Risk factors for determining length of intensive care unit and hospital stays following correction of cervical deformity: evaluation of early severe adverse events

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OBJECTIVE Correction of rigid cervical deformities can be associated with high complication rates and result in prolonged intensive care unit (ICU) and hospital stays. In this study, the authors aimed to examine the risk factors contributing to length of stay (LOS) in both the hospital and ICU following adult cervical deformity (ACD) surgery and to identify severe adverse events that occurred in this setting.

METHODS A retrospective review of ACD patients who underwent posterior-based osteotomies for deformity correction from 2010 to 2019 was performed. Inclusion criteria were cervical kyphosis > 20° and/or cervical sagittal vertical axis (cSVA) > 4 cm. Multivariate analysis was used to identify risk factors independently associated with ICU and hospital LOS.

RESULTS A total of 107 patients were included. The mean age was 63.5 years, and 61.7% were female. Over half (52.3%) underwent 3-column osteotomies, while 47.7% underwent posterior column osteotomies. There was significant correction of all cervical parameters: cSVA (6.0 vs 3.6 cm, $p < 0.001$), cervical lordosis (8.2° vs -5.3°, $p < 0.001$), cervical scoliosis (6.5° vs 2.2°, $p < 0.001$), and T1-slope (40.2° vs 34.5°, $p < 0.001$). There were also reciprocal changes to the distal spine: thoracic kyphosis (54.4° vs 46.4°, $p < 0.001$), lumbar lordosis (49.9° vs 45.8°, $p = 0.003$), and thoracolumbar scoliosis (13.9° vs 11.1°, $p = 0.009$). Overall, 4 patients (3.7%) suffered aspiration-related complications, 3 patients (2.8%) experienced dysphagia requiring a feeding tube, and 4 patients (3.7%) had compromised airways, with 1 resulting in death. The mean ICU and hospital LOS were 2.8 days and 7.9 days, respectively. Multivariate analysis identified three factors independently associated with longer ICU LOS: female sex (3.0 vs 2.4 days, $p = 0.004$), ≥ 12 segments fused (3.5 vs 1.9 days, $p = 0.002$), and postoperative complication (4.0 vs 1.9 days, $p = 0.017$). These same factors were independently associated with longer hospital LOS as well: female sex (8.3 vs 7.3 days, $p = 0.013$), ≥ 12 segments fused (9.4 vs 6.2 days, $p = 0.001$), and complication (9.7 vs 6.7 days, $p = 0.026$).

CONCLUSIONS Posterior-based osteotomies are very effective for the correction of ACD, but postoperative hospital stays are relatively longer than those following surgery for degenerative disease. Risk factors for prolonged ICU and hospital LOS consist of both nonmodifiable (female sex) and modifiable (≥ 12 segments fused and presence of complication) risk factors. Additional multicenter prospective studies will be needed to validate these findings.

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KEYWORDS cervical; intensive care unit; length of stay; osteotomy; deformity

OVER the last several years, there has been an increase in the understanding of adult cervical deformity (ACD) as a complex and heterogeneous disease.^{1,2} The health impact of ACD remains evident, with several studies establishing its severity through health-related quality-of-life measures, where its scores are compa-

rable to or even worse than diseases such as heart disease, breast cancer, blindness, and stroke.^{1–4} This is especially the case when the cervical sagittal vertical axis (cSVA) is greater than 4 cm.^{1,3} Patients with ACD often present with significant disability secondary to the inability to maintain horizontal gaze, abnormal gait, chronic dysphagia, debili-

ABBREVIATIONS 3CO = 3-column osteotomy; ACD = adult cervical deformity; ASD = adult spinal deformity; CL = cervical lordosis; CS = cervical scoliosis; cSVA = cervical SVA; ICU = intensive care unit; LL = lumbar lordosis; LOS = length of stay; NG = nasogastric; PCO = posterior column osteotomy; PEG = percutaneous gastrostomy; PI = pelvic incidence; PT = pelvic tilt; SPO = Smith-Petersen osteotomy; SVA = sagittal vertical axis; TK = thoracic kyphosis; TLS = thoracolumbar scoliosis.

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tating neck pain, and/or neurological deficits (myelopathy and radiculopathy).⁵ Fortunately, prior studies have shown that surgical correction of deformity significantly improves disability and pain in ACD patients.^{6,7}

There is a growing body of literature describing the treatment and management of ACD patients.^{8,9} The correction of severe and/or fixed (ankylosed) cervical and cervicothoracic deformities often requires bone release to achieve goal correction, with the extent of bone removal dependent on the severity of deformity and on anatomical considerations. Most ACD cases can be adequately corrected with posterior-based approaches using multilevel low-grade osteotomies such as Smith-Petersen osteotomies (SPOs) or high-grade osteotomy such as pedicle subtraction osteotomy.⁹ Due to the invasiveness of these surgical techniques and the frailty of the patient demographic, however, complication rates remain relatively high. The limited studies conducted to assess outcomes in ACD correction report complication rates as high as 43.6%, with this number rising to 56.5% when evaluating ACD patients treated via 3-column osteotomy (3CO), despite excellent radiographic improvement.^{10,11} The surgical invasiveness coupled with high complication rates can result in extended intensive care unit (ICU) and overall hospital length of stay (LOS). In addition, the ICU is more resource-intensive, and extended LOS in the ICU places a significant burden on healthcare costs for hospitals.

