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# Prospective multicenter assessment of complication rates associated with adult cervical deformity surgery in 133 patients with minimum 1-year follow-up

**Justin S. Smith, MD, PhD,[1] Thomas J. Buell, MD,[1] Christopher I. Shaffrey, MD,[2,3] Han Jo Kim, MD,[4] Eric Klineberg, MD,[5] Themistocles Protopsaltis, MD,[6] Peter Passias, MD,[6] Gregory M. Mundis Jr., MD,[7] Robert Eastlack, MD,[7] Vedat Deviren, MD,[8] Michael P. Kelly, MD, MSc,[9] Alan H. Daniels, MD,[10] Jeffrey L. Gum, MD,[11] Alex Soroceanu, MD, MPH,[12] Munish Gupta, MD,[9] Doug Burton, MD,[13] Richard Hostin, MD,[14] Robert Hart, MD,[15] Virginie Lafage, PhD,[4] Renaud Lafage, MS,[4] Frank J. Schwab, MD,[4] Shay Bess, MD,[16] and Christopher P. Ames, MD,[17] on behalf of the International Spine Study Group**

[1]Department of Neurosurgery, University of Virginia Health System, Charlottesville, Virginia; Departments of [2]Neurosurgery and [3]Orthopedic Surgery, Duke University, Durham, North Carolina; [4]Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, New York; [5]Department of Orthopaedic Surgery, University of California Davis, Sacramento, California; [6]Department of Orthopaedic Surgery, NYU Hospital for Joint Diseases, New York, New York; [7]Scripps Clinic, San Diego, California; [8]Department of Orthopedic Surgery, University of California, San Francisco, California; [9]Department of Orthopedic Surgery, Washington University in St. Louis, Missouri; [10]Department of Orthopedic Surgery, Brown University, Providence, Rhode Island; [11]Department of Orthopedic Surgery, Leatherman Spine Center, Louisville, Kentucky; [12]Department of Orthopedic Surgery, University of Calgary, Alberta, Canada; [13]Department of Orthopaedic Surgery, University of Kansas Medical Center, Kansas City, Kansas; [14]Department of Orthopaedic Surgery, Baylor Scoliosis Center, Plano, Texas; [15]Department of Orthopaedic Surgery, Swedish Medical Center, Seattle, Washington; [16]Presbyterian St. Luke's Medical Center, Denver, Colorado; and [17]Department of Neurological Surgery, University of California, San Francisco, California

**OBJECTIVE** Although surgical treatment can provide significant improvement of symptomatic adult cervical spine deformity (ACSD), few reports have focused on the associated complications. The objective of this study was to assess complication rates at a minimum 1-year follow-up based on a prospective multicenter series of ACSD patients treated surgically.

**METHODS** A prospective multicenter database of consecutive operative ACSD patients was reviewed for perioperative (< 30 days), early (30–90 days), and delayed (> 90 days) complications with a minimum 1-year follow-up. Enrollment required at least 1 of the following: cervical kyphosis > 10°, cervical scoliosis > 10°, C2–7 sagittal vertical axis > 4 cm, or chin-brow vertical angle > 25°.

**RESULTS** Of 167 patients, 133 (80%, mean age 62 years, 62% women) had a minimum 1-year follow-up (mean 1.8 years). The most common diagnoses were degenerative (45%) and iatrogenic (17%) kyphosis. Almost 40% of patients were active or past smokers, 17% had osteoporosis, and 84% had at least 1 comorbidity. The mean baseline Neck Disability Index and modified Japanese Orthopaedic Association scores were 47 and 13.6, respectively. Surgical approaches were anterior-only (18%), posterior-only (47%), and combined (35%). A total of 132 complications were reported (54 minor and 78 major), and 74 (56%) patients had at least 1 complication. The most common complications included dysphagia (11%), distal junctional kyphosis (9%), respiratory failure (6%), deep wound infection (6%), new nerve root motor deficit (5%), and new sensory deficit (5%). A total of 4 deaths occurred that were potentially related to surgery, 2 prior to 1-year follow-up (1 cardiopulmonary and 1 due to obstructive sleep apnea and narcotic use) and 2 beyond 1-year follow-

**ABBREVIATIONS** ACSD = adult cervical spine deformity; CCI = Charlson Comorbidity Index; DJK = distal junctional kyphosis; EBL = estimated blood loss; ISSG = International Spine Study Group; mJOA = modified Japanese Orthopaedic Association; NDI = Neck Disability Index; PI-LL = mismatch between pelvic incidence and lumbar lordosis; PT = pelvic tilt; SVA = sagittal vertical axis; TS-CL = T1 slope minus cervical lordosis.

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up (both cardiopulmonary and associated with revision procedures). Twenty-six reoperations were performed in 23 (17%) patients, with the most common indications of deep wound infection (n = 8), DJK (n = 7), and neurological deficit (n = 6). Although anterior-only procedures had a trend toward lower overall (42%) and major (21%) complications, rates were not significantly different from posterior-only (57% and 33%, respectively) or combined (61% and 37%, respectively) approaches (p = 0.29 and p = 0.38, respectively).

**CONCLUSIONS** This report provides benchmark rates for ACSD surgery complications at a minimum 1-year (mean 1.8 years) follow-up. The marked health and functional impact of ACSD, the frail population it affects, and the high rates of surgical complications necessitate a careful risk-benefit assessment when contemplating surgery. Collectively, these findings provide benchmarks for complication rates and may prove useful for patient counseling and efforts to improve the safety of care.

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**KEYWORDS** adult; cervical deformity; complications; surgery

Adult cervical spine deformity (ACSD) can have profound impact on quality of life, including pain, disability, and neurological compromise. A recent report assessed the health status of symptomatic ACSD patients presenting for surgical treatment based on the EQ-5D questionnaire.[1] ACSD patients had a mean EQ-5D index that was 34% below the bottom 25th percentile for an age- and sex-matched normative United States population. This negative health impact was evident across all domains of the EQ-5D and was not significantly different based on deformity type. The overall mean EQ-5D index for the ACSD patients was comparable to the bottom 25th percentile scores for blindness/low vision, emphysema, renal failure, and stroke, and was significantly worse than the bottom 25th percentile for other chronic disease states, including chronic ischemic heart disease, malignant breast cancer, and malignant prostate cancer.[1]

Although the impact of ACSD can be substantial, there has been limited progress in understanding and advancing treatment for these conditions in comparison with that of the more commonly recognized thoracolumbar spinal deformities.[2–6] Early reports of surgery for ACSD focused on the most severe forms of ACSD and were often associated with very high rates of morbidity.[7–9] As advances have been made in spinal instrumentation and surgical techniques, as well as improvements in anesthesia, critical care, and perioperative management, a renewed interest in treating these often complex deformities has developed.[10–17] Recent advances have included development of a standardized nomenclature for soft-tissue release and osteotomies for cervical deformity correction,[18] creation of the novel Ames-Smith cervical deformity classification system,[19] and demonstration of improved outcomes at 1 year after surgical treatment for ACSD.[20]

Despite advances in care, surgical treatment of ACSD continues to have high rates of complications.[10,11,21,22] Recent reports have suggested that the population of patients affected by ACSD may be particularly burdened by overall high levels of comorbidities and general frailty.[23–25] Smith and colleagues recently reported an all-cause mortality rate of 9.2% in a cohort of 120 surgically treated ACSD patients at a mean follow-up of 1.1 years.[24] Although many of these mortalities were beyond the perioperative period and may not have been directly related to the surgical treatment, the only significantly associated factor, among demographic, clinical, and surgical parameters, that could be identified was the occurrence of a major complication. Collectively, these findings suggest that the general frailty of the ACSD patient population may result in these patients having considerably reduced tolerance for significant complications, emphasizing the need to better understand the complications associated with these procedures as a means of developing techniques and approaches to reduce their occurrence.

