Clinical Series

The Seattle Spine Team Approach to Adult Deformity Surgery: A Systems-Based Approach to Perioperative Care and Subsequent Reduction in Perioperative Complication Rates

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Abstract

Study Design: Retrospective consecutive case review pre- and postintervention.
Objectives: Characterize the effects of the intervention.
    Summary of Background Data: Complication rates in adult spinal deformity surgery are unacceptable. System approaches are necessary to increase patient safety. This group reported on the dual–attending surgeon approach, a live multidisciplinary preoperative screening conference, and the intraoperative protocol for the management of coagulopathy. The outcomes were demonstrated by complication rates before and after the institution of this protocol.
Methods: Forty consecutive patients in Group A were managed without the 3-pronged approach. A total of 124 consecutive patients in Group B had a dual–attending surgeon approach, were presented and cleared by a live multidisciplinary preoperative conference, and were managed according to the intraoperative protocol.
Results: Group A had an average age of 62 years (range, 39–84 years). Group B had an average age of 64 years (range, 18–84 years). Most patients in both groups had fusions from 9 to 15 levels. Complication rates in Group B were significantly lower (16% vs. 52%) (p < .001). Group B showed significantly lower return rates to the operating room during the perioperative 90-day period (0.8% vs. 12.5%) (p < .001). Group B also had lower rates of wound infection requiring debridement (1.6% vs. 7.5%), lower rates of deep vein thrombosis/pulmonary embolism (3.2% vs. 10%), and lower rates of postoperative neurological complications (0.5% vs. 2.5%) (not significant). Group B had significantly lower rates of urinary tract infection requiring antibiotics (9.7% vs. 32.5%) (p < .001).
Conclusions: These data suggests that a team approach consisting of a dual–attending surgeon approach in the operating room, a live preoperative screening conference, and an intraoperative protocol for managing coagulopathy will significantly reduce perioperative complication rates and enhance patient safety in patients undergoing complex spinal reconstructions for adult spinal deformity.
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Keywords: Complications; Adult; Deformity; System; Approaches

Introduction

    Complications in complex spinal reconstructive surgery in adults are a frequently observed phenomenon [1-8]. The surgical literature contains several reports that document blood loss exceeding a patient's baseline total estimated blood volume sustained during a corrective spinal fusion for scoliosis [9-12]. With the increasing frequency of complex reconstructive surgery for adult spinal deformity,

the same phenomenon is being described in this decade [13-16]. Rampersaud et al. [17] studied intraoperative adverse events and related postoperative complications in spine surgery and found an adverse incidence rate of 10.2%. As the evidence mounts that standardized protocols for high-risk spine surgery patients can reduce complications [18-20], spine surgeons are faced with an increasing need to develop strategies and protocols aimed at reducing risk and increasing patient safety. This need is perhaps nowhere greater than in surgical procedures that propose to correct adult spinal deformities, arguably some of the most dangerous and complication-ridden operations in the surgical armamentarium [3,6,21-27].

To date, many strategies are in use to attempt to reduce perioperative complications in adult deformity surgery. These include better preoperative planning strategies, the use of intraoperative vancomycin, and staging [19,28-33]. Although there are isolated strategies for reducing complications, few centers have studied institutional team protocols and their effect on mitigating complications.

The authors' center changed its approach to adult spinal deformity surgery owing to internal assessment of the complication rates. This approach centers on the use of a live multidisciplinary complex spine conference to assess appropriateness of the proposed surgery. Two attending surgeons are used in the operating room, to increase efficiency and shorten surgical time. The third tenet of the approach uses an intraoperative protocol to manage coagulopathy. This article describes this 3-pronged protocol and tests the hypothesis that the institution of this protocol will lead to a decrease in the incidence of perioperative complication rates.

Methods

Before instituting a major spine protocol, the attending spinal surgeon would see and book any major spine case. The case was not required for presentation in front of a live multidisciplinary spine conference. In addition, treatment could be done with a physician's assistant or a resident instead of 2 attending surgeons. There was no intraoperative protocol to manage or track coagulopathy, and each treatment would be done with an anesthesiologist who was assigned on the day of surgery. A team of complex spine anesthesiologists dedicated to complex adult spinal surgery did not exist. The major spine protocol that was developed is described in this article in preoperative, intraoperative, and postoperative phases. The surgeons in both arms of the study are the same.

