion levels (anterior)	1.9 ± 1.8	1.0 ± 1.8	0.06
Fusion levels (posterior)	6.3 ± 4.4	9.2 ± 5.1	**0.01**
3CO (%)	6 ± 19.5	14 (37.8)	0.08
Anterior osteotomy grade*	1.8 ± 2.1	1.0 ± 1.7	0.11
Posterior osteotomy grade*	2.6 ± 4	4.7 ± 4.8	0.05
Deformity characteristics†			
Cervical (%)	23 (54.8)	19 (45.2)	0.06
Cervico-Thoracic (%)	5 (29.4)	12 (70.6)	
Scoliosis (%)	3 (75)	1 (25)	
Thoracic (%)	3 (33.3)	6 (66.7)	
Secondary driver addressed‡ (%)			
Yes	27 (79.4)	25 (59.3)	**0.02**
No	7 (20.6)	17 (40.7)	
Presence of "+" in any one SRS-Schwab modifiers§ (%)	20 (58.8)	33 (86.8)	**<0.001**
Presence of "++" in any one SRS-Schwab modifiers§ (%)	9 (26.5)	10 (26.3)	0.55

P values in boldface denote significance with P ≤ 0.05.

Anterior and posterior osteotomy grades (see Appendix 1, http://links.lww.com/BRS/B328).

†*Primary cervical deformity descriptor.[23]*

‡*Secondary drivers: cervicothoracic (C6-T2), main thoracic (T3-T9), thoracolumbar (T10-L2), lumbopelvic (L3-S1).*

§*SRS—Schwab modifiers include pelvic tilt, PI-LL mismatch, and C7 SVA.[5]*

BMI indicates body mass index; CCI, Charlson comorbidity index; cSVA, C2-C7 sagittal vertical axis; EBL, estimated blood loss.

postoperatively. Failure to restore cSVA was associated with worse preoperative CPT (64.4° *vs.* 47.8°, $P = 0.01$), the presence of any "+" Schwab modifier ($P = 0.007$), revision surgery ($P = 0.05$), and failure to address the secondary, thoracolumbar driver of the deformity ($P = 0.02$). Patients with failed corrections of cSVA had worse postoperative C2 slope (35.0° *vs.* 23.8°, $P = 0.004$), TS-CL (35.2° *vs.* 24.9°, $P = 0.01$), and CPT (47.9° *vs.* 28.2°, $P < 0.001$) (Table 2).

Analysis of Successful and Failed Restoration of T1 Slope And Cervical Lordosis

Overall and 46 (64.7%) had failed radiographic outcomes with regard to correction of the TS-CL. Table 3 compares demographic and surgical parameters in the patients with Successful *versus* failed corrections of TS-CL at 3 months postoperatively. Failure to correct TS-CL was associated with worse preoperative cervical kyphosis (10.4° *vs.* −2.1°, $P = 0.03$), and worse preoperative CPT (52.6° *vs.* 39.1°, $P = .04$). Patients with failed corrections of TS-CL had worse postoperative C2 slope (30.2° *vs.* 13.3°, $P < .001$), less preoperative cervical lordosis (−3.6 *vs.* −15.1°, $P = .01$), and larger preoperative CPT (37.7° *vs.* 24.0°, $P < 0.001$) (Table 4). Patients with successful correction of TS-CL had more anterior levels operated and higher cumulative anterior osteotomy grade (Table 3).

TABLE 2. For Patients With High Preoperative C2-C7 Sagittal Vertical Axis (>40 mm), Comparison of Radiographic Parameters for Successful and Failed Realignment at 3 Months Postoperatively After Adult Cervical Deformity Surgery