Our objectives in this study were to assess rates of complications at a minimum 1-year follow-up based on a prospective multicenter series of consecutive ACSD patients treated surgically and to assess for demographic, clinical, and surgical parameters associated with their occurrence.

## Methods

### Patient Population and Data Collection

Consecutive patients with ACSD were prospectively enrolled at 13 centers through the International Spine Study Group (ISSG). Contributing surgeons included orthopedic and neurological surgeons with a practice focus on complex spinal reconstruction and deformity treatment. Internal review board approval was obtained at each participating site prior to enrollment. Inclusion criteria for study enrollment were age ≥ 18 years, presence of cervical deformity, and plan for surgical correction of the deformity. Cervical deformity was defined as the presence of at least 1 of the following: cervical kyphosis (C2–7 sagittal Cobb angle > 10°), cervical scoliosis (C2–7 coronal Cobb angle > 10°), C2–7 sagittal vertical axis (SVA) > 4 cm, or chin-brow vertical angle > 25°. Exclusion criteria included presence of active tumor or infection. In addition to the general database inclusion criteria, the present study focused on patients who were eligible for and had achieved minimum a 1-year follow-up from the index surgery. For the subset of patients who did not achieve 1-year follow-up, a separate tabulation of complications was performed to account for all patients and reduce the risk of introducing confounding effects on reported complication rates. This study and the database from which patients were extracted are observational in design. Decisions regarding surgical indications, clinical and radiographic evaluation, surgical procedure and approach, and instrumentation were made by the operating surgeon.

Standardized forms were used to prospectively collect patient demographics, clinical data, surgical proce-

dure details, and complications. Baseline forms included a detailed assessment of comorbidities that collected sufficient data to enable calculation of the Charlson Comorbidity Index (CCI).[26] Prior to surgery and at regular follow-up intervals, patients completed multiple standardized outcomes measures to assess health status, including the modified Japanese Orthopaedic Association (mJOA) score, the Neck Disability Index (NDI), and neck pain score (ranging from 0 to 10, with 0 being no pain and 10 being the worst pain). As part of the study protocol, clinical follow-up windows were standardized across centers and included 3 months (window: 8–16 weeks), 6 months (window: 4–8 months), 1 year (window: 9–23 months), and 2 years (window: 24–30 months). Complication windows were grouped as perioperative (within 30 days from index surgery), early (from 30 to 90 days from index surgery), and delayed (after 90 days from index surgery).

A standardized complications reporting form was completed for the perioperative time interval, for each clinical follow-up, and at any point the site became aware of new complications. Since a standardized formal assessment to detect more subtle cases of dysphagia was not routinely performed, only clinically significant cases of dysphagia are reported. The complication category of instrumentation malposition primarily includes cases in which associated new neurological deficit occurred and/or operative revision was required. Reported cases of deep venous thromboembolism and pulmonary embolism are primarily those detected based on clinical findings and not as a result of routine screening. The de-identified data from each center were sent to a central site where the collective data sets were summarized and analyzed, and the complications were reviewed. The reported complications were classified as minor or major, with complications that involved invasive intervention or had prolonged or permanent morbidity or mortality classified as major.

Standing long-cassette radiographs and cervical anteroposterior and lateral radiographs were obtained at baseline and as indicated at clinical follow-up intervals. All imaging studies were analyzed at a central location using standard techniques[27] and validated software (SpineView, ENSAM Laboratory of Biomechanics).[28,29] Each radiograph was first measured by a research associate who was specifically trained. All measured radiographs were then reviewed for accuracy and corrected as necessary by a senior researcher with extensive experience. Assessed radiographic parameters included C2–7 SVA, T1 slope minus cervical lordosis (TS-CL), C7–S1 SVA, pelvic tilt (PT), and mismatch between pelvic incidence and lumbar lordosis (PI-LL). All alignment parameters were assessed based on standing radiographs.

### Statistical Analysis

Variables were summarized using means and standard deviations for continuous variables and frequencies and percentages for categorical variables. For categorical variables, Pearson chi-square p values were used to assess for statistically significant differences. For continuous variables the normality of distribution was assessed using the Kolmogorov-Smirnov test. Unpaired t-tests were used to assess for differences between normally distributed continuous variables, and the independent-samples Mann-Whitney U-test was used for comparisons between continuous variables without normal distribution. IBM SPSS (version 25, IBM Corp.) was used for statistical analyses. Statistical tests were two-tailed, and $p < 0.05$ was considered statistically significant. Preoperative and operative factors were assessed for association with the occurrence of complications based on univariate analyses. In addition, demographic, clinical, radiographic, and operative parameters and occurrence of complications were assessed and compared based on surgical approach. For the purpose of comparisons, low- and high-grade osteotomies were grouped based on the Ames-Smith classification, with low-grade osteotomies including partial and complete facetectomies, anterior cervical corpectomy, and Smith-Petersen osteotomies (Ames-Smith types 1–4), and high-grade osteotomies including posterior-based open wedge osteotomy, pedicle subtraction osteotomy, and vertebral column resection (Ames-Smith types 5–7).[18]

## Results

### Demographic, Radiographic, and Surgical Parameters

A total of 167 consecutive patients with ACSD met inclusion criteria, and of these 133 (80%) achieved minimum 1-year follow-up (mean 1.8 years). Demographic, radiographic, and surgical parameters are summarized for the 133 patients with minimum 1-year follow-up in Table 1. The mean age was 61.5 years, and the majority of patients (62%) were women. Notably, almost 40% were either active or past smokers, 33% had a diagnosis of depression, 17% had osteoporosis, and most (83.5%) had at least 1 significant comorbidity. Forty-one percent had a history of previous cervical spine surgery, and 25% had previous cervical fusion. The most common diagnoses were degenerative kyphosis (45.1%), iatrogenic kyphosis (17.3%), and cervical kyphoscoliosis (6%). At baseline, the population was significantly impacted by their disease based on multiple patient-reported outcomes measures, including mJOA, NDI, and neck pain score (Table 1). The mean preoperative C2–7 SVA was 45.8 mm, and the mean TS-CL was 38.4°. Although radiographic measures of global spinal alignment (C7–S1 SVA), pelvic compensation (PT), and lumbar lordosis (PI-LL) were on average within normal limits, each measure had a relatively high standard deviation (Table 1). Surgical approaches were anterior only (18%), posterior only (47%), and combined (35%). For the combined approaches, 43 (32.3%) had an anterior followed by a posterior approach, and 3 (2.3%) patients had posterior then anterior then posterior approaches. Common procedures included anterior cervical discectomy and fusion (48.1%) and corpectomy (20.3%). Low- and high-grade osteotomies were performed in 46.6% and 17.3% of patients, respectively.