Major Spine Protocol

Preoperative

Patients referred to the authors' surgical spine clinic who appear to have scoliosis as an underlying diagnosis have a standard set of preoperative studies, including 36-inch anteroposterior and lateral spine films, as well as a dedicated lumbar spine X-ray with flexion-extension views. Patients with symptoms of radiculopathy or neurogenic claudication will also have magnetic resonance imaging of the lumbar spine. Radiographic evaluation includes measurement of sagittal and coronal balance, pelvic parameters, and Cobb angles of major and/or minor curves [34]. A computed tomography scan of the spine and a dual-energy X-ray absorptiometry scan are ordered for potential operative patients. An Oswestry Disability Index and European Quality of Life-5 Dimensions (EQ-5D) questionnaire are obtained for all preoperative patients [35-39].

A patient will enter the researchers' major spine pathway (MSP) by either meeting any of the following criteria: 6 or more levels of fusion; 6 or more hours of case duration; spinal deformity surgery, and/or surgeon expertise deeming the surgery to be sufficiently complex; and significant comorbidities in the cardiac, pulmonary, hemostatic, or neurologic systems. The authors characterize a spinal deformity as scoliosis, kyphosis, or flat-back or any revision case that requires at least 6 levels of fusion. All MSP patients are presented at a monthly conference attended by an internist, a physical medicine and rehabilitation physician, at least 2 members of the dedicated complex spine anesthesiology team, the nurses who coordinate the complex spine patient class, and the operative surgeons. The anesthesiologists and internist review each patient's history and medical issues before the conference. A written summary of the patient's past medical history, relevant laboratory values, screening tests (electrocardiogram, echocardiogram, etc) is then generated and sent via secure e-mail to the conference participants.

Discussion for each patient focuses on both the proposed surgical correction and the preoperative and postoperative medical issues relevant to the patient. Approximately 25% of patients presented at the conference have medical conditions rendering them unsuitable for the extent of surgical treatment proposed; thus a nonoperative plan is generated [40]. Some patients require medical optimization or further studies before a final decision can be made. The surgeon conveys the result of the conference to the patient.

Once a patient has been presented at the conference and deemed a surgical candidate, the surgeon will order any remaining studies described previously, if not already completed. All surgical patients attend a 2-hour class run monthly by clinic nurses and 1 of the spinal deformity surgeons that focuses on the postoperative recovery period and allows for a question-and-answer session. All patients are then engaged in a consent process that includes a discussion of risks including bleeding, infection, proximal junctional kyphosis, rod/hardware failure, postoperative neurologic injury, stroke, death, and blindness during spine surgery [3,41-44].

All patients with normal preoperative coagulation and hematologic panels have 6 U of packed red blood cells and 2 U of thawed plasma typed and crossed. If abnormalities

in hematocrit or coagulation are discovered, additional workup involving internal medicine and hematology (if indicated) are completed.

After preliminary clearance by the conference, an internist performs a thorough preoperative evaluation. The need for further cardiac evaluation for these patients is based on American College of Cardiology/American Heart Association guidelines for perioperative risk stratification [45]. Pulmonary function tests are obtained preoperatively as indicated [46].

All MSP patients have their analgesia managed postoperatively by the Acute Pain Service (Fig. 1), run by the Department of Anesthesiology. The Acute Pain Service in the preoperative area interviews patients to understand their baseline pain and therapy, and to develop a postoperative plan. The attending anesthesiologists who run the pain service and supervise their residents and fellows are closely involved with the complex spine team, and therefore are well aware of the unique issues of the patients as well as the importance of early mobilization and communication with members of the daily rounding primary spine team.

Before starting surgery, the surgeon contacts the intensivist who will be accepting the care of the postoperative patient. This discussion serves to alert the intensivist to the presence of the patient, pre-exisiting comorbidities, and the expected surgical course. After surgery, the intensivist will receive an updated patient status directly from the anesthesia team.

Intraoperative

Figure 2 depicts the operating room layout. In addition to the standard operating room team, MSP calls for 2 attending surgeons working in tandem; the current practice typically includes a neurosurgeon and orthopedic surgeon with specialized spine training. Both surgeons are viewed as equal members of the surgical team rather than having primary or secondary roles [33]. The researchers also use a 2-member anesthesia team and a dedicated anesthesia technician.

