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Clinical Study

Cause and effect of revisions in adult spinal deformity surgery: a multicenter study on outcomes based on etiology

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Abstract

BACKGROUND CONTEXT: While the treatment of adult spinal deformity (ASD) has increasingly favored surgical correction, the incidence of revision surgery remains high. Yet, little has been explored on the association between the etiology of reoperation and patient outcomes.

PURPOSE: To assess the impact of the etiology of revision surgery on postoperative outcomes.

STUDY DESIGN/SETTING: Retrospective cohort analysis.

PATIENT SAMPLE: 891 ASD patients.

OUTCOME MEASURES: Complications, radiographic parameters, disability metrics.

METHODS: Operative ASD patients with at least 1 revision stratified by etiology (mechanical [Mech] −pseudoarthrosis, thoracic decompensation without junctional failure, x-ray malalignment, implant failure, implant malposition, PJK ± major malalignment; infection [Infx]−early vs late onset, major vs minor; wound [Wound]; SI pain [SI Pain]). Excluded multiple etiologies, and intra-operative or medical complications. Data from the immediate visit prior to the final revision was used as baseline (rBL). Follow-up based on visits best aligned to time points after final revision. Radiographic parameters SVA, PI-LL, and PT were used to assess alignment post-revision via ANOVA. Multivariate analysis controlling for relevant covariates assessed outcome differences after final revision surgery.

RESULTS: 891 met inclusion (Age: 60.40±14.17, 77% F, BMI: 27.97±5.87 kg/m2, CCI: 1.80± 1.73). Etiology groups were as follows: Mech: 432; Infx: 296; Wound: 65; SI Pain: 98. Surgically, Infx had lower rates of osteotomy, interbody fusion, and decompression ($p<.05$). Infx and SI Pain demonstrated similar correction in radiographics SVA, PI-LL, and PT ($p>.05$), whereas Mech had significantly less improvement by 2 years ($p<.003$) that improved by 5 years. Compared to without revision, the odds of MCID in ODI were 48.6% lower across groups (OR: 0.514 [.280, .945], p=.032). Indications of x-ray malalignment were 93.0% less likely to reach MCID (OR: 0.071, [.006, .866], p=.038). Similarly, implant failure negatively impacted rates of MCID (40% vs. 15.2%, p=.029). Those with PJK had 57% lower odds of MCID (33% vs 54%, OR: .43, [0.2, 0.9] p= .023), further negated by major malalignment (OR: 0.05, [.07, .97], p=.02). Indications of pseudarthrosis, thoracic decompensation, implant malposition were not significant. Major sepsis had lower rates of MCID compared to minor (6.4% vs. 21.2%), and early onset infection improved compared to late (OR: 1.43, [1.17, 2.98], $p<.001$). In the early follow-up period, the Mech group has significantly worse SRS Pain and Mental Health scores compared to other groups (1-year: Mech 1.56 vs Infx 0.83 vs SI Pain 0.72, $p<.001$; 2-year: 1.88 vs 0.71 vs 0.76, p=.034). Complication rates increased with the number of revisions and with mechanical indication (all $p<.05$). At 5 years, patient satisfaction was significantly more likely to improve compared to early follow-up (OR: 1.22, p=.011), along with improved pain score, in Mech group (0.89 vs 0.49 vs 0.56, p=.081).

CONCLUSIONS: This study focused on the impact of revision as it varies with etiology and time of occurrence postoperatively. Compared to other etiologies, revision surgery due to mechanical complications had less radiographic improvement and worsening patient-reported scores in the early postoperative period despite stabilization at 5 years. The depth of impact of mechanical complication, particularly with the addition of malalignment, merits greater focus during surgical planning.

LEVEL OF EVIDENCE: III.

Keywords: Adult spine deformity; Realignment; Revision; Reoperation; Complications; Etiology

INTRODUCTION

Adult spinal deformity (ASD) is an increasingly prevalent issue within the United States, particularly with the growing elderly population [1,2]. Despite advancements in surgical techniques, instrumentation, and perioperative care, the management of ASD remains challenging, with a notable risk of postoperative complications necessitating revision surgery. These complications encompass a spectrum of issues, including pseudoarthrosis, implant failure, adjacent segment degeneration, neurological deficits, wound complications, and infection [2–4]. The occurrence of such complications not only prolongs patient recovery but also poses a considerable burden on healthcare resources and may compromise the long-term efficacy of surgical intervention. Given the high cost associated with primary surgery, cited to be an average reimbursement rate of up to $60,000 varying with surgical complexity, an examination of postoperative complications leading to revision surgery is necessary [1,2,5].