### Perioperative, Early, and Delayed Complications

A total of 132 complications were reported, including 54 minor and 78 major (Table 2). Overall, 74 (55.6%) patients had at least 1 complication from the time of surgery through last follow-up (mean of 1.8 years), with at least 1 complication occurring in the perioperative, early, and de-

**TABLE 1. Summary of demographic, radiographic, and surgical data of 133 patients surgically treated for ACSD who had a minimum 1-year follow-up**

| Parameter | Value |
|---|---|
| No. of patients w/ ACSD | 133 |
| Demographic parameters | |
| Mean age, yrs | 61.5 ± 10.2 |
| Sex | |
| Male | 50 (37.6) |
| Female | 83 (62.4) |
| Mean BMI | 28.9 ± 7.3 |
| Active smokers | 8 (6) |
| Active or past smoker | 50 (37.6) |
| Presence of ≥1 comorbidity | 111 (83.5) |
| Mean CCI* | 3.2 ± 1.8 |
| Diagnosis of depression | 44 (33.1) |
| Presence of osteoporosis | 22 (16.5) |
| Previous cervical spine surgery | 54 (40.6) |
| Previous cervical spine fusion | 33 (24.8) |
| Diagnostic categories | |
| Degenerative kyphosis | 60 (45.1) |
| Iatrogenic kyphosis | 23 (17.3) |
| Cervical kyphoscoliosis | 8 (6) |
| Cervical scoliosis | 3 (2.2) |
| Traumatic kyphosis | 3 (2.2) |
| Postradiation | 3 (2.2) |
| Congenital kyphosis | 2 (1.5) |
| Others | 31 (23.3) |
| Mean baseline mJOA score | 13.6 ± 2.7 |
| Mean baseline NDI | 47 ± 18 |
| Mean baseline neck pain score | 6.6 ± 2.5 |
| Baseline radiographic parameters | |
| Mean C2–7 SVA, mm | 45.8 ± 24.6 |
| Mean TS-CL, ° | 38.4 ± 20.5 |
| Mean C7–S1 SVA, mm | 0.8 ± 67.6 |
| Mean PT, ° | 19.8 ± 11.2 |
| Mean PI-LL, ° | 1.3 ± 17.7 |
| Surgical parameters | |
| Surgical approach | |
| Anterior only | 24 (18.0) |
| Posterior only | 63 (47.4) |
| Combined | 46 (34.6) |
| Surgical procedures | |
| ACDF | 64 (48.1) |
| Corpectomy | 27 (20.3) |
| Low-grade osteotomy† | 62 (46.6) |
| High-grade osteotomy‡ | 23 (17.3) |
| Mean EBL, mL | 892 ± 1410 |
| Mean operative time, mins | 437 ± 232 |
| Mean no. of fusion levels | 7.8 ± 4.1 |

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**TABLE 1. Summary of demographic, radiographic, and surgical data of 133 patients surgically treated for ACSD who had a minimum 1-year follow-up**

ACDF = anterior cervical discectomy and fusion.
Values are presented as the number of patients (%) unless stated otherwise.
Mean values are presented as mean ± SD.
* Calculated by adding an additional 1 point for each decade above 40 years to the CCI score obtained.
† Low-grade osteotomies included partial or complete facetectomy, Smith-Petersen osteotomy, and corpectomy.
‡ High-grade osteotomies included pedicle subtraction osteotomy, vertebral column resection, and open wedge 3-column osteotomy.

layed time periods in 39.1%, 8.3%, and 20.3% of patients, respectively. On average, patients had approximately 1 complication; however, 44.4% of patients did not have any complications, while the remaining patients experienced from 1 to 7 complications (Fig. 1). The majority (63%) of the minor complications occurred in the 30-day perioperative time period compared with the early postoperative (22%) and delayed (15%) time intervals. Of the total 78 major complications, 41% occurred within the 30-day perioperative interval, 28% occurred between 30 and 90 days after surgery, and 31% occurred between 90 days and the mean 1.8-year follow-up from index surgery (Table 2).

General complication categories and rates of specific complications are summarized in Table 2. Almost 80% of complications were within 5 broad categories: cardiopulmonary (19.5%), neurological (15.8%), dysphagia/gastrointestinal (14.3%), radiographic (11.3%), and infection (10.5%). Overall, the complications with the highest rates included dysphagia (11.3%), distal junctional kyphosis (DJK, 9%), respiratory failure (6%), deep wound infection (6%), new nerve root motor deficit (5.3%), and new sensory deficit (4.5%). Of the 7 new nerve root motor deficits, 3 were C5, all of which occurred within the 30-day perioperative window, with 1 of the C5 deficits requiring a reoperation. Two deaths (1.5%) occurred related to surgery. One mortality was due to cardiopulmonary failure approximately 4 months following revision surgery for DJK, and the other death was related to pulmonary compromise associated with wound washout for delayed deep wound infection. Twenty-six reoperations were performed in 23 (17.3%) patients (20 had 1 reoperation and 3 had 2 reoperations each). The most common indications for reoperation were deep wound infection (n = 8), DJK (n = 7), and neurological deficit (n = 6). A total of 29 complications were associated with the need for reoperation (Table 2), with some reoperations being associated with more than 1 complication. For example, 1 patient had both pseudarthrosis and instrumentation failure that prompted a single reoperation.

The 23 patients treated with a high-grade osteotomy had a total of 18 complications, with 13 (56.5%) having at least 1 complication and 9 (39.1%) having at least 1 major complication (including a mortality). A total of 7 reoperations were required among these 23 patients, with indications including deep wound infection, new nerve root motor deficit, instrumentation failure, pseudarthrosis, and painful/prominent instrumentation.