Pre-operative
- Determine current analgesic regimen; convert to IV morphine equivalents
- Patient should take all normally prescribed analgesics up to the surgery (including morning of surgery)
- Determine preoperative pain score (VAS)
- Consider multimodal regimen:
  - gabapentin 900 mg PO
  - acetaminophen 975 mg PO (take note of other acetaminophen containing analgesics that may be taken proximately by the patient to avoid overdose)

Intraoperative
Consider ketamine 0.5 mg/kg bolus followed by 0.1 mg/kg/hr (lean body mass) infusion
Consider long acting opioid titration towards the end of surgery

Post-operative
Patient controlled analgesia (PCA)
- >36 mg IV morphine or equivalent per day:
  - Consider 50% baseline hourly requirement for baseline infusion
  - Demand dosing can commence at 1-2 mg morphine IV q 8 minutes
- >50 mg IV morphine or equivalent per day:
  - Consider continuing ketamine at 0.05-0.1 mg/kg/hr

On post-operative day (POD) 1:
- Wean IV opioid basal infusion and ketamine (if applicable)
- Start long acting enteral opioid (oxycodone ER or morphine ER)
- Can continue with demand dose IV PCA

On POD 2:
- Wean all IV opioids

Other Considerations:
- Consider continuous pulse oximetry.
- For muscle spasms consider baclofen 5-10 mg PO TID prn or diazepam 1-2 mg IV TID prn
- Transfer care back to the primary spine service when patient on stable oral analgesic regimen

Fig. 1. Pain management pathway of major spine patients. IV = intravenous; VAS = visual analog scale; PO = orally; q = every; ER = extended release; TID = 3 times a day.
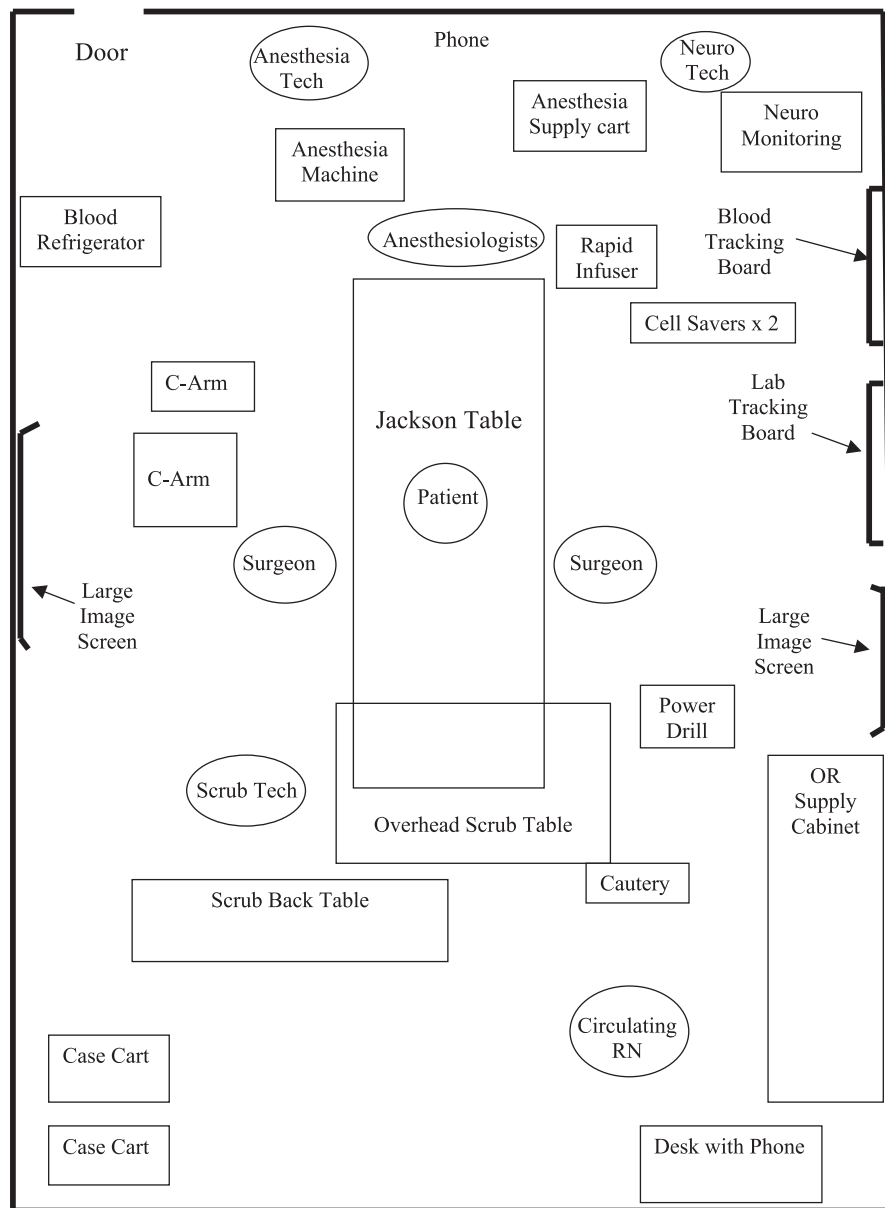
Fig. 2. The operating room standard layout for a complex spine procedure. The layout provides zones of operation for the surgeons and scrub technicians, circulating nurse, anesthesia team, and neuromonitoring team. The walls have 2 large-image screens for projection of radiologic studies. The blood-tracking and laboratory value−tracking boards allow visual summaries of the patient's status for all to see. These boards allow step-by-step clear communication and facilitate decision making during critical hourly team discussions. Neuro Tech = neurological technician; Neuro Monitoring = neurological monitoring; Scrub Tech = scrub technician; OR = operating room; RN = registered nurse.