Radiographic Parameters	ACD Patients With Baseline cSVA >40 mm (N = 49)		
	Successful (cSVA <40 mm) (N = 24, 49%)	Failed (cSVA >40 mm) (N = 25, 51%)	*P*
Preoperative			
C2 slope	46.4 ± 15.7	43.3 ± 35.3	0.72
C2-C7 Cobb	2.25 ± 20.2	5.6 ± 24.3	0.63
cSVA	64.2 ± 15.2	64.2 ± 17.7	0.99
T1 slope	40 ± 15.7	42.3 ± 15.4	0.60
TS-CL	44.6 ± 15.2	49.0 ± 17.2	0.39
T4-T12 kyphosis	40.2 ± 16.5	47.3 ± 16.3	0.13
PI-LL	2.2 ± 21.6	2 ± 14.5	0.97
PT	21.3 ± 9.2	22.7 ± 14.2	0.68
C7 SVA	7.6 ± 75.5	14.4 ± 76.5	0.75
TPA	14.7 ± 11.05	17 ± 13.7	0.53
CPT	47.8 ± 27.7	64.4 ± 24.5	**0.01**
T2-T12 kyphosis	55.1 ± 19.4	60 ± 18.5	0.37
Postoperative (3 mo)			
C2 slope	23.8 ± 8.9	35 ± 14.5	**0.004**
C2-C7 lateral Cobb	−10.8 ± 13.9	−9.2 ± 17.8	0.75
cSVA	33.3 ± 7.3	55.2 ± 9.7	**<0.001**
T1 slope	35.7 ± 9.1	45.5 ± 13.3	**0.005**
TS-CL	24.9 ± 9.3	35.2 ± 15.3	**0.01**
T4-T12 kyphosis	41.2 ± 10.8	51 ± 15.2	**0.01**
PI-LL	4.1 ± 13.0	6.8 ± 24	0.63
PT	23.6 ± 14.3	21.3 ± 8.8	0.49
C7 SVA	27.2 ± 66.7	55.0 ± 83.6	0.21
TPA	16.8 ± 10.3	21.4 ± 16.8	0.25
CPT	28.2 ± 12.7	47.9 ± 17.4	**<0.001**
T2-T12 kyphosis	52.9 ± 11.7	62.1 ± 15.3	**0.02**
Development of DJK >10°			**0.03**
Yes (%)	1 (6.7)	5 (45.5)	
No (%)	14 (93.3)	6 (54.5)	

P values in boldface denote significance with P ≤ 0.05.

ACD indicates adult cervical deformity; C7 SVA, C7-S1 sagittal vertical axis; CL, cervical lordosis; CPT, C2-pelvic-tilt angle; cSVA, C2-C7 sagittal vertical axis; DJK, distal junctional kyphosis, defined as a change in the distal junctional angle of LIV to LIV-2 >10° from preoperatively to postoperatively; LL, lumbar lordosis; PI, pelvic incidence; TPA, T1-pelvic angle; TS-CL, T1 slope and cervical lordosis.

Multivariate Analysis

Multivariate analysis using binary logistic regression revealed that the occurrence of postoperative DJK (kyphosis >10° at LIV to LIV-2 from pre- to post-op) was the only significant parameter associated with suboptimal outcomes with respect to correction of cSVA (odds ratio 0.06, confidence interval 0.01–0.4, $P = 0.004$) and TS-CL (odds ratio 0.15, confidence interval 0.02–0.97, $P = 0.05$).

DISCUSSION

Patients with ACD have major disability and surgery to correct such deformities present unique challenges and potential complications. Smith *et al*[16] demonstrated that patients with operative ACD have poor health status, comparable to the lowest quartile of functioning in patients with blindness, emphysema, renal failure, and stroke. Most reports on outcomes and complications related to ACD surgery are limited by retrospective study designs and limited patient numbers.[6–15,19] These studies have reported high rates of complications.[6–15,19]

The present study is unique in that it is a multicenter, prospective data collection of patients undergoing surgery for ACD and it represents the largest such study to date on the subject. We performed a two-tier analysis using the

TABLE 3. Comparison of Demographic and Surgical Parameters in Successful *Versus* Failed Radiographic Outcomes on the Basis of T1 Slope and Cervical Lordosis at 3 m Postoperatively After Surgery for Adult Cervical Deformity

