



Peak Timing for Complications After Adult Spinal Deformity Surgery

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BACKGROUND: Overall complication rates for adult spinal deformity (ASD) surgery have been reported; however, little data exist on the peak timing associated with specific complications. This study quantifies the peak timing for multiple complication types in an ASD cohort at minimum 2-year follow-up.

METHODS: Multicenter, prospective analysis of all complications after ASD surgery in a consecutively enrolled cohort was performed. Inclusion criteria were ASD, age ≥ 18 years, spinal fusion ≥ 4 levels, and minimum 2-year follow-up. Complications included major and minor and specific complication types. Peak timing of specific complications was identified and described. Regression analysis was performed to assess correlation between patient/surgical factors and complication timing.

RESULTS: There were 280 patients who met the inclusion criteria. Mean follow-up time was 2.9 years (range, 2–5 years). Of the patients, 209 (74.6%) had at least 1 complication, accounting for 529 total complications (258 minor and 271 major). Both major and minor complications peaked at < 3 months. Infection and neurologic complications peaked at < 3 months. Proximal junctional kyphosis had bimodal peaks at < 3 and > 24 months. Implant failure

peaked at 12–24 and > 24 months. There was a significant positive correlation between preoperative sagittal vertical axis and total complications at 6–12 months, major complications at 24 months, and reoperation. Body mass index was associated with total complications and implant failure at 12–24 and > 24 months.

CONCLUSIONS: The peak timing of specific complications after ASD surgery is identifiable. Understanding when these complications are likely to occur may improve patient counseling, early diagnosis, and prophylactic interventions and may help inform future reimbursement models.

INTRODUCTION

Complication rates after adult spinal deformity (ASD) surgery rank among the highest of all surgical specialties, with reported complication rates ranging from 10.5% to 96%.¹ Although reported complication rates have varied widely, a recent carefully designed prospective study by Smith et al.² reported that 52.2% of patients had at least 1 perioperative complication and 69.8% of patients had at least 1 complication within 2 years of follow-up. Although total complication rates

Key words

- Adult spinal deformity
- Complications
- Fusion
- Infection
- PJK
- Outcomes

Abbreviations and Acronyms

- ASD:** Adult spinal deformity
PJK: Proximal junctional kyphosis
SVA: Sagittal vertical axis

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have been widely reported,¹⁻¹¹ little data exist for the peak timing associated with specific complications.

Understanding the timing of complications associated with ASD surgery is critical for counseling patients, establishing payer rates in the era of bundled payments,¹²⁻¹⁶ and understanding restricted payments for admissions because of postoperative complications.^{17,18} Hospitalization costs are significantly elevated after complications¹⁷; therefore, it is imperative to understand the expected timing and rate of specific complications. The purpose of this investigation was to evaluate the peak timing for complications after ASD surgery in a prospective, consecutive ASD cohort with a minimum 2-year follow-up.

METHODS

Institutional review board approval was obtained at all participating spinal deformity centers prior to initiating this study. Patients with ASD that presented to surgical clinics at 11 spine centers across the United States were offered enrollment in the study. Patients entered either the operative or the nonoperative cohort based on their preference and their surgeons' assessment of their suitability for surgery.

Preoperatively, ASD patients were defined as those with at least one of the following parameters: idiopathic or degenerative

deformity with a coronal Cobb angle of at least 20°, sagittal vertical axis (SVA) >5 cm, pelvic tilt >25°, or thoracic kyphosis >60°. Surgeon and patient preferences were used to determine the need for surgery and the surgical procedure type.

Exclusion criteria for this study included a diagnosis of post-traumatic, neuromuscular, and/or congenital spinal deformity, or patient age <18 years of age at presentation. Patients with a history of prior spinal fusion surgery were offered enrollment if they met the aforementioned criteria. Additional inclusion criteria for this study included patients undergoing spinal fusion ≥4 levels and minimum 2-year follow-up.

Complications were divided into major and minor as previously recommended by Glassman et al. (Table 1).¹⁹ Complications were then further divided into specific complication types, including operative, implant failure, infectious (superficial and deep wound infection, pneumonia, and urinary tract infection), neurologic (spinal cord injury, nerve root injury, and bowel/bladder deficit), proximal junctional kyphosis (PJK), complications requiring surgical treatment, and wound hematoma/seroma. Any complication leading to reoperation was considered a major complication.