**TABLE 2. Summary of rates of complications in 133 patients surgically treated for ACSD who had a minimum 1-year follow-up**

| Complication Category & Subgroups | Minor/Major Complications | | | |
|---|---|---|---|---|
| | Periop (<30 days) | Early (30–90 days) | Delayed (>90 days) | Total |
| Cardiopulmonary | 6/11 (12.8%) | 0/7 (5.3%) | 0/2 (1.5%) | 6/20 (19.5%) |
| Respiratory failure | 2/4 | 0/1 | 0/1 | 2/6 (6.0%) |
| Cardiac arrest | 0/4 | 0/0 | 0/0 | 0/4 (3.0%) |
| Pneumonia | 0/2 | 0/0 | 0/1 | 0/3 (2.3%) |
| Cardiac event | 0/1 | 0/2 | 0/0 | 0/3 (2.3%) |
| Arrhythmia/tachycardia | 3/0 | 0/0 | 0/0 | 3/0 (2.3%) |
| Pulmonary embolism | 0/0 | 0/2 | 0/0 | 0/2 (1.5%) |
| Pulmonary other | 0/0 | 0/2 | 0/0 | 0/2 (1.5%) |
| Cardiac other | 1/0 | 0/0 | 0/0 | 1/0 (0.8%) |
| Neurological | 1/5 (4.5%) | 1/5 (4.5%) | 2/7 (6.8%) | 4/17 (15.8%) |
| Nerve root: motor deficit* | 0/4 (2 reop) | 0/2 | 0/1 | 0/7 (5.3%) |
| Nerve root: sensory deficit | 1/1 | 0/1 | 0/3 (2 reop) | 1/5 (4.5%) |
| Radiculopathy | 0/0 | 1/0 | 2/1 | 3/1 (3.0%) |
| Spinal cord deficit | 0/0 | 0/1 | 0/1 (1 reop) | 0/2 (1.5%) |
| Central (cranial) | 0/0 | 0/0 | 0/1 (1 reop) | 0/1 (0.8%) |
| Other | 0/0 | 0/1 | 0/0 | 0/1 (0.8%) |
| Dysphagia/gastrointestinal | 9/5 (10.5%) | 2/0 (1.5%) | 3/0 (2.3%) | 14/5 (14.3%) |
| Dysphagia | 6/4 | 2/0 | 3/0 | 11/4 (11.3%) |
| Ileus | 2/0 | 0/0 | 0/0 | 2/0 (1.5%) |
| Perforated ulcer | 0/1 (1 reop) | 0/0 | 0/0 | 0/1 (0.8%) |
| Other | 1/0 | 0/0 | 0/0 | 1/0 (0.8%) |
| Radiographic | 0/2 (1.5%) | 3/2 (3.8%) | 3/5 (6.0%) | 6/9 (11.3%) |
| DJK | 0/2 (2 reop) | 3/2 (2 reop) | 2/3 (3 reop) | 5/7 (9.0%) |
| Adjacent-segment disease | 0/0 | 0/0 | 1/0 | 1/0 (0.8%) |
| Loss of correction | 0/0 | 0/0 | 0/1 (1 reop) | 0/1 (0.8%) |
| Pseudarthrosis | 0/0 | 0/0 | 0/1 (1 reop) | 0/1 (0.8%) |
| Infection | 3/6 (6.8%) | 3/1 (3.0%) | 0/1 (0.8%) | 6/8 (10.5%) |
| Deep wound infection | 0/6 (6 reop) | 0/1 (1 reop) | 0/1 (1 reop) | 0/8 (6.0%) |
| Superficial wound infection | 3/0 | 1/0 | 0/0 | 4/0 (3.0%) |
| Urinary tract infection | 0/0 | 1/0 | 0/0 | 1/0 (0.8%) |
| Other | 0/0 | 1/0 | 0/0 | 1/0 (0.8%) |
| Operative | 6/3 (6.8%) | 0/0 (0%) | 0/0 (0%) | 6/3 (6.8%) |
| Dural tear | 5/0 | 0/0 | 0/0 | 5/0 (3.8%) |
| Vascular injury | 0/1 | 0/0 | 0/0 | 0/1 (0.8%) |
| Excessive bleeding | 0/1 | 0/0 | 0/0 | 0/1 (0.8%) |
| Monitoring anomaly | 0/1 (1 reop) | 0/0 | 0/0 | 0/1 (0.8%) |
| Other | 1/0 | 0/0 | 0/0 | 1/0 (0.8%) |
| Implant | 0/0 | 0/1 (0.8%) | 0/5 (3.8%) | 0/6 (4.5%) |
| Instrumentation failure | 0/0 | 0/0 | 0/4 (1 reop) | 0/4 |
| Instrumentation painful/prominent | 0/0 | 0/1 (1 reop) | 0/1 (1 reop) | 0/2 |
| Vascular | 0/0 (0%) | 1/3 (3.0%) | 0/1 (0.8%) | 1/4 (3.8%) |
| Deep venous thrombosis | 0/0 | 0/3 | 0/1 | 0/4 (3.0%) |
| Vascular edema | 0/0 | 1/0 | 0/0 | 1/0 (0.8%) |
| Miscellaneous medical | 8/0 (6.0%) | 1/3 (3.0%) | 0/0 (0%) | 9/3 (9.0%) |
| Mental status change | 7/0 | 0/1 | 0/0 | 7/1 (6.0%) |
| Electrolyte SIADH | 1/0 | 1/0 | 0/0 | 2/0 (1.5%) |
| Kidney failure | 0/0 | 0/1 | 0/0 | 0/1 (0.8%) |
| Liver failure | 0/0 | 0/1 | 0/0 | 0/1 (0.8%) |

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**TABLE 2. Summary of rates of complications in 133 patients surgically treated for ACSD who had a minimum 1-year follow-up**

| Complication Category & Subgroups | Minor/Major Complications | | | |
|---|---|---|---|---|
| | Periop (<30 days) | Early (30–90 days) | Delayed (>90 days) | Total |
| Wound (excluding infection) | 1/0 (0.8%) | 1/0 (0.8%) | 0/1 (0.8%) | 2/1 (2.3%) |
| Seroma/hematoma | 1/0 | 1/0 | 0/0 | 2/0 (1.5%) |
| Other | 0/0 | 0/0 | 0/1 (1 reop) | 0/1 (0.8%) |
| Mortality† | 0/0 (0%) | 0/0 (0%) | 0/2 (1.5%) | 0/2 (1.5%) |
| Total (minor/major) | 66 (34/32) | 34 (12/22) | 32 (8/24) | 132 (54/78) |
| Mean no. of complications/patient (mean minor/mean major) | 0.50 (0.26/0.24) | 0.26 (0.09/0.17) | 0.24 (0.06/0.18) | 1.00 (0.41/0.59) |
| No. of patients affected (%) | 52 (39.1%) | 11 (8.3%) | 27 (20.3%) | 74 (55.6%) |

SIADH = syndrome of inappropriate antidiuretic hormone secretion.

* Of the nerve root motor deficits 3 were C5, with all occurring in the perioperative time interval and 1 requiring a reoperation.

† One death was due to cardiopulmonary failure approximately 4 months following revision surgery for distal junctional kyphosis. The other death was related to pulmonary compromise associated with wound washout for delayed deep wound infection.

The 34 patients lost to follow-up before 1 year had a mean follow-up of 0.36 years (SD 0.19 years). Complication rates for these patients up to the time of last follow-up are summarized in Table 3. The general distribution and types of complications among these patients are comparable to those of patients who achieved minimum 1-year follow-up. Two mortalities potentially related to surgery are shown in Table 3, including one that occurred 1 week following surgery and was due to anoxic brain injury potentially secondary to obstructive sleep apnea and narcotic use, and another due to pneumonia that occurred approximately 3 months following index surgery. Thus, the overall mortality rate for the total 167 patients was 2.4%.