ACD surgery and patient characteristics are very different than the treatment and management of thoracolumbar adult spinal deformity (ASD). A detailed understanding of the ICU course following correction of severe ACD is essential to deliver optimal patient care, and currently the literature surrounding this topic is lacking. Given the paucity of studies concentrating on ICU and hospital LOS for ACD patients, specific modifiable and nonmodifiable risk factors for prolonged ICU and hospital stays have yet to be elucidated. Therefore, in this study we aim to define the average ICU and hospital LOS for ACD surgery and identify risk factors for prolonged LOS. This study also discusses the critical components to ICU care and complication prevention methods for patients undergoing ACD surgery via posterior-based osteotomies.

Methods

The study protocol received formal approval by the IRB Committee at the University of California, San Francisco.

Study Cohort

A consecutive cohort of ACD patients who underwent posterior-based osteotomies for deformity correction by the senior author (C.P.A.) from 2010 to 2019 were identified. Inclusion criteria for this study were ACD patients with cSVA of at least 4 cm and/or cervical kyphosis of 20° or more. Patients with a diagnosis of acute trauma, cancer, and/or infection were excluded, resulting in a cohort consisting of primary ACD patients, with degenerative, iatrogenic, and inflammatory pathologies. Indications for surgery included severe disability secondary to chronic dysphagia, debilitating neck pain, abnormal gait, progres-

sive deformity, and/or neurological deficits (myelopathy and radiculopathy). All surgical treatment utilized posterior-based osteotomies, which comprised either multilevel posterior column osteotomies (PCOs; Cervical Osteotomy Ames grade 2) or 3COs (Cervical Osteotomy Ames grade 5 or 6).⁹

Data Collection

Data were collected on a retrospective basis from the electronic medical record. Data of interest were patient demographic and clinical variables such as age (years), sex, BMI, smoking status, and presence of preoperative myelopathy and/or weakness. The presence of medical comorbidities was also assessed and included psychiatric disease, stroke, hypertension, diabetes, thyroid disease, gastrointestinal disease, pulmonary disease, cardiac disease, hyperlipidemia, hepatic disease, and renal disease. All radiographic measurements were recorded and performed on standing scoliosis radiographs. Cervical, thoracolumbar, and spinopelvic parameters were gathered both preoperatively and postoperatively to assess for degree of surgical correction. Measurements included cSVA, cervical lordosis (CL), degree of cervical scoliosis (CS), T1-slope, sagittal vertical axis (SVA), thoracic kyphosis (TK), lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), and thoracolumbar scoliosis (TLS). The methodology for measuring scoliosis radiographs has previously been described.^{12,13} In addition to clinical characteristics, surgical variables were collected and included osteotomy type (PCO vs 3CO), surgical approach, number of segments fused (< 12 vs ≥ 12), use of decompression, estimated blood loss (liters), operative time (minutes), and presence of a postoperative complication. Adverse outcomes that occurred during patients' hospital stay were tabulated as well. The primary outcomes of the study were ICU and total hospital LOS. ICU LOS was calculated as the number of days spent in the ICU following surgery. Total hospital LOS was defined as the cumulative number of days the patient spent in the hospital from date of admission to date of discharge.

Statistical Analysis

Continuous variables such as radiographic parameters were compared using paired Student t-tests to assess for significant changes after surgical correction. Given that our outcome variables of ICU and hospital LOS were continuous variables, linear regressions were utilized to identify factors associated with LOS. Univariate linear regressions were initially performed to identify variables of interest, and covariates with a p value < 0.250 were subsequently incorporated into a multivariate linear regression model to identify independently associated risk factors for extended LOS. All statistical tests were two-tailed, using a p value < 0.050 for statistical significance. Analysis was performed using the R statistical program (version 3.6.1, R Foundation for Statistical Computing).

Results

Patient Characteristics

A total of 107 patients were included in the study. A

summary of demographic, clinical, and surgical characteristics can be found in Table 1. The mean age for our cohort was 63.5 years, and 61.7% of patients were female. The average preoperative BMI was 27.8 kg/m². A majority of patients (71.0%) presented with myelopathy and 40.2% were found to have weakness on examination. The vast majority of patients (82.2%) underwent single-staged posterior-based osteotomies, with only several patients (17.8%) undergoing staged anterior cervical discectomy. Slightly more than half of the patients (52.3%) underwent 3CO as compared to multilevel PCO in the remainder (47.7%). A total of 58 patients (54.2%) had 12 or more segments fused, and 83.2% of all patients underwent decompression. The mean blood loss was 1.1 L with an average operative time of 273.5 minutes. Overall, 43 patients (40.2%) experienced a complication (medical, surgical, or neurological), with medical complications being the most prevalent (26.2%).