In addition to a standard operating room setup, the MSP calls for a blood-tracking board (Fig. 3) and laboratory-tracking board (Fig. 4), which allows the entire operating team to view at a glance the status of coagulation and physiologic laboratory parameters as well as blood product availability. A rapid infuser (Belmont Instruments, Billerica, MA), 2 cell saver units (1 for each surgeon), and a Masimo pulsoximeter (Masimo Corporation, Irvine, CA) with plethysmographic variability index as well as real-time hemoglobin measures [47] and a bispectral index monitor are used.

After induction and central line placement by anesthesia, neuromonitoring leads are placed. It is the authors' standard practice to monitor somatosensory evoked potentials, motor-evoked potentials, and lower extremity electromyography [48-51]. After lead placement, the patient is placed in a Mayfield head holder on a Jackson table [44,52-54].

For cases that will involve a pedicle subtraction osteotomy or fusion extending from the upper thoracic spine to the pelvis, the procedure is planned as a staged operation if the physiological parameters of the patient require this. This decision is made after close discussion with the

Time	Suction Canister	Cell Saver EBL	Field Irrigation	Total EBL	Hct	pH / BE	PT / INR	Platelet Count	Fibrinogen D-Dimer
9:00	N/A	N/A	N/A	N/A	33	7.38/-2.9	13.7/1.1	108	798/2.74
10:03	550	100	0	650	30	7.35/-4.5	14.2/1.1	100	647/2.65
11:00	650	550	0	1200	29	7.38/-3.6	15.3/1.2	95	497/2.94
12:00	800	1250	0	2050	31	7.34/-4.2	16.4/1.3	90	411/2.92
13:04	1300	1700	0	3000	21	7.31/-4.8	18.1/1.5	110	335/2.93
14:01	1500	2000	0	3500	31	7.30/-4.5	17.3/1.4	125	280/3.95
15:05	1600	2200	0	3800	29	7.33/-4.1	17.0/1.4	103	290/7.49

Fig. 3. Example of the visual control for laboratory values and estimated blood loss (EBL). Hourly calculation of blood loss [(suction canister + cell saver canister) − irrigation] and key acid-base, red blood cell, and coagulation parameters are displayed. N/A = not available; Hct = hematocrit; BE = base excess; PT = prothrombin time; INR = international normalized ratio.