### Factors Associated With Complications

Preoperative demographic, clinical, and radiographic factors were assessed for association with the occurrence of any complication and with the occurrence of major complications (Table 4). These factors included sex, age, BMI, smoking status, comorbidities, baseline health-related quality-of-life measures, radiographic alignment parameters, history of previous cervical spine surgery, and

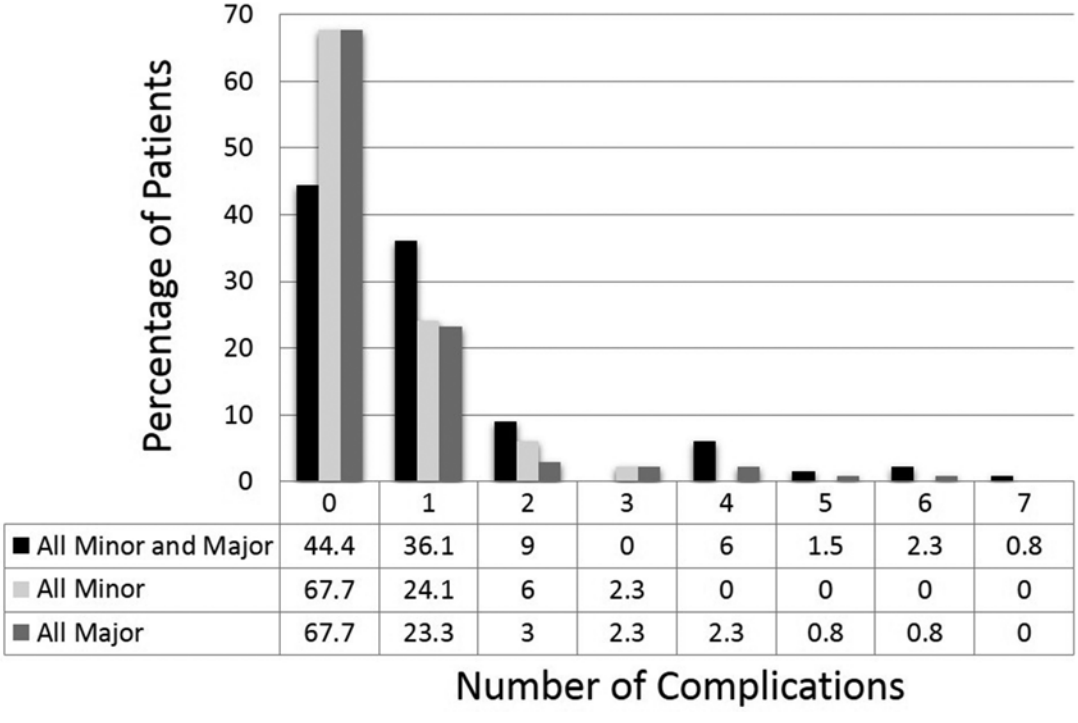


**FIG. 1.** Plot of percentages of patients with indicated number of minor and major complications. Complications include those occurring from the time of surgery through last follow-up.

**TABLE 3. Rates of complications in 34 patients surgically treated for ACSD who did not have a minimum 1-year follow-up***

| Complication Category | Minor/Major Complications | | | |
|---|---|---|---|---|
| | Periop (<30 days) | Early (30–90 days) | Delayed (>90 days) | Total |
| Neurological | 1/6 (20.6%) | 1/0 (2.9%) | 0/0 (0%) | 2/6 (23.5%) |
| Cardiopulmonary | 0/2 (5.9%) | 0/2 (5.9%) | 0/0 (0%) | 0/4 (11.8%) |
| Dysphagia/gastrointestinal | 2/0 (5.9%) | 0/0 (0%) | 0/0 (0%) | 2/0 (5.9%) |
| Radiographic | 0/0 (0%) | 0/0 (0%) | 0/0 (0%) | 0/0 (0%) |
| Infection | 1/0 (2.9%) | 0/2 (5.9%) | 0/0 (0%) | 1/2 (8.8%) |
| Operative | 1/1 (5.9%) | 0/0 (0%) | 0/0 (0%) | 1/1 (5.9%) |
| Implant | 0/1 (2.9%) | 0/1 (2.9%) | 0/0 (0%) | 0/2 (5.9%) |
| Vascular | 0/0 (0%) | 0/0 (0%) | 0/0 (0%) | 0/0 (0%) |
| Miscellaneous medical | 0/1 (2.9%) | 0/0 (0%) | 0/0 (0%) | 0/1 (2.9%) |
| Wound (excluding infection) | 0/0 (0%) | 0/0 (0%) | 0/0 (0%) | 0/0 (0%) |
| Death | 0/1 (2.9%)† | 0/0 (0%) | 0/1 (2.9%)‡ | 0/2 (5.9%) |
| Total (minor/major) | 17 (5/12) | 6 (1/5) | 1 (0/1) | 24 (6/18) |
| Mean complications/patient (minor/major) | 0.50 (0.15/0.35) | 0.18 (0.03/0.15) | 0.03 (0/0.03) | 0.71 (0.18/0.53) |
| No. of patients affected | 16 (47.1%) | 6 (17.6%) | 1 (2.9%) | 19 (55.9%) |

* The mean follow-up was 0.36 ± 0.19 years.
† Occurred approximately 1 week following index surgery and was due to anoxic brain injury potentially secondary to obstructive sleep apnea and narcotic use.
‡ Due to pneumonia approximately 3 months following index surgery.

cervical deformity diagnosis. Of the factors assessed, only age and C2–7 SVA were significantly associated with occurrence of complications. Patients who had a major complication were significantly older than those who did not (62.8 years vs 58.9 years, $p = 0.038$). Greater C2–7 SVA was significantly associated with occurrence of any complication ($p = 0.015$) and with occurrence of major complications ($p = 0.005$).

Surgical parameters, including estimated blood loss (EBL), operative time, number of spinal fusion levels, surgical approach, and surgical procedures were assessed for association with the occurrence of any complication and with the occurrence of major complications (Table 5). Of the factors assessed, only greater number of fusion levels was significantly associated with occurrence of complications ($p = 0.047$).

Of the 33 patients with severe cervical sagittal malalignment (cervical SVA > 60 mm), the treatment approach was anterior only for 1 (3.0%), posterior only for 17 (51.5%), and combined for 15 (45.5%). Patients with severe cervical sagittal malalignment underwent longer-segment instrumentation compared with patients who did not have severe cervical sagittal malalignment (9.6 vs 7.2 vertebral levels, $p = 0.004$). Notably, only 9 (27.3%) of these 33 patients were treated with a high-grade osteotomy, which likely reflects the application of high-grade osteotomies preferentially to stiff/fixed deformities and not necessarily to deformities with the greatest cervical SVA.

