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CLINICAL ARTICLE

When is staging complex adult spinal deformity advantageous? Identifying subsets of patients who benefit from staged interventions

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OBJECTIVE The objective of this study was to identify baseline patient and surgical factors predictive of optimal outcomes in staged versus same-day combined-approach surgery.

METHODS Adult spinal deformity (ASD) patients with baseline and perioperative (by 6 weeks) data were stratified based on single-stage (same-day) or multistage (staged) surgery, excluding planned multiple hospitalizations. Means comparison analyses were used to assess baseline demographic, radiographic, and surgical differences between cohorts. Backstep logistic regression and conditional inference tree analysis were used to identify variable thresholds

ABBREVIATIONS ASD = adult spinal deformity; CCI = Charlson Comorbidity Index; EBL = estimated blood loss; HRQOL = health-related quality of life; NRS = numeric rating scale; PI = pelvic incidence; PI-LL = PI–lumbar lordosis; PROMIS = Patient-Reported Outcomes Measurement Information System; SVA = sagittal vertical axis; TK = thoracic kyphosis.

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associated with study-specific definitions of an optimal outcome in each cohort, defined as no intraoperative or surgery-related in-hospital adverse event.

RESULTS There were 439 patients with complex ASD in the dataset (mean age 64.0 ± 9.3 years, 68% female, mean BMI 28.7 ± 5.5 kg/m^2). Overall, 58.8% of patients were in the same-day group, while 41.2% were in the staged group. Demographically, cohorts were not significantly different ($p > 0.05$), but staged patients were more frail per total Edmonton Frail Scale score ($p = 0.043$). Staged patients also reported greater numeric rating scale scores for back pain than same-day patients ($p = 0.002$). Cohorts were comparable in magnitude of planned correction of C7–S1 sagittal vertical axis, pelvic incidence–lumbar lordosis (PI-LL) mismatch, and T4–12 kyphosis (all $p > 0.05$). Controlling for baseline age, frailty, and number of levels fused, staged patients reported significantly higher PROMIS Discretionary Social Activities scores by 6 weeks ($p = 0.029$). Radiographic outcomes by 6 weeks were comparable between cohorts, in terms of both magnitude of change from baseline and overall result (all $p > 0.05$). Same-day patients were significantly more likely to experience in-hospital complications ($p = 0.013$). When considering frailty thresholds for staging, only a Charlson Comorbidity Index ≤ 1.0 was associated with optimal outcome in same-day patients, while Edmonton Frail Scale score ≥ 7 ($p = 0.036$), ≥ 9 levels fused ($p = 0.016$), and baseline PI-LL mismatch ≥ 15.3° ($p = 0.028$) were associated with optimal outcome for staged patients. Yet, staging alone was not significantly associated with an optimal outcome perioperatively ($p = 0.056$).

CONCLUSIONS While staged and same-day combined-approach surgeries yield comparable radiographic and patient-reported outcomes, certain subsets of complex ASD patients may benefit from staged surgery despite the invariably increased hospital length of stay. Individuals with increased frailty, moderate to severe PI-LL mismatch, and increased anticipated number of levels fused may experience a lower risk of perioperative adverse events if they undergo a staged procedure.

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KEYWORDS complex adult spinal deformity; spine surgery; same-day surgery; staged surgery

Adult spinal deformity (ASD) is a leading cause of disability within the United States and globally. Because of its associated aspects of physiological compensation, it is common for patients to experience substantial pain and extensive functional limitations as the disease progresses.[1,2] Surgical ASD correction has demonstrated notable benefits.[3] Patients with the most severe deformities generally require more complex procedures with increased invasiveness, including longer operative and anesthesia times. Such procedures have been associated with perioperative respiratory, vascular, and infection-related complications, as well as decreased patient satisfaction and elevated healthcare costs.[4,5]