anesthesiologist based on hourly time points. The primary stage is intended to place most or all of the required instrumentation, whereas the second stage is reserved for the correction and final fixation in cases where the entire operation cannot be safely completed in 1 sitting. The time between scheduled stages is typically 3 to 4 days. In these staged patients, a removable inferior vena cava filter is placed and scheduled for removal 6 to 12 weeks after completion of the surgical procedure [55,56]. Inferior vena cava filters are placed only in patients whose surgery would be staged on different days. All patients are given subcutaneous heparin at 5,000 U, 3 times a day, on postoperative day 1. The researchers routinely ambulate patients between the first and second stages. The practice of inferior vena cava filter placement and the use of subcutaneous heparin were the same in the protocol and no-protocol groups.
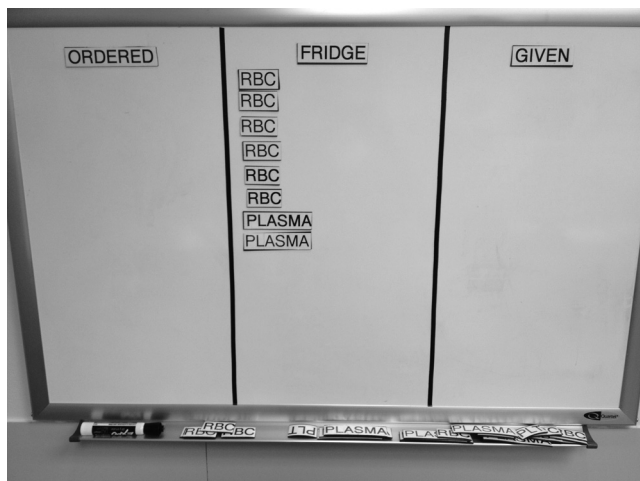

Fig. 4. The blood-tracking board at the beginning of the case. Per protocol, 6 U packed red cells (RBC) and 2 U thawed plasma are in the refrigerator in the room. Thawed plasma is available to avoid delay in the case of progressive consumptive coagulopathy. As units are administered, the corresponding magnet is moved to the Given column. If additional blood products are ordered, additional magnets representing the units ordered are added to that column. When the ordered product arrives in the room and placed in the refrigerator, the corresponding magnet is move to the Fridge column. Thus, visual control of the status of all blood products is provided to the team.

Blood product use during major spine surgery is routine and usually commences before evidence of laboratory derangement. Typically, the authors start to transfuse packed red blood cells after estimated blood loss greater than 250 mL in any case in which they plan to complete the entire operation on the same day. This is different from most surgeries that have ongoing blood loss, where laboratory values are measured and replenished with the appropriate blood product. For plasma, the current authors transfuse after 1 to 2 U red blood cells or an international normalized ratio (INR) greater than 1.2. Although not fully characterized, the authors have observed that waiting until the INR is greater than 1.5 to institute plasma or a hematocrit less than 25 leaves the patient in a precarious situation that is associated with amounts of subjective bleeding as well as laboratory derangements that are difficult to correct, such as the INR. The etiology of coagulopathy during major spine surgery is unknown and likely represents both a dilutional as well as consumptive element [57].

Laboratory measures are done hourly, including arterial blood gas, hemoglobin and hematocrit, platelet count, prothrombin time and INR, fibrinogen, D-dimer, ionized calcium, and lactate. Working with the laboratory, the authors established a rapid turnaround for these laboratory values (20 minutes); results are called into the room as they are made available. The values are then transcribed onto a large laboratory tracking board mounted in the operating room. Once all laboratory values for that hour have returned, the surgical team and anesthesiology team pause, the current physiologic state as well as progress in surgery and any challenges in either are reviewed, and a decision is made to proceed or to stage the surgery. Figure 3 demonstrates an example of the laboratory and estimated blood loss results for a patient.

Postoperative

Near the conclusion of the surgery, the anesthesiologist contacts the intensivist to give a person-to-person report of the events of surgery and blood loss and the physiologic state of the patient. Extubation is routinely attempted in the operating room. The researchers rarely keep patients

intubated and transport to the intensive care unit. Patients are observed overnight in the intensive care unit with strict control of hematocrit, coagulation factors, and platelet count. The vast majority of patients can be transferred to a general care floor on postoperative day 1. They are mobilized with physical therapy over the next 1 to 3 days and are discharged to home or a skilled nursing facility between days 4 and 6.

Outcome measures

Before 2009, 40 consecutive patients underwent complex spine without MSP (no-protocol group). In 2010 to 2011, 124 consecutive patients were completed with MSP (protocol group). All patients in this study were followed postoperatively by an independent research team at the Group Health Research Institute, who examined medical records and readmission data for 90 days from the date of surgery. Measures included return to operating room, wound infection, thromboembolic complications, postoperative neurologic deficit including stroke, urinary tract infection, and mortality. Comparison between pre-MSP and post-MSP patient outcomes were made with Student t test.