### Comparisons by Surgical Approach

Demographic, clinical, radiographic, and operative parameters were compared by surgical approach (Table 6). Compared with deformities treated with a posterior-only or combined approaches, those treated with an anterior-only approach had significant less severity of deformity based on C2–7 SVA ($p < 0.001$) and TS-CL ($p = 0.026$). Combined approaches had the highest EBL and longest operative times, followed by posterior-only approaches, and then by anterior-only approaches ($p < 0.001$ for both). The overall numbers of patients affected by complications or those requiring reoperation for a complication did not differ significantly based on surgical approach (Table 6). Dysphagia rates were significantly higher for anterior-only (17%) and combined (20%) compared with posterior-only (2%) approaches ($p = 0.006$).

## Discussion

This prospective multicenter study provides an assessment of the types and rates of complications associated with the surgical treatment of ACSD based on a mean follow-up of 1.8 years. To help ensure complete collection of complications, standardized forms were used to collect complication data, study coordinators were present and actively engaged at each site, and the data were regularly audited at a central location. In contrast to thoracolumbar spinal deformities, for which several studies have documented the occurrence of complications associated with surgical treatment, the literature on ACSD complications is very limited. Although previous reports have documented complications associated with ACSD surgery, these studies have several limitations, including retrospective design, focus on one surgeon or one center, inclusion of early complications only, and limited follow-up.[10,11,21] The present study was designed to overcome many of these limitations, and it has produced what is likely the most complete assessment of complications associated with ACSD currently available. The findings of this study may be helpful for preoperative patient counseling, better understanding of expected complication rates, and ongoing efforts to prevent or reduce the occurrence of complications.

**TABLE 4. Complications associated with surgery for ACSD stratified by preoperative parameters**

| Preop Parameter | Any Minor or Major Complication | | | Any Major Complication | | |
|---|---|---|---|---|---|---|
| | Yes | No | p Value | Yes | No | p Value |
| Sex | | | >0.99 | | | >0.99 |
| Male | 28 (56) | 22 (44) | | 16 (32) | 34 (68) | |
| Female | 46 (55) | 37 (45) | | 27 (33) | 56 (67) | |
| Mean age, yrs | 62.3 ± 9.1 | 60.7 ± 11.0 | 0.26 | 62.8 ± 9.9 | 58.9 ± 10.4 | **0.038** |
| Mean BMI | 28.9 ± 7.7 | 28.8 ± 6.8 | 0.93* | 29.0 ± 7.5 | 28.8 ± 7.3 | 0.79* |
| Active smoker | | | 0.47 | | | 0.72 |
| Yes | 6 (75) | 2 (25) | | 3 (38) | 5 (62) | |
| No | 68 (55) | 56 (45) | | 40 (32) | 84 (68) | |
| Active or past smoker | | | 0.28 | | | 0.25 |
| Yes | 25 (50) | 25 (50) | | 13 (26) | 37 (74) | |
| No | 49 (60) | 32 (40) | | 30 (37) | 51 (63) | |
| ≥1 comorbidity | | | 0.35 | | | 0.63 |
| Yes | 64 (58) | 47 (42) | | 37 (33) | 74 (67) | |
| No | 10 (45) | 12 (55) | | 6 (27) | 16 (73) | |
| Osteoporosis diagnosis | | | 0.10 | | | 0.08 |
| Yes | 16 (73) | 6 (27) | | 11 (50) | 11 (50) | |
| No | 58 (52) | 53 (48) | | 32 (29) | 79 (71) | |
| Mean CCI† | 3.1 ± 1.9 | 3.3 ± 1.7 | 0.65* | 2.8 ± 1.6 | 3.4 ± 1.9 | 0.25* |
| Mean baseline mJOA score | 13.5 ± 2.8 | 13.8 ± 2.5 | 0.52* | 13.3 ± 3.0 | 13.8 ± 2.6 | 0.37* |
| Mean baseline NDI | 48.6 ± 17.2 | 45.3 ± 18.6 | 0.29 | 48.9 ± 15.8 | 46.3 ± 18.8 | 0.44 |
| Mean baseline neck pain score | 6.7 ± 2.5 | 6.6 ± 2.5 | 0.56* | 6.4 ± 2.8 | 6.7 ± 2.4 | 0.85* |
| Mean baseline C2–7 SVA, mm | 50.8 ± 24.5 | 39.6 ± 23.5 | **0.015** | 55.5 ± 24.5 | 41.6 ± 23.6 | **0.005** |
| Mean baseline TS-CL, ° | 41.8 ± 23.6 | 34.3 ± 15.1 | 0.11* | 44.7 ± 26.8 | 35.7 ± 16.5 | 0.09* |
| Mean baseline C7–S1 SVA, mm | 9.5 ± 76.3 | −10.3 ± 53.0 | 0.17* | 1.7 ± 84.7 | 0.3 ± 58.8 | 0.74* |
| Previous cervical surgery | | | 0.48 | | | 0.85 |
| Yes | 28 (52) | 26 (48) | | 17 (31) | 37 (69) | |
| No | 46 (59) | 32 (41) | | 26 (33) | 52 (67) | |
| Previous cervical fusion | | | 0.69 | | | 0.83 |
| Yes | 17 (52) | 16 (48) | | 10 (30) | 23 (70) | |
| No | 57 (57) | 43 (43) | | 33 (33) | 67 (67) | |
| Diagnostic category | | | 0.74 | | | 0.13 |
| Degenerative kyphosis | 30 (50) | 30 (50) | | 15 (25) | 45 (75) | |
| Iatrogenic kyphosis | 15 (65) | 8 (35) | | 9 (39) | 14 (61) | |
| Cervical kyphoscoliosis | 5 (63) | 3 (37) | | 3 (38) | 5 (62) | |
| Cervical scoliosis | 0 (0) | 3 (100) | | 0 (0) | 3 (100) | |
| Traumatic kyphosis | 2 (67) | 1 (33) | | 2 (67) | 1 (33) | |
| Post radiation | 3 (100) | 0 (0) | | 3 (100) | 0 (0) | |
| Congenital kyphosis | 1 (50) | 1 (50) | | 1 (50) | 1 (50) | |
| Others | 16 (52) | 15 (48) | | 10 (32) | 21 (68) | |

Values are presented as the number of patients (%) unless stated otherwise. Mean values are presented as mean ± SD. Boldface type indicates statistical significance.

* Mann-Whitney U-test (nonparametric).

† Calculated by adding an additional 1 point for each decade above 40 years to the CCI score obtained.