Parameters	TS-CL (deg) at 3 Months Postoperative Interval		
	Successful (TS-CL <20) (N = 27)	Failed (TS-CL > 20) (N = 62)	*P*
Demographic			
Age	61.3 ± 10.7	63.2 ± 19.9	0.47
BMI	29.1 ± 7.5	29.3 ± 7.9	0.89
CCI	0.4 ± 0.7	0.9 ± 1.2	0.09
Female (%)	14 (56)	29 (65.9)	0.28
Previous fusion (%)	12 (48)	22 (47.8)	0.53
Smoker (%)	1 (4)	4 (9.3)	0.38
Surgical			
EBL	557 ± 679	1083 ± 980	**0.02**
OP time	452 ± 276	395 ± 284	0.42
Fusion levels (anterior)	2.6 ± 1.9	0.9 ± 1.6	**<0.001**
Fusion levels (posterior)	5.8 ± 4.9	9.0 ± 4.7	**<0.001**
3CO (%)	4 (19)	16 (34.8)	0.15
Anterior osteotomy grade*	2.4 ± 2.2	0.9 ± 1.5	**0.002**
Posterior osteotomy grade*	3.2 ± 4.7	4.0 ± 4.5	0.46
Primary deformity characteristics†			
Cervical (%)	18 (42.9)	24 (57.1)	0.13
Cervicothoracic (%)	4 (23.5)	13 (76.5)	
Scoliosis (%)	1 (33.3)	2 (66.6)	
Thoracic (%)	2 (35.2)	7 (64.8)	
Secondary driver addressed‡ (%)			
Yes	19 (76)	28 (61)	0.15
No	6 (24)	18 (39)	
Presence of '+' in any one Schwab modifier§ (%)	17 (68)	36 (78.3)	0.25
Presence of '++' in any one Schwab modifier§ (%)	6 (24)	13 (28.3)	0.46

P values in boldface denote significance with $P \leq 0.05$.
**Anterior and posterior osteotomy grades (see Appendix 1, http://links.lww.com/BRS/B328).*
†Primary cervical deformity descriptor.[23]
‡Location of the secondary drivers of deformity: cervicothoracic (C6-T2), main thoracic (T3-T9), thoracolumbar (T10-L2), lumbopelvic (L3-S1).
§SRS—Schwab modifiers include pelvic tilt, PI-LL mismatch, and C7 SVA.[5]
BMI indicates body mass index; CCI, Charlson comorbidity index; cSVA, C2-C7 sagittal vertical axis; EBL, estimated blood loss.

cSVA and TS-CL radiographic parameters as criteria for cervical deformity. Unlike the thoracolumbar deformity literature which is dominated by sagittal spinal misalignment most often resulting from degenerative lumbar kyphoscoliosis and iatrogenic lumbar flatback deformity, ACD represents a complex and heterogeneous group of pathologies with multiple etiologies. For this reason, classification systems of cervical deformity employ a multitude of radiographic parameters to assess cervical alignment. Among the multiple parameters of ACD described in the literature, the cSVA and TS-CL have been most commonly reported.[13,17,18,20,23–27] Tang *et al*[13] demonstrated that a cSVA greater than 4 cm correlated with worse disability by the Neck Disability Index and the SF-36.

In the present study, 46% of the patients with baseline cSVA malalignment had failed postoperative radiographic outcome as defined by persistent cSVA greater than 4 cm. Failure to correct the cSVA was associated with a failure to correct a secondary, thoracolumbar driver of the cervical deformity. Smith *et al*[28] demonstrated that thoracolumbar sagittal deformity can drive an increase in the cSVA, a malalignment that resolves after correction of the

TABLE 4. For Patients With High Preoperative T1 Slope and Cervical Lordosis (>20°), Comparison of Radiographic Parameters for Successful and Failed Realignment at 3 Months Postoperatively After Adult Cervical Deformity Surgery

Radiographic Parameters	ACD Patients With Baseline TS-CL >20° (N = 71)		
	Successful (TS-CL <20°) (N = 17, 23.9%)	Failed (TS-CL >20°) (N = 54, 76.1%)	*P*
Preoperative			
C2 slope	30 ± 13.5	42.3 ± 26.2	0.08
C2-C7 Cobb	−2.1 ± 19.7	10.4 ± 19.3	**0.03**
C2-C7 SVA	45.8 ± 20.5	52.4 ± 26.7	0.38
T1 slope	30 ± 18.8	33.7 ± 17.4	0.45
TS-CL	30.2 ± 12.4	44.9 ± 17.4	**0.004**
T4-T12 Cobb	36.7 ± 17.1	41.4 ± 16.6	0.31
PI-LL	1 ± 17.5	2.8 ± 19.6	0.72
PT	20.4 ± 11.6	21 ± 12.5	0.86
C7 SVA	−1 ± 80	12.5 ± 70.5	0.53
TPA	14.2 ± 13.3	15.4 ± 13	0.75
CPT	39.1 ± 14	52.6 ± 26.5	**0.04**
T2-T12	47.2 ± 21.3	50.5 ± 19.8	0.55
Postoperative (3 mo)			
C2 slope	13.3 ± 6.6	30.2 ± 12.6	**<0.001**
C2-C7 Cobb	-15.1 ± 12.1	-3.6 ± 15.0	0.01
C2-C7 SVA	33.8 ± 16.5	41.2 ± 17.7	0.16
T1 slope	29.6 ± 13.2	35.6 ± 14.7	0.16
TS-CL	13.8 ± 5.3	34.1 ± 12.8	**<0.001**
T4-T12 Cobb	39.5 ± 14.3	42.9 ± 16.3	0.45
PI-LL	1.8 ± 15.8	4.8 ± 20.9	0.58
PT	20.6 ± 10.4	20.8 ± 12.9	0.96
C7 SVA	15.8 ± 67.7	38.3 ± 74.3	0.29
TPA	16 ± 12.5	17.7 ± 14.6	0.68
CPT	24 ± 10.1	37.7 ± 18.5	**0.005**
T2-T12	50.1 ± 14.2	51.8 ± 17.6	0.73
Development of DJK > 10deg			0.23
Yes (%)	1 (10)	8 (28.6)	
No (%)	9 (90)	20 (71.4)	