The percentage of patients incurring each complication was calculated. The percentage of total complications was also calculated and recorded because some patients had multiple

Table 1. Distribution of Patients with Complications (N = 280)

Complication	Total	t = 0	t < 3 Months	t = 3–6 Months	t = 6–12 Months	t = 12–24 Months	t > 24 Months
Patients with a complication	209 (74.6)	107 (38.2)	118 (42.1)	16 (5.7)	28 (10.0)	51 (18.2)	43 (15.4)
Patients with a minor complication	158 (56.4)	66 (23.6)	86 (30.7)	7 (2.5)	9 (3.2)	20 (7.1)	19 (6.8)
Total patients with a major complication	144 (51.4)	59 (21.1)	60 (21.4)	9 (3.2)	21 (7.5)	34 (12.1)	24 (8.6)
Patients with a complication requiring return to OR	79 (28.2)	14 (5.0)	33 (11.8)	9 (3.2)	17 (6.1)	23 (8.2)	11 (3.9)
Patients with an infection	29 (10.4)	2 (0.7)	27 (9.6)	1 (0.4)	3 (1.1)	2 (0.7)	1 (0.4)
Proximal junctional kyphosis	37 (13.2)	1 (0.4)	12 (4.3)	4 (1.4)	7 (2.5)	6 (2.1)	10 (3.6)
Implant failure	42 (15.0)	0 (0)	0 (0)	1 (0.4)	7 (2.5)	20 (7.1)	19 (6.8)
Revision for implant failure	6 (2.1)	0 (0)	0 (0)	1 (0.4)	5 (1.8)	11 (3.9)	7 (2.5)
Neurologic	60 (21.4)	15 (5.4)	21 (7.5)	2 (0.7)	2 (0.7)	5 (1.8)	3 (1.1)
Spinal cord injury	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Nerve root injury	5 (1.8)	5 (1.8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Nerve root injury requiring surgery	2 (0.7)	2 (0.7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Bowel and bladder deficit	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Motor deficit	18 (6.4)	6 (2.1)	11 (3.9)	1 (0.4)	0 (0)	0 (0)	0 (0)
Motor deficit requiring surgery	5 (1.8)	2 (0.7)	2 (0.7)	1 (0.4)	0 (0)	0 (0)	0 (0)
Radiculopathy	24 (8.6)	1 (0.4)	10 (4.6)	3 (1.1)	2 (0.7)	6 (2.1)	2 (0.7)
Radiculopathy requiring surgery	9 (3.2)	0 (0)	4 (1.4)	3 (1.1)	0 (0)	2 (0.7)	0 (0)
Sensory deficit	11 (3.9)	3 (1.1)	2 (0.7)	3 (1.1)	0 (0)	2 (0.7)	1 (0.4)
Sensory deficit requiring surgery	2 (0.7)	0 (0)	0 (0)	1 (0.4)	0 (0)	1 (0.4)	0 (0)

Values are number of patients (%).
OR, operating room.

complications. The timing of each complication after surgery was recorded for each patient and categorized as $t = 0$ for intraoperative complications and $t < 3$ months, $t = 3-6$ months, $t = 6-12$ months, $t = 12-24$ months, and $t > 24$ months. The peak timing of each complication category was calculated by pooling the patients with each complication and recording the number of patients in each timing category.

Total complications and total number of patients with at least 1 complication were examined. Percent of patients experiencing a complication was also examined. Peak timing for each complication was identified and presented graphically to give a visual representation of when a patient is at increased risk for the various complications.