Results

The no-protocol group (pre-MSP) had a mean age of 62 years (range, 39 to 84 years) that was similar to the protocol group's mean of 64 years (range, 18 to 84 years). Overall complication rates in the protocol group were significantly lower, with a total complication rate of 16%, versus the no-protocol group's total complication rate of 52% ($p < .001$). The protocol group showed significantly lower return rates to the operating room during the perioperative 30-day period (0.8% vs. 12.5%; $p < .001$). The protocol group also had lower rates of wound infection requiring debridement (1.6% vs. 7.5%), lower rates of deep vein thrombosis/pulmonary embolism (3.2% vs. 10%), and lower rates of postoperative neurological complications (0.5% vs. 2.5%), although these measures did not reach statistical significance. The protocol group had dramatically lower rates of urinary tract infection requiring antibiotics (9.7% vs. 32.5%; $p < .001$) (Table 1).

Table 2 lists the demographics and surgical approaches used in each group. The table demonstrates that anterior approaches were more represented in the no protocol group and minimally invasive (MIS) lateral approaches for anterior fusion were more common in the protocol group. The protocol group had a greater number of 3-column osteotomies (not significant).

Table 3 shows specific reasons for return to the operating room within 90 days of the index operation. The postoperative day for each event (calculated as the number of days from the index procedure) is also shown. None of the cases in Table 3 had anterior or MIS lateral approaches. All wound infections were posterior.

Discussion

The results of this study indicate that a concerted collaborative approach consisting of a dual–attending surgeon team, a complete preoperative screening process, and a robust intraoperative protocol for managing coagulopathy can significantly reduce perioperative complication rates and enhance patient safety in patients undergoing complex spinal reconstructions for adult spinal deformity. Other institutions have described the need for organized system processes [18] to diminish the significant risk associated with these surgical procedures [6,58,59], but to our knowledge the current report is the first analysis of system approaches and their direct effect at reducing this extreme risk of complications.

The primary strengths of this study lie in the standardized nature of the protocol described and the breadth of factors that it covers. All patients who were enrolled in the major spine pathway had minimal variability in surgeons, preoperative clearance protocol, intraoperative anesthetic team, and postoperative management. The intraoperative protocol for managing coagulopathy has likewise been standardized across the institution and is not subject to variation between anesthesiologists.

To our knowledge this is the first study to describe the use of a multidisciplinary live preoperative conference to clear adult deformity patients for surgery. The author'group previously reported that approximately 25% of patients presented here [40] were not deemed suitable candidates for major reconstructions owing to pulmonary and cardiac co-morbidities. Conference discussions are predicated on the belief that both non-surgeon members (eg, internal medicine, anesthesia) and surgeon members of the committee have equal power to decide the suitability of a case; yet this flexibility to remove politics and economic incentives from the discussion may not be applicable to all institutions.

Coagulopathy is a ubiquitous phenomenon in adult spinal deformity surgery, but only a few protocols have been offered to track and manage this vexing problem [9,12-15,57]. The authors describe a clear and robust protocol to manage intraoperative coagulopathy during advanced spinal reconstructive surgery. Their experience also demonstrated that the success of this protocol depends

Table 1
Spine team approach.

	No protocol (%)	Protocol (%)	p
Overall complication rate	52	16	$<.001$
Return to the operating room	12.5	0.8	$<.001$
Wound infection	7.5	1.6	NS
Deep vein thrombosis/pulmonary embolism	10	3.2	NS
Postoperative neurologic deficit	2.5	0.5	NS
Urinary tract infection	32.5	9.7	$<.001$

NS = not significant.

Table 2

Demographics and surgical approaches of protocol and no-protocol groups.

	No protocol	Protocol	p
	N=40	N=124	
Age, mean	62	64	1.0
Levels fused, mean	11	13	.92
Anterior and posterior approaches, n (%)	10 (25)	12 (10)	.029
Posterior alone (TLIF) with Smith Petersen osteotomies, n (%)	30 (75)	93 (75)	1.0
Lateral (XLIF) + posterior, n (%)	0	19 (15)	.004
Cases staged on different days, n (%)	10 (25)	31 (25)	1.0
Three-column osteotomies, n (%)	3 (7.5)	19 (15)	.29

TLIF = Transforaminal Lumbar Interbody Fusion; XLIF = minimally invasive extreme lateral interbody fusion.

on institutional administrative support in addition to approval from anesthesiology, surgical services, and the institutional blood bank.