P values in boldface denote significance with P ≤ 0.05.

ACD indicates adult cervical deformity; C7 SVA, C7-S1 sagittal vertical axis; CL, cervical lordosis; CPT, C2-pelvic-tilt angle; cSVA, C2-C7 sagittal vertical axis; DJK, distal junctional kyphosis, defined as a change in the distal junctional angle of LIV to LIV-2 >10° from preoperatively to postoperatively; LL, lumbar lordosis; PI, pelvic incidence; TPA, T1-pelvic angle; TS-CL, T1 slope and cervical lordosis.

underlying thoracolumbar deformity. One of the interesting findings of the present study was that failed radiographic outcomes in the cSVA malaligned group were associated with a higher baseline CPT. This radiographic parameter, CPT, accounts for both cervical and thoracolumbar deformity concurrently and it increases when deformity is present in both regions (Figure 1B).[24] This speaks to the importance of obtaining full spine radiographs as a standard in the preoperative work up of cervical deformity. Assessing the CPT parameter preoperatively in all patients undergoing cervical deformity correction can identify the presence of concurrent thoracolumbar deformity so that it is not neglected. At a minimum it ensures that both cervical and thoracolumbar alignments are assessed before a surgical plan is executed. Ramchandran *et al*[20] demonstrated that 57% of surgeons changed their operative plan for cervical deformity corrections to include longer fusion constructs when presented with long cassette radiographs. In the present study, cSVA failure was associated with longer posterior fusion levels; however, this finding may be confounded by worse preoperative global cervicothoracic alignment.

The multivariate analysis identified that DJK was the primary factor associated with failed radiographic outcomes with regard to malalignment by both the cSVA and TS-CL (Figure 4A–D). There are few series that report on DJK. Most are from Scheuermann and adolescent idiopathic scoliosis literature.[29,30] This prospective multicenter series on cervical deformity surgery demonstrates that DJK a prevalent and unique complication in the ACD population. The link between DJK and recognizing and correcting the secondary, thoracolumbar drivers of the cervical deformity needs to be investigated further in future studies with longer follow-up.

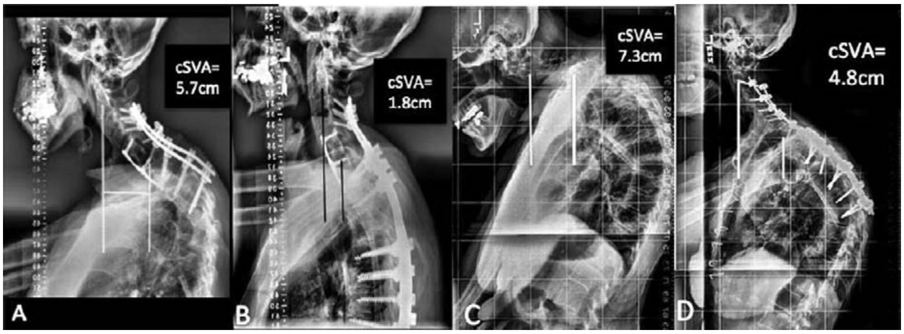

Figure 4. A, Preoperative radiographs of a patient with cervical deformity following a prior anterior/posterior cervical fusion surgery. **B**, 3-Month postoperative radiographs of the same patient who underwent a revision surgery consisting of a three-column osteotomy at T2 and fusion from C2-T9 with adequate restoration of cervical alignment. **C**, Preoperative radiographs of another patient with cervical deformity due to a large upper thoracic kyphosis and partially flexible dropped head syndrome. **D**, **B**, 3-Month postoperative radiographs of the same patient who underwent a three-column osteotomy at T2 and fusion from C2-T7 with the development of distal junctional kyphosis and suboptimal restoration of cervical alignment.