Preoperative and Postoperative Radiographic Parameters

Table 2 describes the changes in radiographic measurements after surgical correction. Overall, there was significant correction of all cervical parameters: cSVA (6.0 vs 3.6 cm, $p < 0.001$), CL (8.2° vs -5.3°, $p < 0.001$), CS (6.5° vs 2.2°, $p < 0.001$), and T1-slope (40.2° vs 34.5°, $p < 0.001$). There were also reciprocal changes to the distal spine: TK (54.4° vs 46.4°, $p < 0.001$), LL (49.9° vs 45.8°, $p = 0.003$), and TLS (13.9° vs 11.1°, $p = 0.009$). Cervical, thoracolumbar, and spinopelvic parameters were compared in three distinct cohorts: all patients, patients who underwent high-grade osteotomies, and patients who underwent low-grade osteotomies. When considering patients who underwent 3CO, significant improvement was observed in all cervical measurements: cSVA (6.5 vs 3.8 cm, $p < 0.001$), CL (2.3° [kyphosis] vs -6.7° [lordosis], $p < 0.001$), CS (5.5° vs 1.8°, $p = 0.002$), and T1-slope (48.6° vs 35.8°, $p < 0.001$). In addition, there were significant changes in the thoracolumbar spine: TK (64.4° vs 47.7°, $p < 0.001$) and LL (52.4° vs 46.8°, $p = 0.002$). For the PCO group, significant improvements were observed for all cervical parameters except for T1-slope: cSVA (5.4 vs 3.4 cm, $p < 0.001$), CL (14.6° [kyphosis] vs -3.9° [lordosis], $p < 0.001$), CS (7.4° vs 2.7°, $p = 0.004$), and T1-slope (31.4° vs 33.1°, $p = 0.347$); there were no significant changes in distal spinal alignment measures. In all three groups, there was no significant change in spinopelvic parameters.

Adverse Events During Hospital Stay Following ACD Surgery

In Table 3 we report the most significant adverse outcomes observed in patients following ACD correction surgery. Overall, the rates of severe events that occurred during either ICU or hospital stay were low, remaining below 5% for all complications surveyed. The highest incidence was seen with 5 patients (4.7%) who developed pneumonia/pneumonitis, 4 of whom suffered this complication due to an aspiration-related event. A total of 3 patients (2.8%) experienced severe dysphagia following surgery, with 2 requiring placement of a nasogastric (NG) or percutaneous gastrostomy (PEG) tube. With regard to

TABLE 1. Overall demographics and clinical data of ACD patients who underwent surgical correction

Demographic/Clinical Variable	Value
No. of patients	107
Mean age $\pm$ SD, yrs	63.5 $\pm$ 10.1
Sex, n (%)	
Male	41 (38.3)
Female	66 (61.7)
Mean BMI $\pm$ SD, kg/m ²	27.8 $\pm$ 6.6
Smoker, n (%)	
Active	15 (14.0)
Former	41 (38.3)
Never	51 (47.7)
Preop myelopathy, n (%)	
Yes	76 (71.0)
No	31 (29.0)
Preop weakness, n (%)	
Yes	43 (40.2)
No	64 (59.8)
Osteotomy type, n (%)	
3CO	56 (52.3)
Other	51 (47.7)
Surgical approach, n (%)	
Anterior-posterior	19 (17.8)
Posterior only	88 (82.2)
No. of segments fused, n (%)	
<12	49 (45.8)
≥ 12	58 (54.2)
Decompression, n (%)	
Yes	89 (83.2)
No	18 (16.8)
Staged procedure, n (%)	
Yes	14 (13.1)
No	93 (86.9)
Any complication, n (%)	
Yes	43 (40.2)
No	64 (59.8)
Medical complication, n (%)	
Yes	28 (26.2)
No	79 (73.8)
Surgical complication, n (%)	
Yes	19 (17.8)
No	88 (82.2)
Neurological complication, n (%)	
Yes	18 (16.8)
No	89 (83.2)
Mean estimated blood loss $\pm$ SD, L	1.1 $\pm$ 1.5
Mean operative time $\pm$ SD, mins	273.5 $\pm$ 105.5
Mean ICU LOS $\pm$ SD, days	2.8 $\pm$ 2.3
Mean hospital LOS $\pm$ SD, days	7.9 $\pm$ 3.9

TABLE 2. Radiographic changes to cervical, thoracolumbar, and spinopelvic parameters in ACD patients who underwent surgical correction, stratified by osteotomy type