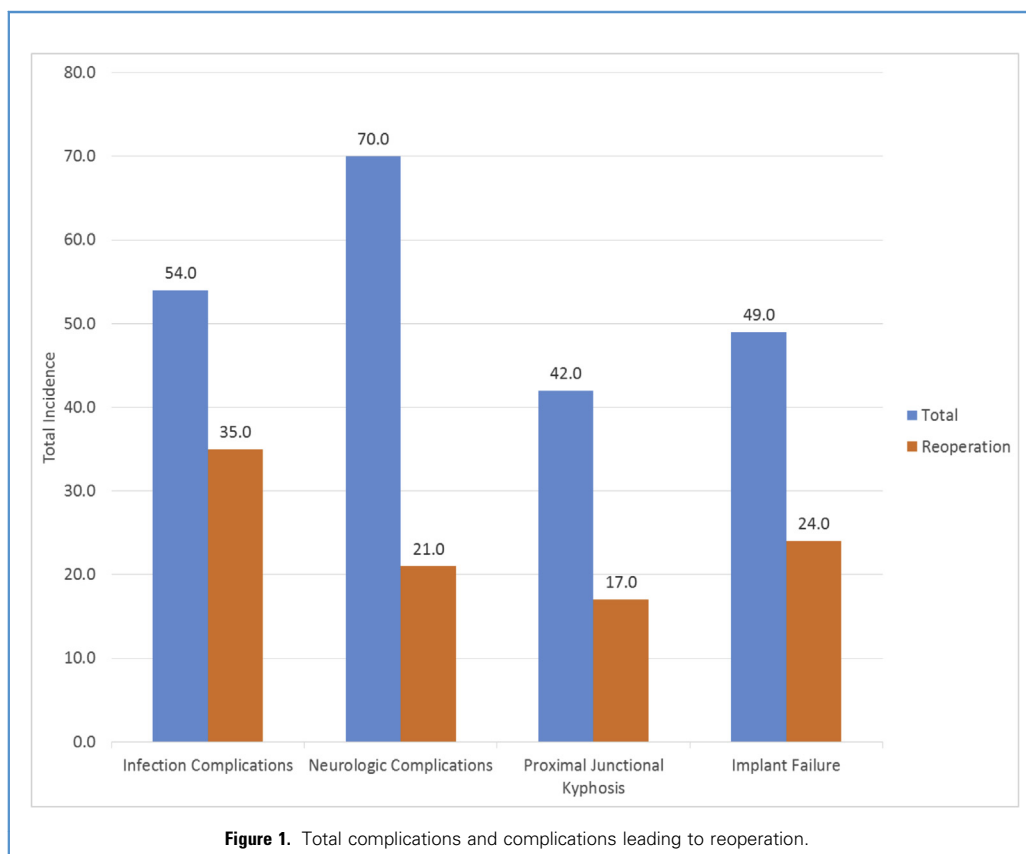
Additionally, linear regression analysis was performed to examine correlations between patient/surgical factors and each complication at each time point. Specific patient/surgical factors analyzed as possible predictor variables included the following: posterior bone morphogenetic protein 2 dose, interbody bone morphogenetic protein 2 dose, number of levels fused (anterior), number of levels fused (posterior), preoperative coronal Cobb angle, preoperative SVA, first postoperative SVA, preoperative pelvic incidence-lumbar lordosis, first postoperative pelvic incidence-lumbar lordosis, preoperative lumbar lordosis, first postoperative lumbar lordosis, change in lumbar lordosis, total osteotomies, number of 3-column osteotomies, American Society of Anesthesiologists grade, estimated blood loss, operative time, age, and body mass index. Linear regression analysis was chosen