Recent studies on the subject of cervical deformity have begun to focus on the crucial relationship between T1 slope and cervical lordosis.[25,26] The relationship between PI-LL has been used effectively as a measure of lumbopelvic alignment and PI-LL is an effective perioperative tool for planning surgical corrections for lumbar flatback deformity.[5,31] This relationship is mirrored in the cervical spine in which T1 slope has been shown to correlate with cervical lordosis. When the TS-CL relationship is disrupted, subaxial cervical deformity is present or the underlying thoracolumbar deformity is so severe that it creates an excessively large T1 slope that outstrips the ability of cervical spine to balance alignment.[25,26] Protopsaltis *et al*[26] demonstrated that even in the presence of underlying thoracolumbar deformity, if the mismatch between T1 slope and cervical lordosis (TS-CL) is greater than 17°, then cervical deformity is present. Ames *et al*[25] demonstrated that among patients who had undergone posterior cervical fusions, a TS-CL mismatch of 20° corresponded to a cSVA of more than 4 cm, the published threshold for cervical deformity.

In the present series, the rate of failure to correct TS-CL was higher when compared to correction of cSVA (64.7% *vs.* 46.4%). This may reflect the difficulty in improving the cervical lordosis particularly in the revision setting. Surgeons are less likely to perform three-column osteotomies in the cervical region above C7 which limits the degree to which TS-CL can be improved. Factors associated with successful correction of TS-CL included more levels fused anteriorly and larger anterior osteotomy grade (Table 3). These associations suggest an improved capacity to improve cervical lordosis when utilizing multilevel anterior interbody fusion particularly when coupled with a higher grade anterior osteotomy such as complete uncovertebral resection. However, such techniques are not viable options in a revision setting in which a multilevel fusion is present without open disc spaces. Moreover, when the decision is made to perform a three-column ostoeomy in the upper thoracic spine as is often the case in revision ACD surgeries, cervical lordosis is not directly improved. Rather, such osteotomies decrease the T1 slope; however, the T1 slope improvement can be mitigated by relaxation of lumbar hyperlordosis and a decrease in pelvic retroversion as demonstrated by Ramchandran *et al*.[32] Surgeons need to consider such subjacent reciprocal alignment changes when planning surgeries to correct cervical deformities, particularly when they occur in the cervicothoracic junction and the upper thoracic spine. When TS-CL mismatch is present, the results of this study support the conclusion that an anterior approach osteotomy should be considered whenever feasible, utilizing open disc spaces when there is not a rigid fusion.

The primary limitations of the present study are the short-term follow-up and the lack of PROMs. However, this study is intended to demonstrate whether the corrections in these challenging patients are sufficient from the outset. The results demonstrate that the high rate of radiographic failures implies incomplete correction at the time of surgery or very early failure due to DJK which may be linked to the secondary deformity factors discussed above. Longer follow-up is necessary to gauge if there is further deterioration of the deformity corrections with time and the impact of the malalignment on health-related quality of life measures. The strengths of this study are the multicenter and prospective design. Moreover, it represents the largest compilation of patients undergoing surgery for cervical deformity to date.

Surgery to correct ACD can be challenging. Factors that were associated with failure to correct the cSVA included revision surgery, worse preoperative C2 Pelvic Tilt angle, concurrent thoracolumbar deformity, and failure to correct the secondary, thoracolumbar drivers of the deformity. Failure to correct the TS-CL mismatch was associated with worse preoperative cervical kyphosis and worse preoperative C2 Pelvic Tilt angle. The occurrence of early post-operative DJK is a major determinant of postoperative radiographic failures. Patients with ACD should be assessed for concurrent thoracolumbar deformity and full spine radiographic assessments are essential when planning their cervical deformity surgery.

➢ Key Points

- ❑ Factors associated with failure to correct positive cervical alignment included revision surgery, worse preoperative CPT, and concurrent thoracolumbar deformity.

- ❑ Failure to correct the TS-CL mismatch was related to worse preoperative cervical kyphosis and CPT.
- ❑ Corrections that did not account for secondary, thoracolumbar deformity drivers resulted in suboptimal radiographic outcomes.
- ❑ Occurrence of early postoperative DJK significantly affects postoperative outcomes.

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