The number of complications and patients affected in the present study are substantially higher than those in previous reports, which is likely reflective of the length of follow-up, prospective study design, and focus on collection of complications. Overall, 132 complications occurred, with 74 (55.6%) of the 133 patients affected by 1 or more complications. In a literature review from Etame and colleagues on outcomes and complications for cervical spine deformity based on 14 retrospective studies with a total of 399 patients, the authors reported mortality rates ranging from 3.1% to 6.7%, major medical complication rates ranging from 3.1% to 44.4%, and an overall neuro-

**TABLE 5. Complications associated with surgery for adult cervical deformity stratified by surgical parameters**

| Surgical Parameter | Any Minor or Major Complication | | | Any Major Complication | | |
|---|---|---|---|---|---|---|
| | Yes | No | p Value | Yes | No | p Value |
| Mean EBL, mL | 982 ± 959 | 850 ± 1580 | 0.51* | 908 ± 873 | 872 ± 1883 | 0.98* |
| Mean operative time, mins | 434 ± 260 | 439 ± 220 | 0.34* | 428 ± 244 | 448 ± 219 | 0.64* |
| Mean no. of fusion levels | 8.8 ± 4.3 | 7.3 ± 3.9 | 0.075* | 8.3 ± 4.0 | 7.2 ± 4.1 | **0.047*** |
| Surgical approach | | | 0.29 | | | 0.38 |
| Anterior only | 10 (42) | 14 (58) | | 5 (21) | 19 (79) | |
| Posterior only | 36 (57) | 27 (43) | | 21 (33) | 42 (67) | |
| Combined | 28 (61) | 18 (39) | | 17 (37) | 29 (63) | |
| Surgical procedures | | | | | | |
| ACDF | | | 0.60 | | | >0.99 |
| Yes | 34 (53) | 30 (47) | | 21 (33) | 43 (67) | |
| No | 40 (58) | 29 (42) | | 22 (32) | 47 (68) | |
| Corpectomy | | | 0.20 | | | 0.10 |
| Yes | 12 (44) | 15 (56) | | 5 (19) | 22 (81) | |
| No | 62 (58) | 44 (42) | | 38 (36) | 68 (64) | |
| Low-grade osteotomy† | | | 0.39 | | | 0.58 |
| Yes | 37 (60) | 25 (40) | | 22 (35) | 40 (65) | |
| No | 37 (52) | 34 (48) | | 21 (30) | 50 (70) | |
| High-grade osteotomy‡ | | | >0.99 | | | 0.47 |
| Yes | 13 (57) | 10 (43) | | 9 (39) | 14 (61) | |
| No | 61 (55) | 49 (45) | | 34 (31) | 76 (69) | |

Values are presented as the number of patients (%) unless stated otherwise. Mean values are presented as mean ± SD. Boldface type indicates statistical significance.
* Mann-Whitney U-test (nonparametric).
† Low-grade osteotomies included partial or complete facetectomy, Smith-Petersen osteotomy, and corpectomy.
‡ High-grade osteotomies included pedicle subtraction osteotomy, vertebral column resection, and open wedge 3-column osteotomy.

logical complication rate of 13.5%.[11] Etame and colleagues also provided a literature review on surgical treatment of cervicothoracic kyphosis due to ankylosing spondylitis; based on 6 retrospective studies with a total of 227 patients, they reported an overall complication rate ranging from 26.9% to 87.5% and a mortality rate of 2.6%.[10] Koller and colleagues provided a multicenter retrospective review of complications associated with surgical treatment of severe and rigid cervical kyphosis and reported that 22% of patients experienced a major long-term complication and 14% required revision surgery.[30] Based on a retrospective review of the NSQIP (National Surgical Quality Improvement Program) database, DePasse and colleagues reported that among 950 patients treated with a cervical spine osteotomy the overall medical complication rate was 15.8%, and the reoperation rate was 3.4%.[31]

Perhaps the greatest value in studying operative complications is the ability to use the results to find strategies and techniques to reduce their occurrence and improve procedure safety and cost-effectiveness. This strategy has been applied to several major complications associated with thoracolumbar deformity surgery,[32] including the introduction of multirod constructs to reduce the occurrence of rod fractures,[33–35] applications of tethers to reduce the occurrence of proximal junctional kyphosis,[36–38] and administration of intraoperative tranexamic acid to reduce the occurrence of excessive blood loss.[39] In the present study, the most common complications associated with ACSD surgery, accounting for almost 80% of overall complications, were concentrated in 1 of 5 categories: cardiopulmonary, neurological, dysphagia/gastrointestinal, radiographic, and infection. The high rates of cardiopulmonary complications may be due in part to the significant functional compromise often present in ACSD patients seeking surgical care and the overall frailty of this population. Improved preoperative cardiopulmonary optimization by specialists and potentially programs to facilitate cardiopulmonary "prehabilitation" may help to reduce postoperative cardiopulmonary complications.[40] The high rates of new neurological deficits suggest the need for more sensitive intraoperative neuromonitoring techniques. In addition, changes in surgical strategies may decrease the incidence of neurological deficits. For example, shifting 3-column osteotomies to the T2 vertebral level instead of C7 or T1, when feasible, may substantially reduce the occurrence of C7–T1 nerve compromise.[41,42] Deep wound infections occurred in 6% of patients and were a common reason for reoperation. Broader application of intrawound vancomycin powder, which was not consistently used in patients in this series, may reduce the occurrence of this complication.[43,44] DJK, which occurred in 9% of patients and led to 7 reoperations, remains a significant challenge in the treatment of ACSD. This warrants further investigation to improve surgical alignment strategies, facilitate the determination of optimal caudal vertebral endpoints for instrumenta-

**TABLE 6. Comparison of complications based on surgical approach for ACSD**

| Parameter | Surgical Approach | | | p Value |
|---|---|---|---|---|
| | Anterior Only (n = 24) | Posterior Only (n = 63) | Combined (n = 46) | |
| Mean age, yrs | 59.3 ± 11.8 | 60.8 ± 10.9 | 63.2 ± 8.8 | 0.29 |
| Mean BMI | 28.5 ± 6.3 | 28.8 ± 7.1 | 29.1 ± 8.1 | 0.96* |
| Mean CCI† | 2.7 ± 1.9 | 3.0 ± 1.6 | 3.8 ± 2.0 | 0.056* |
| Mean baseline NDI | 42.3 ± 17.1 | 50.5 ± 19.5 | 45.1 ± 15.1 | 0.10 |
| Mean baseline mJOA score | 14.4 ± 2.0 | 13.6 ± 2.9 | 13.3 ± 2.8 | 0.29* |
| Mean baseline neck pain score | 6.4 ± 2.4 | 6.6 ± 2.6 | 6.8 ± 2.5 | 0.79* |
| Mean baseline C2–7 SVA, mm | 27.2 ± 22.0 | 52.4 ± 22.4 | 46.7 ± 24.4 | **<0.001** |
| Mean baseline TS-CL, ° | 27.9 ± 15.7 | 40.2 ± 18.7 | 41.7 ± 23.5 | **0.026*** |
| Mean baseline C7–S1 SVA, mm | 18.3 ± 79.2 | −6.1 ± 61.9 | 0.8 ± 68.4 | 0.58* |
| Mean no. of fusion levels | 3.1 ± 0.9 | 9.7 ± 4.1 | 7.7 ± 3.1 | **<0.001*** |
| Mean EBL, mL | 88 ± 77 | 959 ± 894 | 1220 ± 2059 | **<0.001*** |
| Mean operative time, mins | 440.8 ± 199 | 344 ± 180 | 537 ± 259 | **<0.001*** |
| Low-grade osteotomy‡ | 9 (38) | 29 (46) | 24 (52) | 0.50 |
| High-grade osteotomy§ | 0 (0) | 21 (33) | 2 (4) | **<0.001** |
| Complication rates¶ | | | | |
| Any complication | 10 (42) | 36 (57) | 28 (61) | 0.29 |
| Any major | 5 (21) | 21 (33) | 17 (37) | 0.38 |
| Any periop or early | 7 (29) | 31 (49) | 22 (48) | 0.22 |
| Any reop | 3 (12) | 12 (19) | 8 (17) | 0.77 |
| Neurological complication | 3 (12) | 10 (16) | 5 (11) | 0.74 |
| Dysphagia | 4 (17) | 1 (2) | 9 (20) | **0.006** |
| Deep wound infection | 1 (4) | 3 (5) | 2 (4) | 0.99 |
| Cardiopulmonary complication | 1 (4) | 6 (10) | 8 (17) | 0.21 |