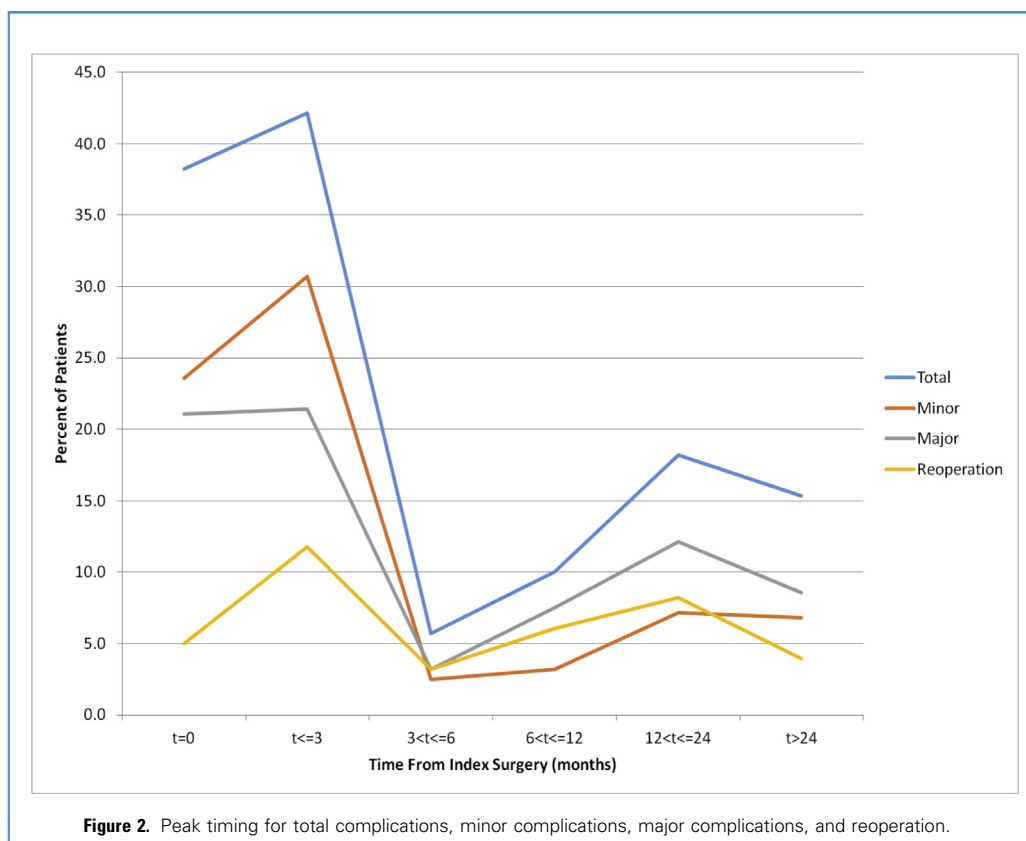
for this analysis because it was possible for patients to have multiple complications of the same type within the same time period. For example, it was possible for a patient to have multiple wound infections within the <3 -month time period. Linear regression analysis was best able to capture this particular nuance in the data. After division by time point and complication type, there was some attrition in complication data points. No regression analyses were performed for complications/time points with an occurrence equal to zero. Predictor variables which did not have a significant independent effect on each specific complication type/time point were excluded from reporting.

RESULTS

In total, 450 patients underwent surgery for ASD and were eligible for the study, with 297 having complete data for analysis. Of these, 280 patients met the study inclusion criteria and were therefore included. The mean age of the cohort was 57.6 years (range, 18.6–84.4 years), with a mean follow-up of 2.9 years (range, 2–5 years).

Of the 280 patients, 74.6% ($n = 209$) had at least 1 complication. There were 29 (10.4%) patients who had an infection complication, 60 (21.4%) who had a neurologic complication, 37 (13.2%) with PJK, and 42 (15.0%) with implant failure. A total of 79 patients (28.2%) had a complication that required surgical treatment over the course of the study period (Table 1). Numerous patients had >1 complication, and some patients experienced multiple instances of the same complication (e.g., infection). Of





the 54 infection complications, 35 (64.8%) required surgical treatment, compared with 30% (21/70) of the neurologic complications, 40.5% (17/42) of the PJK complications, and 49.0% (24/49) of the implant failure complications (Figure 1).

There were 529 total complications identified, including 258 minor and 271 major complications. One hundred and fifty-three (28.9%) complications occurred at $t < 3$ months, 204 (38.6%) complications occurred at $t < 3$ months, 25 (4.7%) complications occurred at $t = 3-6$ months, 33 (6.2%) complications occurred at $t = 6-12$ months, 63 (11.9%) complications occurred at $t = 12-24$ months, and 51 (9.6%) complications occurred at $t > 24$ months (Table 1).

Peak Timing

Major and minor complications peaked at $t < 3$ months (Figure 2). Return to the operating room peaked at $t < 3$ months, with 56 complications requiring surgical treatment, which was most commonly because of infection (44 of 56 complications).

Infection complications peaked at $t < 3$ months, accounting for 81.5% (44/54) of total infections. Neurologic complications peaked at $t = 0$ and $t < 3$ months, accounting for 68.6% (48/70) of total neurologic complications. PJK had bimodal peaks at $t < 3$ months and $t > 24$ months, accounting for 30.0% (13/42) and 23.8% (10/42) of cases, respectively. Implant failure peaked at $t = 12-24$ months and $t > 24$ months, with 83.7% (41/49) of implant failures occurring after 1 year (Figure 3).