Radiographic Parameter	Preop		Postop		Correction	p Value
	Mean	SD	Mean	SD		
All patients						
cSVA (cm)	6.0	1.9	3.6	1.5	2.4	<0.001
CL (°)	8.2	26.8	−5.3	17.2	13.5	<0.001
CS (°)	6.5	10.8	2.2	4.3	4.3	<0.001
T1-slope (°)	40.2	20.4	34.5	13.0	5.7	<0.001
SVA (cm)	3.0	5.6	4.0	4.9	1.0	0.186
TK (°)	54.4	19.5	46.4	16.0	8.0	<0.001
LL (°)	49.9	15.1	45.8	15.4	4.1	0.003
PI (°)	56.3	14.2	55.3	13.8	1.0	0.181
PT (°)	22.0	11.1	22.1	10.8	0.1	0.857
TLS (°)	13.9	14.3	11.1	11.2	2.8	0.009
High-grade (3CO)						
cSVA (cm)	6.5	1.9	3.8	1.6	2.7	<0.001
CL (°)	2.3	24.5	−6.7	19.4	9.0	<0.001
CS (°)	5.5	9.0	1.8	3.5	3.7	0.002
T1-slope (°)	48.6	20.7	35.8	12.7	12.8	<0.001
SVA (cm)	2.9	5.3	3.6	5.0	0.7	0.377
TK (°)	64.4	15.9	47.7	11.9	16.7	<0.001
LL (°)	52.4	13.7	46.8	13.8	5.6	0.002
PI (°)	55.7	12.9	54.0	12.7	1.7	0.115
PT (°)	21.5	10.7	20.2	10.1	1.3	0.178
TLS (°)	11.8	14.5	9.0	8.9	2.8	0.067
Low-grade (PCO)						
cSVA (cm)	5.4	1.7	3.4	1.5	2.0	<0.001
CL (°)	14.6	27.9	−3.9	14.6	18.5	<0.001
CS (°)	7.4	12.3	2.7	5.0	4.7	0.004
T1-slope (°)	31.4	16.0	33.1	13.3	1.7	0.347
SVA (cm)	3.1	5.9	4.3	4.8	1.2	0.333
TK (°)	43.7	17.4	45.1	19.4	1.4	0.136
LL (°)	47.2	16.2	44.7	17.0	2.5	0.322
PI (°)	57.0	15.7	56.7	14.8	0.3	0.756
PT (°)	22.7	11.6	24.0	11.4	1.3	0.110
TLS (°)	16.2	13.8	13.5	13.0	2.7	0.061

Boldface type indicates statistical significance.

airway and respiratory status, 4 patients (3.7%) exhibited symptoms of pulmonary edema and subsequent hypoxemia, with 3 patients requiring prolonged postoperative intubation. One of the 4 patients had acute airway decompensation and required emergency reintubation; despite desperate measures of endotracheal intubation and eventually an emergency cricoideotomy, the patient died from diffuse cerebral hypoxia.

Identifying Risk Factors Associated With LOS

The mean values for ICU LOS, as well as unstandardized beta coefficients with p values from univariate and multivariate linear regressions for each of our variables,

TABLE 3. Patients with severe adverse events during their hospital stay following ACD correction surgery

Postop Event	No. of Patients (%)
No. of patients (total)	107
Aspiration-related complication	4 (3.7)
Pneumonia/pneumonitis	5 (4.7)
Airway edema/compromise*	4 (3.7)
Pulmonary edema/hypoxemia	4 (3.7)
Delayed extubation	3 (2.8)
Dysphagia	3 (2.8)
PEG/NG tube requirement	2 (1.9)
Hypotension	3 (2.8)

* Required prolonged intubation or reintubation.

can be found in Table 4. The mean ICU LOS was 2.8 days. Factors that were found to be independently associated with extended LOS in the ICU upon multivariate analysis were sex, number of segments fused, and presence of a complication. Female patients were associated with longer LOS in the ICU (3.0 vs 2.4 days, beta coefficient 1.4, $p = 0.004$) than their male counterparts. Additionally, patients who had 12 or more segments fused (3.5 vs 1.9 days, beta coefficient 1.5, $p = 0.002$) and the presence of any type of complication (4.0 vs 1.9 days, beta coefficient 2.5, $p = 0.017$) were associated with longer ICU stays.

Table 5 shows the mean values for total hospital LOS, as well as results from the univariate and multivariate linear regressions. The average total hospital LOS was 7.9 days. Multivariate analysis once again demonstrated that sex, number of segments fused, and presence of a complication were independently associated with prolonged total hospital LOS. Female patients were observed to have longer overall hospital stays (8.3 vs 7.3 days, beta coefficient 2.0, $p = 0.013$). Patients with 12 or more segments fused during surgery had longer overall hospital stays (9.4 vs 6.2 days, beta coefficient 2.6, $p = 0.001$). Patients with any complication also had longer hospital stays overall (9.7 vs 6.7 days, beta coefficient 2.4, $p = 0.026$).

Discussion

While the understanding of ACD as a complex surgical disease continues to increase, there is still a relative paucity of literature on the topic as compared to its counterpart in thoracolumbar ASD. Despite this, it is clear that there is a direct correlation between cSVA and worse function and increased disability in ACD patients, especially when the cSVA is greater than 4 cm.^{1,3} Fortunately, continued advances in surgical technique and the gradual adoption of standardized protocols for treating ACD have led to improved surgical treatments for ACD patients. In addition, multiple studies have shown that patients who undergo surgical correction for ACD gain significant improvement in their deformity-related symptomatology, including relief of debilitating pain.^{6,7}

Despite the fact that patients can benefit tremendously from surgical correction of ACD, these cases often warrant extensive soft-tissue releases, osteotomies, and

TABLE 4. Average ICU LOS and linear regression models for ACD patients, by demographic, medical, and surgical characteristics