The incidence and etiology of revision surgery following corrective procedures for ASD have been the subject of extensive investigation in recent years. Several studies have reported varying rates of revision surgery, reaching up to 58%, highlighting the multifactorial nature of postoperative complications in this patient population [3,5]. In attempting to elucidate the nature and need for revision surgery, Burke et al. (2022) found that failure in ASD surgery can be subdivided into 4 distinct categories: clinical failure, radiographic failure, the need for reoperation, and lack of cost-effectiveness [2]. Furthermore, the presence of comorbidities and patient-specific factors may influence the risk of postoperative complications and subsequent revision surgery. Amongst the risk factors studied for increased rates of revision surgery were age, bony failure with a high degree of kyphosis, and comorbidities such as osteoporosis and obesity [3,4,6,7].

Despite these insights, there has been little exploration of the association between the etiology of reoperation and its differences in long-term patient reported outcome measures. In this study, we seek to assess the factors associated with the incidence of revision surgery following ASD correction in a cohort of patients treated surgically for spinal deformity. We hypothesized that there are specific factors related to the type of postoperative complication that may worsen the rates of revision surgery.

METHODS

Data source and study design

A retrospective cohort study of prospectively collected multicenter adult spinal deformity database was conducted. This dataset consists of clinical, surgical, and outcome data from fourteen centers across the United States and Canada. Institutional Review Board approval and informed consent was obtained prior to enrollment. Patient eligibility and data collection material have been described in previous publications, and spinal deformity was defined as any coronal Cobb angle $\geq 20^{\circ}$, sagittal vertical axis (SVA) ≥ 5 cm, pelvic tilt (PT) $\geq 25^{\circ}$, or thoracic kyphosis (TK) $\geq 60^{\circ}$ [8]. We included operative adult spinal deformity patients who had complete radiographic and health-related quality of life (HRQL) data up to 2-year follow-up and required at least 1 revision spine surgery in the current maturity of this dataset.

Data collection

Demographic data consisted of age, gender, body mass index (BMI), history of prior fusion, and baseline comorbidities categorized using the Charlson Comorbidity Index (CCI). Surgical parameters consisted of levels fused, operative time, length of stay, surgical approach, use of decompressions, and osteotomies. A standardized complication reporting form was completed for each clinical follow-up, and at any point, the site became aware of a new complication or adverse event. Patient-reported outcome measures, prospectively collected at baseline and follow-up intervals, included: modified Oswestry Disability Index for low back pain (ODI), Scoliosis Research Society Questionnaire 22r (SRS-22r) [9]. The minimum clinically important difference (MCID) values for this patient population were set at 12.8 for the ODI, 4.9 for the SF-36 physical component score, 0.587 for SRS pain, 0.8 for SRS appearance, 0.375 for SRS activity, and 0.42 for SRS mental based on previously published values [10,11]. Outcome assessments were completed via patient surveys at baseline and during subsequent follow-up encounters up to 2 years following surgery. Radiographic parameters measured were pelvic tilt, pelvic incidence (PI), sagittal vertical axis (SVA), lumbar lordosis (LL, T12-S1), and mismatch between pelvic incidence and lumbar lordosis (PI-LL).

Radiographic data collection

Full-length free-standing lateral spine radiographs (36-inch cassette) were collected and assessed at baseline and follow-up. Radiographs will be reviewed for postoperative correction and revision surgery. All radiographic analyses of the spinal axis will be performed using full spine EOS imaging that includes sagittal and coronal visualization of the top of the skull to the bottom of the foot. Sagittal and coronal radiographic parameters will obtained from the EOS radiographs using appropriate radiographic imaging and measurement software, including Spineview® (Laboratory of Biomechanics, Paris, France) and Surgimap® as previously validated [12–14]. The EOS system produces high-quality radiographs with a much lower dose of radiation compared to traditional methods [15].

Patient stratification and grouping

Operative ASD patients with 1 or greater revisions were stratified according to the etiology of reoperation. They were grouped accordingly into 4 major categories: Mechanical (Mech), Infection (Infx), SI Pain (SI Pain), and Wound (Wound). Those with multiple etiologies, as well as intraoperative or medical complications requiring surgical intervention, were excluded. Further information regarding indications for revision surgery by cohort can be found in Table 1. Data from immediate visits prior to final revision was used as a baseline time point for patients (rBL). Follow up time points were based on visits that best aligned to time points after final revision.

Statistical analysis

Frequency distributions and summary statistics were calculated for all demographic, clinical, surgical, and radiographic variables. Univariate analyses were used to compare etiology groups regarding demographics, surgical descriptors, and radiographic parameters. Independent sample t-tests were used to assess differences in continuous variables. Deformity severity at follow-up and clinical outcomes, including complication rates, was assessed. Multivariate analysis controlling for age, frailty, surgical invasiveness, and baseline disability was used to assess outcome differences after final revision surgery. All p-values <.05 were considered significant. All statistical analyses were conducted using SPSS, version 25.0 (Armonk, NY).