One way in which surgeons seek to mitigate procedural risk is through a staged intervention, in which different parts of the procedure are performed on different days, often with a short interval for recuperation built in over an intervening time window. By breaking the surgical intervention into stages, the surgeon can optimize the correction of deformities, potentially minimize intraoperative blood loss, and lower the chances of neurological complications.[6,7] A same-day approach, however, may also be preferable in that it offers the advantage of achieving immediate global correction of the spinal deformity, shortening the overall treatment duration and improving costs and patient satisfaction.[6,7]

The most effective approach to managing severe ASD remains a topic of debate, with no clear consensus on which strategy produces superior results. There may be certain patient characteristics and other predisposing factors that are associated with superior results after a staged procedure, as opposed to a same-day intervention. In this context, we sought to evaluate factors associated with an optimal outcome following same-day or staged procedures. We hypothesized that patients with more severe deformities and higher levels of frailty would preferentially benefit from staged interventions.

Methods

Study Design and Inclusion Criteria

In this study we analyzed data from ASD patients enrolled in a multicenter prospective study. This dataset collects clinical, surgical, and outcome data from 18 participating centers across the United States and Canada. The inclusion and exclusion criteria of the dataset have been detailed in previously published studies.[8–10] Patients aged 18 years or older were included for retrospective review and enrolled in the registry from 2020 to present with either radiographic evidence or procedural or geriatric criteria characteristic of complex ASD. Radiographic evidence for complex ASD is defined as follows: pelvic incidence–lumbar lordosis (PI-LL) mismatch ≥ 25°, T1 pelvic angle ≥ 30°, sagittal vertical axis (SVA) > 15 cm, thoracic scoliosis ≥ 70°, thoracolumbar/lumbar scoliosis ≥ 50°, or global coronal malalignment > 7 cm. Procedural details characteristic of complex ASD involved three-column osteotomies and/or anterior column reconstruction of the spine or posterior spinal fusion > 12 levels. Geriatric deformity surgery was defined as age > 65 years with a minimum of seven levels of spinal instrumentation during surgery with an intention-to-treat deformity. Institutional review board approval was gained at each participating site, and each enrolled patient provided informed consent. Patients undergoing staged surgery usually first underwent an anterior or lateral lumbar interbody fusion, with a subsequent posterior fusion.

Data Collection

This multicenter study, registered as the clinical trial "Multi-Center Prospective Evaluation of Complex Adult Spinal Deformity Surgery" (registration no.: NCT04194138, ClinicalTrials.gov), aims to track the rapid advancements in spine instrumentation. Eligible patients are identified based on specific demographic and radiographic criteria during initial presentations or preoperative visits. On qualifying, patients complete clinical surveys, undergo detailed radiographic assessments, and receive comprehensive medical and neurological examinations. Postsurgery, surgeons complete case report forms that detail every aspect of the surgical intervention. Follow-up visits are scheduled at 6 weeks, 1 year, and 2 years postoperatively to monitor for any medical, radiographic, or mechanical complications. During these visits, patients are subjected to routine low-dose, full free-standing EOS radiographs and complete a standardized set of health-related quality of life (HRQOL) surveys. All collected data are entered by site coordinators and rigorously verified by an external team. This team also manages queries on the interactive data management site and integrates all findings into a comprehensive database.

We abstracted demographic data for eligible patients, including age at time of surgery, sex, BMI, history of prior fusion, Edmonton Frail Scale score, baseline comorbidities categorized using the Charlson Comorbidity Index (CCI), and history of total hip or total knee arthroplasty.

Surgical parameters collected included number of levels fused, operative time, estimated blood loss (EBL), length of stay, surgical approach, and use of decompressions and osteotomies. Any adverse events were reported through a standardized form, and perioperative and postoperative outcomes were routinely recorded at preestablished time intervals. Patient-reported outcome measures included the modified Oswestry Disability Index score for low-back pain, Scoliosis Research Society-22r score, numeric rating scale (NRS) score for pain, and Patient-Reported Outcomes Measurement Information System (PROMIS) domains: Anxiety, Depression, Pain Interference, Physical Function, and Social Satisfaction.