Tables 2 and 3 demonstrate the surgical characteristics and specific complications of each group. Both groups had a similar number of cases that were staged on different days. Whereas the no-protocol group had more anterior surgery, it had fewer cases in which a 3-column osteotomy was used. The protocol group had more lateral surgery, but it also had a higher number of more complex osteotomies that are more prone to complications. Nevertheless, the protocol group had had far fewer complications owing to the standardized system processes espoused by this analysis.

One of the significantly reduced complications was that of urinary tract infection. There was no difference in the handling of urinary catheters during the entire study period. The authors believe that the significantly reduced urinary tract infection rate in the protocol group demonstrates improved mobilization, which is a surrogate measure of overall complications.

One weakness of this study deals with the composition of the 2 groups. Because the study involved a lengthy time period, the authors have seen a shift away from traditional

Table 3

Reasons for return to operating room within 90 days of index operation, and postoperative day.

No-protocol group
Irrigation and debridement of wound infection, POD 13
Irrigation and debridement of wound infection, POD 23
Irrigation and debridement of wound infection, POD 17
Neurological deficit requiring hardware revision (extruded TLIF graft), POD 1
Leg pain caused by pedicle screw breach, POD 3
Protocol group
Neurological deficit caused by stenosis at L3 PSO closure site, POD 1

POD = postoperative day; PSO = Pedicle Subtraction Osteotomy; TLIF = Transforaminal Lumbar Interbody Fusion.

anterior surgery, as has been seen at many centers owing to the described morbidity of the anterior approach [60-64]. The authors think that the team approach espoused by this analysis clearly demonstrates improvement in perioperative complication rates. Decreased anterior approaches could certainly add to this phenomenon, but they cannot solely be responsible for the significant improvement in perioperative complication rates.

This study had several additional weaknesses, the first of which arises from the incentive structure for the physicians involved in the study. All physicians at the authors' medical center are paid a salaried wage. This freedom from direct financial reimbursement could present a bias toward conservatism in case selection. This weakness may also limit the applicability of this protocol to institutions that are reimbursed directly by case volume. Second, the researchers have found that organizing and running a live multidisciplinary preoperative screening conference requires protected time for physicians, which may not be a feasible option at all institutions. They think that such a conference will happen if it is part of a required checklist to proceed to complex spinal surgery. Third, the current coagulopathy protocol requires obtaining hourly intraoperative laboratory values, which adds a moderate cost to an already expensive surgical procedure and suggests the need for institutional support that is willing to absorb these costs. This financial requirement may therefore limit the ability to adopt this protocol at all institutions. Although the up-front costs of instituting the entire protocol will be high, the authors hypothesize that significant cost savings and increased patient safety will occur in the long run as fewer expensive complications leading to hospital readmission are encountered. Further economic data are under review by the current research team; a detailed analysis of this will be forthcoming. Either way, the authors of this article believe that increasing costs up front to standardize protocols will increase patient safety with adult spinal deformity patients undergoing surgery. It is their hope that further analyses such as this one will be published, stressing protocol and improved patient safety. Such an analysis can be directly given to the hospital administrator as justification for increased resources.

Finally, a central tenet of the authors' approach is that the team protocol carries weight over the individual, and thus all surgeons and anesthetists adhere to the uniform protocols described here when performing complex spine cases. This uniformity may not be possible in an institution in which there are a large number of department members with varying seniority, and may also therefore interfere with resident and fellow education. The authors are affiliated with a large tertiary care academic medical center in which residents are an integral part of the curriculum. Orthopedic or neurosurgical residents are welcome to scrub adult spinal deformity cases with the understanding that the protocol calls for 2 attending surgeons in any case that fits MSP criteria. The authors recommend an approach as detailed by Ames et al. [33] in a large training institution

for highly complex cases such as those involving pedicle subtraction osteotomy.

Current rates of complications in adult spinal deformity surgery remain unacceptably high, and system approaches can reduce complications and mitigate risk. To our knowledge this is the first study demonstrating the positive effect of a live multidisciplinary preoperative conference, a dual−attending surgeon approach in the operating room, and a thorough intraoperative protocol for the management of coagulopathy and resulting significant reduction of perioperative complication rates.

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