Values are presented as the number of patients (%) unless stated otherwise. Mean values are presented as mean ± SD. Boldface type indicates statistical significance.
* Mann-Whitney U-test (nonparametric).
† Calculated by adding an additional 1 point for each decade above 40 years to the CCI score obtained.
‡ Low-grade osteotomies included partial or complete facetectomy, Smith-Petersen osteotomy, and corpectomy.
§ High-grade osteotomies included pedicle subtraction osteotomy, vertebral column resection, and open wedge 3-column osteotomy.
¶ Number of patients affected.

tion, and potentially aid development of novel junctional support techniques.

It is well recognized that older age is a significant risk factor for complications in adult thoracolumbar deformity surgery.[32,45] The present study confirms a similar association in ACSD patients. It is notable that none of the other baseline demographic or clinical parameters assessed were significantly predictive of complication occurrence, including BMI, smoking status, CCI, and history of previous cervical spine surgery. Among the radiographic and surgical parameters assessed, the factors that were significantly associated with the occurrence of complications were greater baseline C2–7 SVA and greater number of spinal fusion levels. These associations likely reflect that more severe deformities and those requiring more extensive reconstructions have a greater risk of complications.

Anterior-only, posterior-only, and combined approaches were performed in 18%, 47%, and 35% of the patients in this series, respectively. Patient age, BMI, and baseline measures of disability, myelopathy, and pain did not differ significantly based on surgical approach. Deformities selected for an anterior-only approach were less severe based on the C2–7 SVA and TS-CL compared with deformities treated with a posterior-only or combined approach. Significantly more vertebral levels were fused when a posterior-only or combined approach was used compared with an anterior-only approach, and nearly all of the high-grade osteotomies were performed in the posterior-only approach group. Despite these differences, it is notable that the overall and major complication rates did not differ significantly based on surgical approach. As may be expected, the incidence of dysphagia was very low with posterior-only approaches and was much higher with anterior-only and combined approach procedures.

It may seem counterintuitive that patients treated with a high-grade osteotomy had complication rates similar to those not treated with a high-grade osteotomy. Although the reasons for this are not entirely clear, there are potential explanations. First, the rates of complications with high-grade osteotomy in this series are high, with the 23 patients undergoing these osteotomies collectively having 18 complications, including 14 major complications, 1 death, and 7 reoperations. However, the patients in this study in general had relatively severe deformities, and it

may be that the alternative treatments to address these deformities, which included a high proportion of combined approaches and long-segment posterior fusions with multilevel osteotomies, simply had similarly high complication rates as those encountered with high-grade osteotomies. Second, that the complication rates associated with high-grade osteotomies in this series do not significantly exceed those of other correction techniques may be reflective of the considerable experience that the enrolling surgeons have with these osteotomies.

In the present study, 80% of patients reached minimum 1-year follow-up. Of the remaining 34 patients, there were 2 deaths. One occurred 1 week after surgery and was due to anoxic brain injury potentially secondary to obstructive sleep apnea and narcotic use, and the other was due to pneumonia that occurred approximately 3 months after surgery. The reasons that the remaining 32 patients did not achieve 1-year follow-up are unknown. To account for all patients and assess whether the occurrence of complications could be a factor in failure to follow up, complications in this subset of patients were separately assessed. Among the patients lost to follow-up before 1 year, there did not appear to be an unusual number of complications or disproportionate number of more impactful complications compared with those who achieved 1-year follow-up. Based on this assessment, it does not appear that the primary reason that some patients were lost to follow-up prior to 1 year was due to complications.

The primary strengths of the present study include the multicenter prospective design and the focus on achieving complete collection of complications through the use of the same collection forms for data across study sites, presence of a research coordinator at each site, and routine auditing of the data. Notably, the multicenter study design should increase the generalizability of the findings, since there is not only considerable heterogeneity in cervical deformity pathologies but also in strategies for surgical treatment.[16] The limited ability to detect milder forms of some complications is a limitation of the present study. For example, since formal assessment for postoperative dysphagia was not routinely performed, more subtle cases of dysphagia were likely not detected. In addition, since many sites do not routinely perform postoperative CT imaging, the documented cases of instrumentation malposition are primarily those that result in a neurological deficit and/or require a revision procedure, and the reported cases of pseudarthrosis are primarily those associated with instrumentation failure or the need for revision surgery.

## Conclusions

This prospective multicenter study provides an assessment of the types and rates of complications associated with the surgical treatment of ACSD based on a mean follow-up of 1.8 years. Among 133 patients, a total of 132 complications (54 major and 78 minor) were reported, and 74 (55.6%) patients were affected by 1 or more of these complications. The findings of this study may be helpful for preoperative patient counseling, better understanding of expected complication rates, and efforts to prevent or reduce the occurrence of complications.

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## Author Contributions

Conception and design: Smith, Shaffrey, Kim, Klineberg, Protopsaltis, Passias, Mundis, Eastlack, Deviren, Kelly, Daniels, Gum, Soroceanu, Gupta, Burton, Hostin, Hart, V Lafage, R Lafage, Schwab, Bess, Ames. Acquisition of data: Smith, Shaffrey, Kim, Klineberg, Protopsaltis, Passias, Mundis, Eastlack, Deviren, Kelly, Daniels, Gum, Soroceanu, Gupta, Burton, Hostin, Hart, V Lafage, R Lafage, Schwab, Bess, Ames. Analysis and interpretation of data: Smith, Buell. Drafting the article: Smith, Buell. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Smith. Statistical analysis: Smith. Administrative/technical/material support: Smith. Study supervision: Smith.

## Correspondence

Justin S. Smith: University of Virginia Health System, Charlottesville, VA. jss7f@virginia.edu.