Table 1
Indications for revision surgery by cohort

Cohort	Indication for revision surgery
Mechanical	Pesudarthrosis
	Thoracic decompensation without junctional failure
	Radiographic malalignment
	Implant failure
	Implant malposition
	Post-Junctional Kyphosis with major malalignment
	Post-Junctional Kyphosis without major malalignment
Infection	Early onset infection
	Late onset infection
	Minor sepsis
	Major sepsis
Wound	Wound complication issues
SI Pain	SI joint pain

Abbreviations: PJK: Post-Junctional Kyphosis; SI: Sacroiliac.

Results

Cohort overviews

350 patients met the inclusion criteria. The mean age in this cohort was 60.40±14.17years, 79% were female, the mean BMI was 27.9±5.6 kg/m2, and the mean Charlson Comorbidity Index (CCI) was 1.80±1.73. The subsequent stratification into cohorts by etiology of reoperation yielded the following: Mech: 132 patients; Infx: 96 patients; Wound: 45 patients; SI Pain: 77 patients.

Surgical descriptors

Regarding surgical characteristics, the mean number of levels fused was 11.8±4.4, the mean estimated blood loss (EBL) was 1841.6 mL, and the mean operative time was 449.6 minutes. 58.9% of patients (n=149) underwent a posterior-only approach, while 41.1% of patients (n=104) underwent a combined approach. Overall, 195 patients (77.1%) had an osteotomy as part of their index procedure. Of these, 72 patients underwent a three-column osteotomy. 141 patients underwent a Smith-Petersen osteotomy, 61 underwent a pedicle subtraction osteotomy, 4 underwent a Corpectomy, and 8 underwent a Vertebral Column Resection.

Cohort analysis

Surgically, Infx had lower rates of osteotomy (p=.033), interbody fusion (p=.020), and decompression (p=.034) compared to Mech and SI Pain groups for revision surgery. Infx and SI Pain demonstrated similar correction in the radiographic parameters SVA, PI-LL, and PT post-revision (p>.05). In contrast, Mech had significantly less improvement in correction by 2 years post-revision (p<.003) that improved by 5 years post-revision. At 5 years post-revision, patient satisfaction was 22% more likely to improve across all groups compared to early follow-up (OR: 1.22, [1.15, 8.94], p=.011).

Outcomes of patients by revision etiology

Detailed results of achieving MCID in ODI based on revision etiology can be viewed in Table 2. Patients who had revisions due to pseudarthrosis, thoracic decompensation, and implant malposition were found to not significantly impact rates of achieving MCID in ODI. Major sepsis had lower rates of MCID compared to minor (6.4% vs. 21.2%). Compared to patients with late-onset infections,

Table 2
Likelihood of achieving MCID in ODI based on revision etiology

MCID in ODI			
Etiology of Revision	Odds Ratio	95% CI	p-value
All Revisions	0.514	0.28-0.945	.032
Mechanical			
Malaligned	0.071	0.006-0.866	.038
PJK	0.43	0.2-0.9	.023
PJK + Malaligned	0.05	0.07-0.97	.02
Infection			
Early Onset Infection	1.33	1.17-2.98	<.001

Abbreviations: ODI: Oswestry Disability Index; PJK: Post-Junctional Kyphosis.

those with an early-onset infection were more likely to achieve MCID in ODI (OR: 1.43, [1.17, 2.98], p<.001).

Impact of complication timing on outcomes

Additional results of the effect of complication timing on patient outcomes can be found in Table 3. Mech, Infx, and SI Pain cohorts had similar SRS-Total Scores across follow-up time periods as compared to other groups (all p>.05). Mech group had a greater rate of achieving MCID in ODI in the late follow-up period at 5 years post-revision compared to those in the 1-year post-revision period (23.7% vs 9.9%, p=.022). The Mech group maintained significantly higher rates for SRS-Mental and ODI scores at late follow-up (both p≤.05). Overall complication rates increased with the number of revisions and with mechanical indication (all p<.05).

Discussion

Revision surgery rates after adult spinal deformity correction are an important metric for the severity of postoperative complications. The cause and need for secondary surgery have been studied to correlate to patient factors such as age, obesity, osteoporosis, and increasing degree of deformity. The current study aims to elucidate further the surgical etiology for revision surgery amongst ASD patients over the course of five years.

