

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 heterogeneous 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 $>10^\circ$), cervical scoliosis (C2–C7 coronal Cobb angle $>10^\circ$), 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 (C2PT) 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

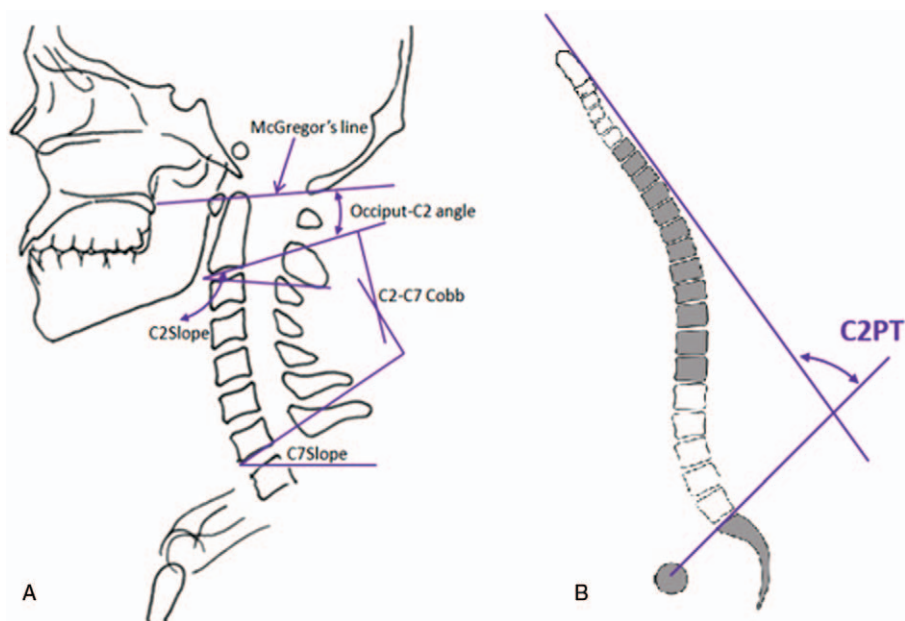


Figure 1. Schematic representation of cervical radiographic parameters. **A**, Upper cervical lordosis is measured by the Cobb angle between McGregor line and the line along the endplate of C2. **B**, C2 pelvic tilt (C2PT) is the angle subtended by a line along the posterior vertebral body of C2 and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

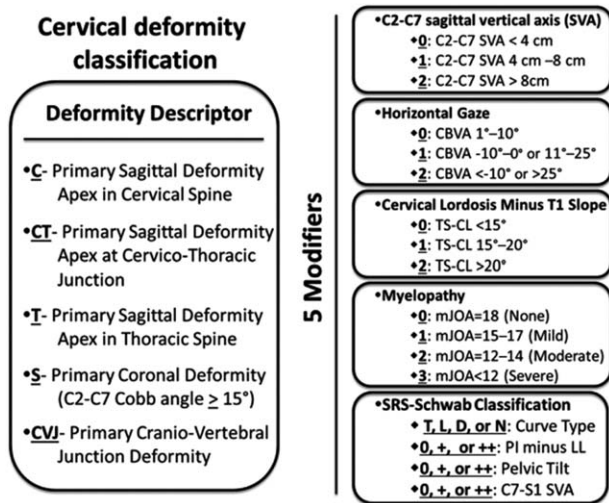


Figure 2. The cervical deformity classification of Ames *et al*²³ includes the deformity descriptor and 5 Modifiers. D indicates double; L, lordosis; N, none; T, thoracic.

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 Spine-View (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 \pm 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

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

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.

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)	<i>P</i>
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 $P \leq 0.05$.

*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%)	<i>P</i>
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 $P \leq 0.05$.

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