Radiographic Data Collection

Full-length freestanding lateral spine radiographs (36-inch cassette) were collected and assessed at baseline and follow-up visits. EOS imaging incorporates both sagittal and coronal comprehensive views from the top of the skull to the bottom of the foot, with radiographic sagittal and coronal measurement and analysis supported by SpineView (ENSAM Laboratory of Biomechanics).[11–13] The spinopelvic radiographic parameters measured were pelvic tilt, pelvic incidence (PI), SVA, thoracic kyphosis (TK; T4–12), and T1 pelvic angle. Spinopelvic alignment was determined by the criteria of the Global Alignment and Proportion score and sagittal age-adjusted score.[14,15]

Clinical Outcomes

We defined an optimal outcome as the absence of adverse events intraoperatively, during the hospitalization, or within the first 6 weeks postoperatively, as this is the time period that most likely represents when patients are most directly susceptible to procedure-related events influenced by decisions around the procedural approach.[16,17] Complications, defined by Klineberg et al.[18] and validated,[19] were categorized as either minor or major, based on the definitions provided by Glassman et al.,[20] with the latter involving prolonged or permanent morbidity[21,22] (Table 1). Furthermore, the complications were delineated as either medical or surgery related. Medical complications involved any notable cardiovascular, pulmonary, musculoskeletal, nervous system gastrointestinal, or superficial wound conditions. Surgery-related complications were instead related to the implant, new-onset neurological findings, or symptomatic changes in radiographic alignments such as proximal junctional kyphosis (PJK) and proximal junctional failure (PJF). PJK was defined as the development of an angle $< -10°$ and/or a change in angle $< -10°$ between baseline and follow-up. PJF was defined as a PJK angle $< -28°$ and a difference in PJK angle $< -22°$ from baseline to follow-up.[23]

In the first 6 weeks postsurgery, we recorded not only the predefined complications but also adverse events. The criteria for adverse events include outcomes that 1) result in death, 2) are life-threatening or place the patient at immediate risk of death at the time of occurrence, 3) require or prolong hospitalization, 4) cause persistent or significant disability or incapacity, or 5) are considered by the participating surgeons to represent significant hazards. Examples of adverse events include death, cardiac arrest, stroke/cerebrovascular accident, sepsis/septic shock, myocardial infarction, renal failure, pulmonary embolism, peripheral nerve injury, ventilator use for > 48 hours, unplanned intubation, or an unplanned return to the operating room, among others.

The primary outcome was the achievement of the study-specific definition of optimal outcome, with surgical approach (same-day vs staged) as the primary predictor. Healthcare resource utilization, such as length of stay and patient-reported outcome measures, were considered secondarily.

Statistical Analysis

Means comparison tests were used to compare baseline demographic, radiographic, and surgical differences between the staged and same-day procedural groups. Continuous variables were assessed for normality using the Shapiro-Wilk test. Homogeneity of variances for categorical variables was evaluated using Levene's test. Differences in categorical variables were analyzed using Pearson's chi-square test or Fisher's exact test when the expected counts were < 5. Differences in continuous variables were assessed using independent-samples t-tests or the Mann-Whitney U-test, as appropriate. Multivariate analyses were used to compare postoperative outcomes factoring in baseline and operative differences. Backstep logistic regression and conditional inference tree (CIT) analysis were used to detect variable thresholds associated with an optimal outcome overall and then stratified by surgical cohort. Specially for CIT, R version 3.3.1 (R Foundation for Statistical Computing) was used conjointly with IBM SPSS Statistics for Windows version 29.0 (IBM Corp.) for preprocessing and analysis of the data. We allocated 75%