Linear regression analysis revealed significant correlations between preoperative SVA and total complications at $t = 6-12$

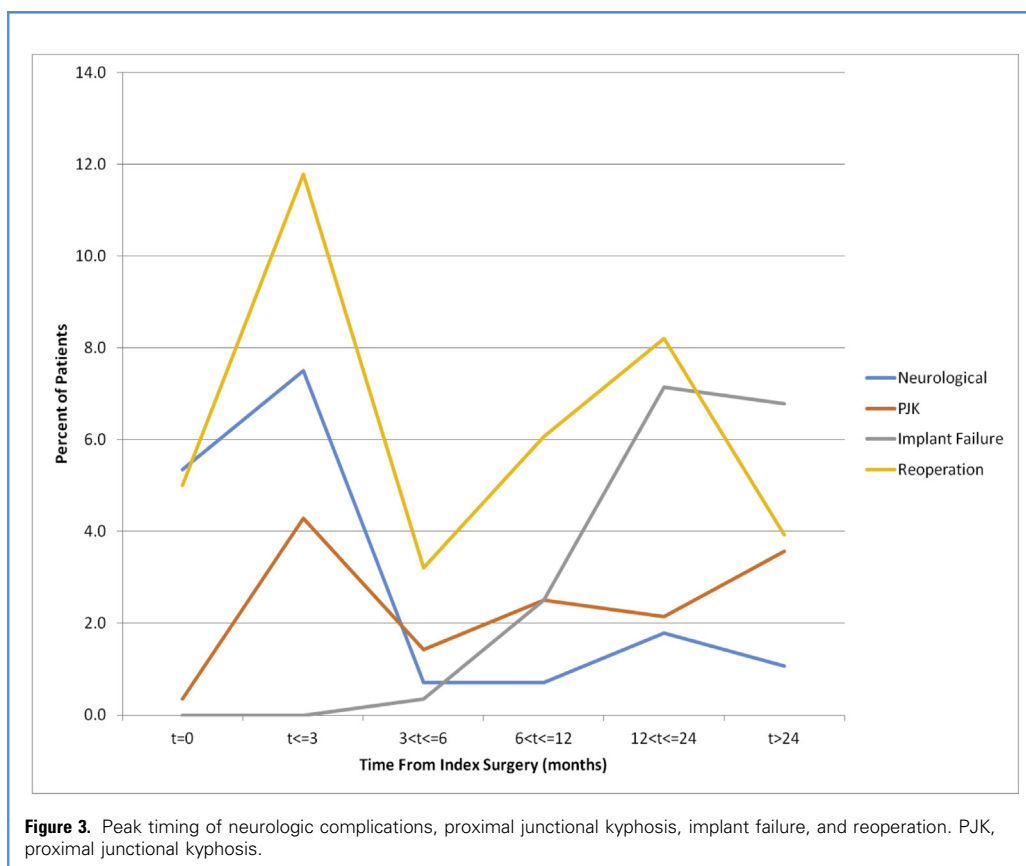
months ($R^2 = 0.018$; $P = 0.0246$), implant failure at $t = 6-12$ months ($R^2 = 0.035$; $P = 0.0017$), total complications at $t = 12-24$ months ($R^2 = 0.024$; $P = 0.0093$), minor complications at $t = 12-24$ months ($R^2 = 0.015$; $P = 0.0382$), major complications at $t > 24$ months ($R^2 = 0.023$; $P = 0.0110$), reoperation at $t > 24$ months ($R^2 = 0.026$; $P = 0.0070$), and implant failure at $t > 24$ months ($R^2 = 0.019$; $P = 0.0228$).

DISCUSSION

The peak timing of specific complications after ASD surgery is identifiable. This study found that both major and minor complications peaked at < 3 months; however, PJK and implant failure had additional peaks after 1-year follow-up. These data will help inform surgeons and patients regarding the risks associated with ASD surgery.