Characteristic	ICU Stay					
	Mean (days)	SD	Beta Coefficient	Univariate p Value	Beta Coefficient	Multivariate p Value
Age (yrs)						
<55	3.7	2.6	Ref	Ref	Ref	Ref
55–70	2.6	2.1	–1.1	0.116	–1.0	0.131
>70	2.8	2.4	–0.8	0.296	–0.8	0.283
Sex						
Male	2.4	1.8	Ref	Ref	Ref	Ref
Female	3.0	2.5	0.6	0.167	1.4	0.004
BMI (kg/m ²)						
<18.5	1.8	1.5	Ref	Ref	Ref	Ref
18.5–25	2.5	2.6	0.7	0.558	–0.7	0.563
25–30	3.3	2.2	1.5	0.205	0.7	0.595
>30	2.6	2.0	0.9	0.475	0.7	0.548
Smoking status						
Active	2.3	2.2	Ref	Ref	Ref	Ref
Former	3.2	2.7	1.0	0.161	0.7	0.300
Never	2.5	1.8	0.2	0.712	0.1	0.906
Comorbidities						
Psychiatric						
No	2.6	2.2	Ref	Ref		
Yes	3.0	2.3	0.4	0.327		
Stroke						
No	2.7	2.3	Ref	Ref		
Yes	3.4	2.1	0.7	0.279		
Hypertension						
No	2.8	2.4	Ref	Ref		
Yes	2.6	2.1	–0.2	0.642		
Diabetes						
No	2.8	2.3	Ref	Ref		
Yes	2.4	1.7	–0.4	0.572		
Thyroid						
No	2.7	2.3	Ref	Ref		
Yes	3.0	1.5	0.3	0.668		
Gastrointestinal						
No	2.8	2.4	Ref	Ref		
Yes	2.7	2.0	–0.1	0.896		
Pulmonary						
No	2.8	2.4	Ref	Ref		
Yes	2.7	1.7	–0.0	0.985		
Cardiac						
No	2.7	2.3	Ref	Ref		
Yes	2.9	1.7	0.2	0.716		
Hyperlipidemia						
No	2.9	2.3	Ref	Ref	Ref	Ref
Yes	2.1	2.0	–0.8	0.153	–0.7	0.279
Hepatic						
No	2.8	2.3	Ref	Ref		
Yes	2.7	2.1	0.0	0.968		

CONTINUED ON PAGE 183 »

» CONTINUED FROM PAGE 182

TABLE 4. Average ICU LOS and linear regression models for ACD patients, by demographic, medical, and surgical characteristics

Characteristic	ICU Stay					
	Mean (days)	SD	Beta Coefficient	Univariate p Value	Beta Coefficient	Multivariate p Value
Comorbidities (<i>continued</i>)						
Renal						
No	2.8	2.3	Ref	Ref		
Yes	2.0	0.8	−0.8	0.501		
Preop weakness						
No	3.0	2.5	Ref	Ref	Ref	Ref
Yes	2.4	1.7	−0.6	0.185	−0.4	0.413
Abnormal gait						
No	2.7	2.3	Ref	Ref		
Yes	2.8	2.3	0.1	0.873		
Kyphosis						
<20°	2.7	2.6	Ref	Ref		
≥20°	2.9	1.8	0.2	0.593		
cSVA (cm)						
<4	2.4	2.0	Ref	Ref	Ref	Ref
4–6	2.4	1.8	0.1	0.937	0.5	0.488
6–8	3.1	2.7	0.7	0.876	0.7	0.339
>8	3.4	2.6	1.1	0.234	0.6	0.492
Osteotomy type						
High-grade	3.3	2.3	Ref	Ref	Ref	Ref
Low-grade	2.1	2.0	−1.2	0.007	0.1	0.811
Segments fused						
<12	1.9	1.6	Ref	Ref	Ref	Ref
≥12	3.5	2.4	1.6	<0.001	1.5	0.002
Approach						
Combined	3.7	2.7	Ref	Ref	Ref	Ref
Posterior	2.5	2.1	−1.2	0.034	−0.5	0.385
Laminectomy						
No	3.3	2.7	Ref	Ref		
Yes	2.6	2.2	−0.6	0.275		
Any complication						
No	1.9	1.5	Ref	Ref	Ref	Ref
Yes	4.0	2.7	2.0	<0.001	2.5	0.017
Medical complication						
No	2.3	1.7	Ref	Ref	Ref	Ref
Yes	4.1	3.0	1.8	<0.001	−0.4	0.674
Surgical complication						
No	2.6	2.3	Ref	Ref	Ref	Ref
Yes	3.6	1.9	1.0	0.08	−3.7	0.116
Neurological complication						
No	2.6	2.3	Ref	Ref	Ref	Ref
Yes	3.6	1.9	1.0	0.07	3.6	0.109

Boldface type indicates statistical significance.