TABLE 1. Major and minor complication classification

	Intraop Complications	Postop Complications Noted Before Hospital Discharge	Complications Noted at Follow-Up
Major	Bowel or bladder deficit	Bowel or bladder deficit	Instrumentation or junctional failure
	Cardiac arrest	Death	Cerebrovascular accident
	Cauda equina deficit	Deep vein thrombosis	Infection—deep wound
	Cauda equina injury	Infection—deep	Myocardial infarction
	Cord deficit	Motor deficit	Major neurological deficit
	Death	Myocardial infarction	Pneumonia
	Inadvertent extubation	Neurological complications	Pulmonary emboli
	Malignant hyperthermia	Optic deficit	Deep vein thrombosis
	Nerve root injury	Pneumonia	Wound dehiscence
	Optic deficit	Pulmonary embolism	Vascular injury
	Vascular injury	Reintubation	
	Visceral injury	Sepsis	
		Stroke	
		Other cardiopulmonary	
Minor	CSF	Infection—superficial	Infection—superficial
	Excessive bleeding	Postop radiculopathy	Minor neurological deficit
	Ineffective fixation	Sensory deficit	Postop CSF leak
	Intraop coagulopathy	Skin complications	Seroma
	Pedicle infraction	Excessive postop bleeding	Thrombophlebitis—superficial
	Posterior element fracture	Thrombophlebitis—superficial	
	Vertebral body fracture		

of our cohort for testing and developing the model, while the remaining 25% was reserved for validation after the model's development. Packages used in R include "party" and "rpart." The first part of the analysis consisted of a random forest set of 2000 CITs (subsampling without replacement) used to identify potential factors that affect optimal outcomes in the same-day cohort and staged cohort. A variable importance table (Gini gain criterion) was generated via the varimp() function in the R "party" package; this table outlined the importance of possible predictors of our target variable. All influencing factors were discovered and carried over to an IBM SPSS database where logistic regressions were conducted to show their effect size as odd ratios, as well as their significance as possible predictors. Results were expressed using odds ratios and 95% confidence intervals. Statistical significance for all analyses was set at a p value < 0.05. All statistical analyses were conducted using SPSS version 28.0 (IBM Corp.).

Results

Cohort Overviews

We included 439 patients in this analysis. The mean age was 64.0 ± 9.3 years, 68% were female, the mean BMI was 28.7 ± 5.5 kg/m^2, and the mean CCI was 1.9 ± 1.6. Same-day procedures were performed in 58.8% of included patients, while 41.2% were staged.

Surgical Descriptors

The mean number of levels fused was 12, the mean EBL was 1841.6 mL, and the mean operative time was 449.6 minutes. Overall, 78.4% of patients underwent an osteotomy as part of their index procedure. Of these patients, 23.8% underwent a three-column osteotomy. The mean operative time difference between groups was not statistically significant (staged: 639.92 minutes vs same-day: 597.59 minutes, $p < 0.333$). The difference in number of levels fused was also not statistically significant (staged: 11.86 levels vs same-day: 13.35 levels, $p < 0.128$) (Table 2).

Baseline and Surgical Comparison of Staged Versus Same-Day Patients

Both cohorts were not significantly different in terms of age, sex, and BMI (all $p > 0.05$), although staged patients had significantly higher total Edmonton Frail Scale scores ($p = 0.043$). Both cohorts were not significantly different in magnitude of planned correction of C7–S1 SVA, PI-LL mismatch, and TK (all $p > 0.05$). At baseline, staged patients reported greater NRS scores for back pain than same-day patients ($p = 0.002$). Same-day patients were more likely to undergo a procedure for motor deficit ($p = 0.028$). Staged patients experienced significantly greater hospital length of stay ($p = 0.013$).

Comparison of Complications and Patient-Reported Outcomes

Controlling for baseline frailty, there were no significant radiographic differences at baseline or in the degree of planned correction between the same-day and staged cohorts. Radiographic outcomes by 6 weeks were similar between cohorts, both in terms of the magnitude of change from baseline and overall (all $p > 0.05$) (Table 3). Staged