Table 3
Impact on the timing of complication on patient reported outcomes

Impact of complication timing on outcomes				
Outcome measure	Cohort			p-value
	Mech	Infx	SI pain	
SRS pain and mental health				
1 year postoperatively	1.56	0.83	0.72	**<.001**
2 years postoperatively	1.88	0.71	0.76	**.034**
SRS pain				
5 years postoperatively	0.89	0.49	0.56	.081

Abbreviations: SRS: Scoliosis Research Society Questionnaire 22r.

Mechanical complications, including pseudarthrosis, implant failure, and malalignment, constituted the largest subgroup, highlighting the technical challenges and potential limitations of hardware fixation in ASD correction. However, Mech patients significantly improved disability scores over time, particularly at the 5-year follow-up, suggesting a delayed but sustained benefit from surgical intervention. This delayed improvement may be attributed to the gradual resolution of mechanical complications and adaptation to corrected spinal alignment. Mechanical complications, including implant failure and malalignment, were associated with lower rates of achieving MCID in ODI scores, indicating persistent disability and functional limitations. In contrast, patients who had no complications that indicated them for revision surgery were significantly more likely to achieve MCID in ODI scores. Similarly, patients with PJK and major malalignment demonstrated poorer outcomes, highlighting the importance of paying careful attention to sagittal and coronal balance in ASD correction. Infections, particularly those with major sepsis and late onsets, were associated with worse clinical outcomes, underscoring the critical role of infection prevention and early intervention in optimizing surgical results.

Our analysis revealed distinct patterns of clinical outcomes and patient satisfaction over time. Mechanical complications were associated with worse pain and mental health scores in the early postoperative period but demonstrated comparable outcomes to other etiology groups at long-term follow-up. One additional finding of note was that patients in the SI Pain cohort had similar SRS Pain and Mental Health scores at 1- and 5 years post-revision. This result aligns with previously validated data demonstrating that some ASD patients have SI pain that never fully resolves [16–18]. The cause of this pain is often multifactorial and can take many years to resolve. However, Patient satisfaction improved across all groups at 5 years postoperatively, suggesting a gradual adaptation to surgical outcomes and improved quality of life over time. However, overall complication rates increased with the number of revisions and mechanical indications, emphasizing the importance of addressing underlying mechanical issues and optimizing surgical techniques to minimize the risk of revision surgery.

Several limitations should be acknowledged in interpreting our findings. The retrospective nature of the study may introduce selection bias and limit causal inference. Another limitation is our exclusion of patients with multifactorial etiologies that indicated them for revision surgery. Wound issues can progress to subsequent systemic or local infections and in such cases, it would be worthwhile to investigate the true causality for revision. However, to reduce as many possible confounding factors as we could, we elected to exclude patients with multifactorial indications for revision. Additionally, the multicenter design may contribute to variations in surgical techniques and postoperative care protocols, potentially influencing outcomes. Future studies ought to focus on further identifying modifiable risk factors

for revision surgery in ASD patients. Furthermore, long-term follow-up beyond 5 years is warranted to assess the durability of surgical outcomes and the impact of aging-related changes on spinal deformity progression. The study of such factors will aid in clinical improvement and understanding of the development of radiographic and mechanical complications following corrective ASD surgery. We recommend that these factors be used as an integrative tool in surgical planning outside of the current parameters. As such, we encourage these findings to be replicated and validated to fully determine their true impact on clinical practice.

In conclusion, our study provides comprehensive insights into the rates, etiologies, and outcomes of revision surgery following orthopedic corrective procedures for adult spinal deformity. By delineating the clinical characteristics and prognostic factors associated with revision surgery, our findings underscore the importance of multidisciplinary collaboration to optimize patients perioperatively, meticulous preoperative planning, and patient-centered care in optimizing surgical outcomes and enhancing the quality of life in ASD patients.

Conclusions

This study focused on the effect of revision as it varies with etiology and time of occurrence postoperatively. Patients with early-onset infections had superior outcomes to those with delayed-onset or sepsis, highlighting the importance of a need to develop further infection prevention and early treatment protocols in adult spinal deformity surgery. Compared to other etiologies, patients revisiting surgery due to mechanical complications had less radiographic improvement and worsening patient-reported scores in the early postoperative period despite stabilization at 5 years. The depth of impact of mechanical complication, particularly with the addition of malalignment, merits greater focus during surgical planning. Despite these patients undergoing revision surgery, it is essential to note that patient satisfaction was likely to improve at their 5-year follow-up regardless of etiology.

Ethical review committee statement

Institutional Review Board approval was obtained before enrolling patients in the prospective database. Informed consent was obtained from each patient prior to enrollment.

Declaration of Competing Interest

One or more of the authors declare financial or professional relationships on ICMJE-TSJ disclosure forms.

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