TABLE 5. Average hospital LOS and linear regression models for ACD patients by demographic, medical, and surgical characteristics

Characteristic	Hospital Stay					
	Mean (days)	SD	Beta Coefficient	Univariate p Value	Beta Coefficient	Multivariate p Value
Age (yrs)						
<55	8.6	2.7	Ref	Ref		
55–70	7.6	3.7	–1.0	0.421		
>70	8.6	4.9	0.0	0.986		
Sex						
Male	7.3	3.1	Ref	Ref	Ref	Ref
Female	8.3	4.3	1.0	0.179	2.0	0.013
BMI (kg/m ²)						
<18.5	5.3	1.5	Ref	Ref	Ref	Ref
18.5–25	8.9	5.0	3.7	0.074	1.0	0.645
25–30	8.2	3.7	2.9	0.154	0.8	0.688
>30	7.1	2.7	1.8	0.369	0.6	0.780
Smoking status						
Active	8.1	3.3	Ref	Ref		
Former	8.9	5.1	0.8	0.485		
Never	7.1	2.6	–0.9	0.411		
Comorbidities						
Psychiatric						
No	7.6	3.5	Ref	Ref	Ref	Ref
Yes	8.6	4.5	1.0	0.189	0.6	0.397
Stroke						
No	7.8	3.9	Ref	Ref		
Yes	8.9	4.1	1.1	0.343		
Hypertension						
No	8.1	4.2	Ref	Ref		
Yes	7.7	3.5	–0.5	0.516		
Diabetes						
No	7.9	4.0	Ref	Ref		
Yes	8.4	3.4	0.6	0.612		
Thyroid						
No	7.8	3.7	Ref	Ref		
Yes	8.7	5.4	0.9	0.456		
Gastrointestinal						
No	7.9	3.6	Ref	Ref		
Yes	8.1	4.4	0.2	0.781		
Pulmonary						
No	8.0	4.1	Ref	Ref		
Yes	7.6	3.1	–0.4	0.639		
Cardiac						
No	7.8	4.0	Ref	Ref		
Yes	8.7	3.3	0.9	0.403		
Hyperlipidemia						
No	8.0	3.9	Ref	Ref		
Yes	7.6	4.0	–0.5	0.652		
Hepatic						
No	7.9	3.6	Ref	Ref		
Yes	9.0	6.9	1.1	0.455		

CONTINUED ON PAGE 185 »

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TABLE 5. Average hospital LOS and linear regression models for ACD patients by demographic, medical, and surgical characteristics

Characteristic	Hospital Stay					
	Mean (days)	SD	Beta Coefficient	Univariate p Value	Beta Coefficient	Multivariate p Value
Comorbidities <i>(continued)</i>						
Renal						
No	7.9	3.9	Ref	Ref		
Yes	8.3	2.2	0.3	0.869		
Preop weakness						
No	8.2	3.7	Ref	Ref		
Yes	7.6	4.2	−0.6	0.474		
Abnormal gait						
No	7.9	3.7	Ref	Ref		
Yes	8.0	4.2	0.1	0.878		
Kyphosis						
<20°	7.9	3.8	Ref	Ref		
≥20°	8.2	4.2	0.3	0.703		
cSVA (cm)						
<4	7.3	3.1	Ref	Ref	Ref	Ref
4–6	7.0	3.2	−0.3	0.806	0.7	0.551
6–8	8.5	4.7	1.2	0.3705	1.5	0.245
>8	10.2	3.7	2.9	0.055	2.5	0.083
Osteotomy type						
High-grade	8.7	3.7	Ref	Ref	Ref	Ref
Low-grade	7.1	3.9	−1.6	0.029	−0.2	0.783
Segments fused						
<12	6.2	2.7	Ref	Ref	Ref	Ref
≥12	9.4	4.1	3.3	<0.001	2.6	0.001
Approach						
Combined	9.8	3.9	Ref	Ref	Ref	Ref
Posterior	7.5	3.8	−2.3	0.018	−0.9	0.286
Laminectomy						
No	9.0	3.6	Ref	Ref	Ref	Ref
Yes	7.7	3.9	−1.3	0.203	−0.5	0.600
Any complication						
No	6.7	3.2	Ref	Ref	Ref	Ref
Yes	9.7	4.1	3.0	<0.001	2.4	0.026
Medical complication						
No	7.2	3.4	Ref	Ref	Ref	Ref
Yes	10.1	4.3	2.9	<0.001	0.4	0.763
Surgical complication						
No	7.8	4.0	Ref	Ref		
Yes	8.4	3.1	0.6	0.550		
Neurological complication						
No	7.8	4.0	Ref	Ref		
Yes	8.4	3.2	0.5	0.589		

Boldface type indicates statistical significance.

long construct fusions in order to achieve the desired results.^{10,11,14} Similar to prior studies, our results demonstrate that posterior-based osteotomies and soft-tissue releases are able to achieve excellent surgical correction.^{8,10–12,15–17} When looking at improvement in radiographic measurements across all patients, we observed that both cervical and thoracolumbar measurements significantly improved without changes in spinopelvic parameters. However, on subgroup analysis of 3CO and PCO, only 3CO was associated with significant changes in T1-slope and thoracolumbar parameters, highlighting the power of 3COs for ACD correction. It is also important to note that the subset of patients undergoing 3CO on average had greater preoperative cSVA (neck translation), CL (more lordosis), T1-slope, and TK than PCO cases. Conversely, PCO cases had abnormal cSVA to a lesser degree with lower CL (worse kyphosis). This trend highlights how surgical approach as well as osteotomy type and location depend heavily on the specific type of ACD being treated.⁹ For ACD with abnormal cSVA (> 4 cm) due to an abnormally high T1-slope (> 30°), the deformity stems mainly from a cervicothoracic or upper thoracic deformity. In such cases, a 3CO is warranted to augment the abnormally high T1-slope. For positive cSVA mainly due to cervical kyphosis in the subaxial spine (normal T1-slope), multilevel PCO should be sufficient.^{6,11,18–20}