Surgeons should be aware of the peak timing for the occurrence of these complications to facilitate patient counseling, improve patient care, and properly inform patients for consent. Furthermore, payers are moving toward bundled payment models^{12,14,16}; therefore, understanding when complications occur, and their incidence rates, are essential to inform payers and those that negotiate with payers so that appropriate reimbursement models can be developed.

Complications after spine surgery are costly.^{11,17} For example, Yeramani et al.¹¹ found that the direct costs to treat ASD postoperative infections range from \$15,817 to \$38,701, whereas Daniels et al.¹⁷ reported an increase of up to 4.3 times the cost



of an uncomplicated index surgery over 3-month follow-up for deep vein thrombosis after spine surgery.

Although not all complications after ASD surgery can be predicted, some that are may also be preventable. Recent advances in preoperative, intraoperative, and postoperative strategies have led to a decrease in certain complication rates. A prime example is the decrease in intraoperative bleeding because of advances in anti-fibrinolytic administration protocols.^{10,20-23} Similarly, with the advent of routine intrawound vancomycin powder placement, infection rates after ASD surgery have decreased.²⁴⁻²⁷ Godil et al.²⁸ estimated that use of topical vancomycin powder will result in a cost savings of \$433,765 per 100 posterior spinal fusions. Additionally, instrumentation advances including outrigger or satellite rod placement have decreased the rate of rod fracture.²⁹ Finally, optimizing sagittal alignment has continued to advance, and ongoing efforts to determine optimal alignment goals are being developed and will likely decrease the rates of alignment failure and PJK.^{20,30-34}

Several additional potentially important clinical implications can be examined with this data. For example, assessing the timing of neurologic complications may assist in prevention efforts. Most neurologic complications in this series were noted intraoperatively and in the 3-month postoperative window. These largely represent intraoperative nerve root injuries and neuro-monitoring alerts and postoperative radiculopathy and weakness in the perioperative period. No complete spinal cord injuries

occurred in this cohort. Careful intraoperative techniques and response to neuromonitoring alerts may assist in lowering these rates. Late neurologic deficits, which were related to PJK and were less common, may be prevented with modern advanced PJK prevention strategies, such as ligamentoplasty and cement augmentation.

Linear regression analysis revealed significant positive correlations between preoperative SVA and total complications at 6–12 months and reoperation rate and major complications at >24-month follow-up, highlighting the impact of high SVA in the development of complications. R^2 values of these models are generally small; therefore, only a small percent of the variability in reoperation and complication rates can be explained by preoperative SVA alone. There are likely multifactorial effects that are not completely captured in this analysis. Additionally, there may be variables which are not included in the linear regression models, such as patient frailty and surgeon experience, that might explain more variability of the dependent variables. Given these findings, surgeons who treat spinal deformity should consider counseling patients with high SVA regarding a higher likelihood of immediate and delayed complications. Interestingly, no significant correlation was found between delayed PJK (>24 months) and any variables tested, highlighting the need for further dedicated research to assess risk factors for delayed PJK.

This study has several potential limitations. First, as a retrospective analysis, this study is at risk for all of the biases

inherent to observational studies, including selection bias, information bias, and confounding. Second, we assessed ASD patients as a group, and previous studies have shown that complication rates vary based on patient and surgical factors. Therefore, future studies may further examine peak timing of complications, taking into account additional factors such as patient frailty, surgeon experience, and surgical invasiveness. Furthermore, there is the potential for selection bias because only patients with 2-year follow-up were included in this study, and those with shorter follow-up or those lost to follow-up may have differing complication profiles compared with the study population. Finally, no detailed assessment of complication magnitude was included, aside from the delineation of minor versus major complications. Some complications may lead to severe deviations in treatment and recovery, whereas others will

have minimal impact. Further research into the long-term effects of complication magnitude is warranted and could examine complication clustering and the effect of complications on quality-adjusted life years. Despite these limitations, this study is an important initial investigation and provides baseline data for future studies. Such data may ultimately help payers, and those negotiating with payers, better understand the expected rate and timing of complications after ASD procedures. This information may be applicable when assessing appropriate reimbursement rates and policies, especially in the presence of perioperative complications.

This study examined the peak timing of complications after ASD surgery and provides valuable data regarding the expected complication rate and timing of adverse events after ASD surgery for patients, surgeons, and payers.

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