TABLE 2. Baseline differences between same-day and staged patients

	Same-Day	Staged	p Value
Age, yrs	64	63.3	0.364
BMI, kg/m^2	28.7	28.7	0.807
Female sex, %	67.6	73.1	0.348
HRQOL measures			
Edmonton Frail Scale score	3.29	4.96	**0.043**
NRS back pain score	6.4	8.3	**0.002**
NRS leg pain score	4.95	4.81	0.819
Oswestry Disability Index score	45.1	48.3	0.745
Scoliosis Research Society-22 score	2.79	2.74	0.495
PROMIS Anxiety	55.1	57.6	0.775
PROMIS Depression	52.1	54.9	0.903
PROMIS Pain Interference	64.4	66.4	0.327
PROMIS Physical Function	34.8	33.8	0.815
PROMIS Social Satisfaction	41.0	39.2	0.779
Radiographic parameters			
SVA, mm	91.7	100.7	0.646
Sacral slope, °	29.0	27.1	0.651
Pelvic tilt, °	27.7	33.1	0.197
PI, °	56.8	60.2	0.405
PI-LL mismatch, °	26.5	35.8	0.133
Planned SVA correction magnitude, mm	94.8	95.1	0.654
Planned PI-LL mismatch correction magnitude, °	21.9	25.3	0.138
Planned TK correction magnitude, °	35.0	41.0	0.328

Values are presented as mean unless otherwise indicated. Boldface type indicates statistical significance.

TABLE 3. Postoperative outcome comparisons between same-day and staged patients

	Same-Day	Staged	p Value
Op time, mins	597.6	639.9	0.333
No. of levels fused	11.9	13.4	0.128
EBL, mL	1250.7	1562.3	0.241
Anterior IBF	86.5	84.6	0.838
Posterior IBF	5.4	7.7	0.719
Lat IBF	13.5	15.4	0.840
VCR or corpectomy, %	3	4	0.803
Length of stay, days	7.6	9	0.013
SICU stay, %	59	65	0.640
Pulmonary effusion, %	3	0	0.044
Atelectasis, %	3	0	0.007
Cardiac event w/in 30 days, %	16	8	0.007
Non–surgical site infection, %	2	0	0.04
Surgical site infection, %	1	1	0.183
Neurological deficit, %	10	4	0.039

IBF = interbody fusion; SICU = surgical intensive care unit; VCR = vertebral column resection.
Values are presented as mean unless otherwise indicated.

patients reported significantly higher PROMIS Discretionary Social Activities scores by 6 weeks (p = 0.029). Otherwise, there were no differences in HRQOL metrics between groups at all time points. Same-day patients were significantly more likely to have more in-hospital complications, controlling for baseline frailty (p = 0.013).

Predictive Analysis of Achieving Optimal Outcomes in Staged Versus Same-Day Patients

Following multivariable regression, staging alone was not significantly predictive of achieving optimal outcome perioperatively (p = 0.056). Only CCI ≤ 1.0 (OR 1.2, 95% CI 1.01–1.4; p = 0.48) was associated with an optimal outcome in same-day patients. Total Edmonton Frailty Scale score ≥ 7 (OR 0.5, 95% CI 0.268–0.958; p = 0.036), ≥ 9 levels fused (OR 1.9, 95% CI 1.121–3.068; p = 0.016), and baseline PI-LL mismatch ≥ 15.3° (OR 0.9, 95% CI 0.813–0.988; p = 0.028) were associated with optimal outcome for staged patients (Table 4).

Discussion

While same-day procedures may seem more convenient and less daunting to patients considering surgical correction of ASD, it is important for surgeons to objectively discuss the risks and benefits of alternative approaches, including staged interventions. Given the current healthcare climate, most previous work on complex ASD has understandably focused on minimizing blood loss, reducing complications, and maximizing the efficiency of healthcare delivery.[24,25] Although staged surgeries inherently lengthen overall hospital stay and associated costs, there may be benefits to disbursing the intense physical burden of surgery across multiple days. Moreover, there may be certain classes of patients who benefit more from staged surgeries than from same-day procedures, such as those with greater baseline frailty or a need for greater deformity correction and more intensive interventions.