Given the paucity of comprehensive literature for ACD surgery, it is important to continue investigating clinical questions such as what risk factors may prolong patient ICU and hospital LOS after ACD surgery. The average ICU and total hospital LOS in our cohort were 2.8 days and 7.9 days, respectively. For both ICU and total hospital stay, we observed that many variables were significant on univariate analysis. However, given the high degree of association and likelihood of confounders within these variables, it was important to create a comprehensive multivariate model as well to identify independent associations.²¹ To this end, we incorporated not only variables that were significant on univariate analysis, but also all variables with a *p* value < 0.250. The risk factors ultimately found to be independently associated with both longer ICU and hospital LOS were female sex, 12 or more segments fused during surgery, and the presence of a complication. Two of the 3 identified variables (fusion levels and the presence of a complication) are potentially modifiable in practice with goals of minimizing the need for prolonged ICU and hospital LOS.

The longer LOS stay for patients with 12 or more segments fused is likely explained by the fact that number of segments fused serves as a proxy for complexity and invasiveness of the surgery being performed. Often, the complexity is dictated by the deformity severity and need for particular surgical strategies. These results are consistent with a 2019 study by Horn et al. and the International Spine Study Group (ISSG) to predict extended operative time and length of inpatient stay in ACD corrective surgery, which also showed greater number of segments fused (7 or more in their study) and complications to be associated with extended LOS.²² Thus, it is essential to choose the appropriate surgical strategy and counsel your patients accordingly.

As identified in this study, the presence of a complication was also independently associated with longer ICU (4.0 vs 1.9 days) and hospital (9.7 vs 6.7 days) LOS. Presence of complication was significant in multivariate models for both ICU and total hospital stay, with large beta coefficients of 2.6 and 2.4, respectively, illustrating the large impact (approximately 2.5-day increase in LOS in each regression model) that complication profile had on LOS. Interestingly, when complication type was isolated, none of the specific types of complications (medical, surgical, or neurological) remained significant in the multivariate model; neurological complication was the closest in trending toward significance (*p* = 0.109), with a large beta coefficient of 3.6 indicating a large increase in LOS for patients with neurological complications versus those without. The results of our study corroborate prior cervical spine studies (nondeformity cohorts) that highlight overall postoperative complication rates as predictive of increased LOS.^{23,24}

Perioperative complications are especially important to consider in ACD patients as they are generally a much frailer subset of patients, especially when compared to patients being treated for degenerative disease or thoracolumbar ASD. This increased frailty stems from a multitude of factors, including malnourishment and subsequent cachexia, which can occur as a result of their cervical deformity. Multiple studies have measured the vulnerability of ACD patients using metrics such as the cervical deformity frailty index and the Quality of Life in Swallowing Disorders questionnaire, which has shown a high level of preoperative swallowing dysfunction in ACD cohorts.^{25,26} In particular, a study by Miller et al. showed that cervical deformity patients exhibited a mean preoperative cervical deformity frailty index of 0.44 (severe frailty) and highlighted a significant association between increasing patient frailty and postoperative outcomes, including complication rate, in ACD patients.²⁵ As a result of their multisystem impairments, patients with a high degree of frailty demonstrate diminished physiological response to surgery-related stressors.²⁷ Therefore, ACD patients who undergo deformity correction are often at higher risk of perioperative complications. The significance of complication status in the multivariate model is not surprising, but emphasizes the importance of patient optimization in the preoperative setting, morbidity prevention, and appropriate complication management. It is crucial to understand the optimal perioperative care of ACD patients following deformity correction. As mentioned earlier, neurological deficits have the most impact on need for prolonged ICU and hospital LOS. For ACD correction, most deficits are a result of isolated nerve root weakness (such as C5 and C8 palsy) rather than spinal cord injury. The most effective way to minimize neurological risk is to utilize intraoperative neuromonitoring, but its effectiveness for nerve root monitoring in ACD has not been studied.

An additional aim of this study was to identify patients who suffered severe adverse events during their ICU or hospital stays, to better inform the need for ICU management and continuous pulse monitoring postoperatively. While the overall rate of complications in this study was relatively high (40.2%), we saw a low incidence of severe

adverse events (< 5%) during patients' ICU and hospital stays. Almost all ACD patients who undergo large corrections warrant ICU care for a variety of reasons: hemodynamic instability (requiring rapid transfusions), blood pressure augmentation, close neurological monitoring, adequate pain control, and airway management. Blood pressure augmentation (especially in the presence of neuromonitoring changes) is critical for ensuring that spinal cord perfusion is sufficient, and this can be immediately titrated according to changes in the neurological examination. In this study, 3 patients (2.8%) suffered from hypotension during their hospitalization. Frequent neurological examination is also critical for being able to detect further complications such as a compressive hematoma resulting in spinal cord injury, especially following 3CO. Unlike the management of thoracolumbar ASD patients, one of the most important aspects of caring for ACD patients after surgery is safe and proper airway management. ACD patients are at extremely high risk for airway obstruction secondary to manipulation of the neck with concurrent tracheal and palatal edema (due to prolonged prone positioning and large fluid shifts during surgery).^{28,29} Intubating these patients while in extremis is extremely difficult and, at times, not possible without emergency cricothyrotomy, especially following cervical fusion in which there is limited neck extension.²⁹ A total of 3 patients (2.8%) were kept intubated for a prolonged period secondary to concern for airway edema, and 1 patient (0.9%) required emergency reintubation during their postoperative hospital stay. Unfortunately, that 1 patient could not be reintubated (via endotracheal routes) and required an emergency bedside cricothyrotomy due to compromised airway. Despite all attempts, the patient suffered global hypoxic ischemia with rapid deterioration, resulting in death. As such, management of the airway is essential and needs to be carefully discussed with the anesthesia and ICU teams, with sufficient plans put into place prior to the operation. In addition to fragile respiratory status, ACD patients are at high risk for dysphagia and aspiration; this risk is present even without approaching the spine anteriorly.^{30–32} In our study, 3 patients (2.8%) experienced dysphagia, with 2 requiring placement of an NG or PEG tube to provide sufficient nutrition. There were also 5 patients (4.7%) who experienced pneumonia/pneumonitis as a result of aspiration-related complications.

The importance of this study lies in our ability to identify higher-risk populations of patients that may warrant extra attention for risk stratification and minimization of postoperative morbidity. As the risk factors identified in this study are both nonmodifiable and modifiable risk factors, the clinical impact of our results stems from the ability to understand which patients may be at higher risk when performing ACD correction surgery, so they can be monitored accordingly. Ultimately, this can develop into standardized protocols for management of patients based on perioperative characteristics. In 2019, Ayrian et al. published the results of their collaborative study between neuroanesthesiologists and spine surgeons, which sought to implement a strict perioperative management protocol for complex spine surgery across all spine regions (cervical, thoracic, lumbar, and multiple regions).³³ The aim of the

study was to determine if following a rigorous and methodical perioperative protocol could decrease total hospital and ICU LOS after elective complex spine surgery. Their study showed that implementation of a standard spine surgery protocol significantly reduced total hospital and ICU LOS for their patients, with no significant differences in the rates of postoperative complications between the two groups. However, as similar protocols start to become adopted more widely at hospitals, it is important to distinguish between degenerative disease, thoracolumbar ASD, and ACD as separate disease entities that may warrant unique procedures and protocols. By better understanding the clinical course of ACD correction surgery, we can begin to devise similar protocols on a larger scale that are specific to correction of cervical deformities; this will allow us to provide a safer and more beneficial operative course for patients.

The limitations of this study are primarily in its retrospective design. One of the drawbacks of a retrospective analysis is the possibility of the results being skewed based on selection bias. All patients were treated at a tertiary care spine center that receives referrals from many different regions, so the patient population may not accurately model the general demographic for this disease. Additionally, given the retrospective nature of the study, it is possible that confounding variables remain in our analysis that might have been explained by additional variables or measurements that were not collected. In addition, ACD remains a far less common disease than thoracolumbar ASD, and as such sample sizes and patient cohorts are significantly smaller, oftentimes hampering our ability to conduct meaningful analysis. However, the strength of our study also relates to the size of our overall patient cohort as a single-institution experience, which minimizes inter-surgeon variability in technique and protocol. Our sample size of 107 patients is also relatively large when compared to similar studies in the literature for ACD, of which most are multiinstitutional studies. Regardless, it is vital that further prospective studies be conducted for validation of our findings, and that additional analysis should follow as more patient data become available.

Conclusions

Surgical correction of rigid ACD can be challenging and, in most cases, requires the use of posterior-based osteotomies including multilevel SPO and 3CO. While these surgical techniques can achieve excellent radiographic improvement, they remain invasive and can be associated with high complication rates as well as prolonged ICU and hospital LOS. Our study suggests that sex, number of segments fused, and complication profile are independently associated risk factors for prolonged LOS in both the ICU and the hospital. For both hospital and ICU LOS, our results showed that female patients, as well as those with 12 or more segments fused or any complication during/following ACD correction surgery, had significantly longer LOS. While these variables encompass both modifiable and nonmodifiable risk factors, patients meeting these criteria may warrant extra attention postoperatively. Complications following ACD correction surgery, however,

could benefit from continued refinement of surgical technique and postoperative management as well as additional studies profiling clinical outcomes in these patients. It is important that these findings be validated in prospective studies as we continue to learn more about surgical outcomes following ACD correction.

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Author Contributions

Conception and design: Lau, Joshi, Deviren, Ames. Acquisition of data: Lau, Joshi, Deviren, Ames. Analysis and interpretation of data: Lau, Joshi, Ames. Drafting the article: Joshi. Critically revising the article: Lau, Joshi, Ames. Reviewed submitted version of manuscript: Lau, Joshi, Haddad, Ames. Approved the final

version of the manuscript on behalf of all authors: Lau. Statistical analysis: Lau, Joshi. Study supervision: Lau, Deviren, Ames.

Supplemental Information

Previous Presentations

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