We found that staging appeared to increase the likelihood of attaining optimal outcome in individuals with greater frailty, patients with larger deformities, and those undergoing more extensive surgeries. Otherwise, it appeared that the least comorbid patients (CCI < 1.0) were more likely to attain optimal outcomes following same-

TABLE 4. Predictors of optimal outcome for same-day and staged cohorts

	OR (95% CI)	p Value
Same-day		
CCI ≤1.0	1.2 (1.01–1.4)	0.048
Staged		
Total Edmonton Frail Scale score ≥7	0.5 (0.268–0.958)	0.036
≥9 levels fused	1.9 (1.121–3.068)	0.016
Baseline PI-LL mismatch ≥15.3°	0.9 (0.813–0.988)	0.028

day procedures. This represents a small and specific subgroup of patients who are likely to do well in most circumstances when compared with the larger ASD population as a whole. Patients within this comorbidity threshold are likely fit enough to undergo circumferential fusion in a single setting, and it is possible that undergoing two separate procedures may introduce unnecessary risk.

However, patients with a large PI-LL mismatch (≥ 15.3°) or requiring a high number of fused levels (≥ 9) were more likely to achieve an optimal outcome using a staged approach. These findings likely indicate surgical invasiveness thresholds beyond which same-day surgery may predispose patients to a higher risk of postoperative adverse events, especially in frail individuals with diminished physiological reserve to tolerate the stress associated with severe deformity correction. Both staged and same-day patients showed similar results in terms of correcting radiographic deformity, which aligns with the existing literature, and would be expected given the lack of randomization associated with this retrospective study with potential for confounding by indication.[26] This would also explain why we found no difference for the procedural approach, overall, in terms of influencing the likelihood of an optimal outcome.

There remains a paucity of specific data regarding staging in complex ASD. The currently available literature is heavily confounded by heterogeneity in terms of operative indication, size of the patient population, and surgical objectives, resulting in inconclusive findings on the whole. For example, Passias et al. previously reported that staged surgeries resulted in a higher likelihood of adverse events including deep vein thrombosis.[27] It should be noted that these findings were reflective of a period prior to 2006, and considerable advances have been made in perioperative optimization, surgical techniques, intraoperative technologies, and postoperative recovery-enhancing protocols since the publication of that work. More recently, Than et al. reported no differences between staging and same-day procedures in patients undergoing minimally invasive surgery.[7] However, these authors also reported significantly higher complication rates among staged patients. Conversely, Gum et al. found no significant differences in staged versus nonstaged vertebral column resection populations.[28] In contrast to these previous investigations, the present study has the advantages of a large study population, being performed at multiple centers over a time window proximate to the present, and relying on the most modern techniques and perioperative approaches for delivering surgical care.

We acknowledge several limitations inherent to the present work. First, the retrospective nature lends itself to confounding by indication, which we could only effectively address by stratifying the procedural groups. Second, the brevity of the follow-up period may fail to capture any delayed effects, although we maintain that the impact of the surgical strategy is minimal beyond 6 weeks of surgery. Nonetheless, there is certainly room for future work with a greater focus on differences in long-term outcomes, if any. Additionally, other factors such as surgeon experience and institutional practices may influence outcomes and were not specifically examined in this study. There is also likely variation in the multicenter data in terms of availability of hospital resources and acceptance of staging infrastructure. We were unable to ascertain whether decisions for staged procedures were made up front, or if they were influenced by unplanned intraoperative issues. Such nuances of decision-making may confound our findings regarding postoperative outcomes. Future directions of the study context may include establishing easily identifiable preoperative factors to guide decision-making regarding staging, as well as assessment of the optimal time window between stages.

Conclusions

Staging provides a viable alternative to lengthy same-day surgeries in which patients with the most severe ASD may incur greater risk and experience more complications. We have identified thresholds for frailty, comorbidity, severity of spinal deformity, and planned surgical invasiveness, beyond which we would recommend that surgeons consider a staged approach for spinal deformity correction. Staging may appear as a larger investment upfront, but its benefits include minimizing complications, facilitating optimal outcomes, and ultimately decreasing healthcare resource utilization. By distributing the surgical stress across a longer time frame, at-risk patients may be able to better tolerate the physiological impact of surgery.

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