Impact of a Perioperative Protocol on Length of ICU and Hospital Stay in Complex Spine Surgery

Eugenia Ayrian, MD, Shihab H. Sugeir, MD,* Anush Arakelyan, MPH,† Dimiter Arnaudov, MD,* Patrick C. Hsieh, MD,† Jeremy V. Laney, MD,* Peter Roffey, MD,* Thang D. Tran, MD,* Chelsia L. Varner, MD,* Kevin Vu, MD,* Vladimir Zelman, MD,* and John C. Liu, MD†*

Background: In an attempt to improve patient care, a perioperative complex spine surgery management protocol was developed through collaboration between spine surgeons and neuroanesthesiologists. The aim of this study was to investigate whether implementation of the protocol in 2015 decreased total hospital and intensive care unit (ICU) length of stay (LOS) and complication rates after elective complex spine surgery.

Materials and Methods: A retrospective cohort study was conducted by review of the medical charts of patients who underwent elective complex spine surgery at an academic medical center between 2012 and 2017. Patients were divided into 2 groups based on the date of their spine surgery in relation to implementation of the spine surgery protocol; before-protocol (January 2012 to March 2015) and protocol (April 2015 to March 2017) groups. Outcomes in the 2 groups were compared, focusing on hospital and ICU LOS, and complication rates.

Results: A total of 201 patients were included in the study; 107 and 94 in the before-protocol and protocol groups, respectively. Mean (SD) hospital LOS was 14.8 ± 10.8 days in the before-protocol group compared with 10 ± 10.7 days in the protocol group ($P < 0.001$). The spine surgery protocol was the primary factor decreasing hospital LOS; incidence rate ratio 0.78 ($P < 0.001$). Similarly, mean ICU LOS was lower in the protocol compared with before-protocol group (4.2 ± 6.3 vs. 6.3 ± 7.3 d, respectively; $P = 0.011$). There were no significant differences in the rate of postoperative complications between the 2 groups ($P = 0.231$).

Conclusion: Implementation of a spine protocol reduced ICU and total hospital LOS stay in high-risk spine surgery patients.

Key Words: complicated spine, high-risk spine, intraoperative protocol, perioperative care

(*J Neurosurg Anesthesiol* 2019;00:000–000)

Vertebral abnormalities resulting in low back pain and neurological deficits are a major health care issue. Low back pain is the most common health problem worldwide, affecting about 80% of people at some point in their lifetime.[1] It is the second most common cause of adult disability in the United States, with greater prevalence than heart conditions, stroke, and cancer combined.[1] Over the last 20 years, complex spine surgery procedures have increased significantly (from 1.3 to 19.9 per 100,000 population receiving Medicare in the United States) and this has been associated with increased resource utilization and 30-day mortality.[2] Increasing spine surgery complexity is also associated with a higher rate of perioperative complications; life-threatening complications occur after 2.3% of spinal decompression surgeries compared with 5.6% after complex fusions.[2]

Given the complex nature of many spine surgery procedures, effective communication within the multidisciplinary team plays an important role in improving patient outcomes. In addition to the combined efforts of spine surgeons and anesthesiologists, complex spine procedures require coordinated input from preoperative consulting specialists, intraoperative neuromonitoring technicians, critical care specialists, cell salvage technicians, blood bank specialists, and nursing teams. Although protocol-based medicine has been criticized for impeding independent thought and clinical expertise, it can provide a framework for preventing many quantifiable mistakes and communication failures, thereby improving quality of care[3] and decreasing perioperative morbidity and mortality.[4] There are a number of existing publications that describe the benefits of perioperative care pathways in complex spine surgery.[5,6] Some also include prehabilitation which has been shown to

Received for publication August 28, 2018; accepted July 11, 2019.
From the Departments of *Anesthesiology; and †Neurosurgery, Keck School of Medicine, University of Southern California, Los Angeles, CA.
Study was presented under the name: "Protocolized Perioperative Care for Complex Spine Surgeries and the Resulting Reduction in ICU/Hospital Length of Stay" at: (1) American Society of Anesthesiologists (ASA) Annual Meeting in San Francisco, October 13, 2018 (Session EA-19-1). (2) SNACC Annual Meeting in San Francisco on October 12, 2018.
The authors have no funding or conflicts of interest to disclose.
Address correspondence to: Eugenia Ayrian, MD. E-mails: eayrian@med.usc.edu; eugenia.ayrian@gmail.com.
Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website, www.jnsa.com.

DOI: 10.1097/ANA.0000000000000635

accelerate restoration of baseline functional capacity after surgery,[7,8] reduce postoperative complications,[8,9] and decrease in-patient costs.[10]

Considering the complexity of many spine procedures and the necessity of improving patient care at our institution we implemented a perioperative protocol for patients undergoing complex-risk/high-risk spine procedure in April 2015 (Supplemental Digital Content 1, http://links.lww.com/JNA/A192); this was developed using evidence-based recommendations.[1,4,5,11–17]

The elective spine surgery protocol included guidelines for preoperative optimization, intraoperative anesthetic and fluid/transfusion management, laboratory utilization, and transfer of care to the intensive care unit (ICU) team after surgery. Preoperative optimization was aided by the establishment of bimonthly interdisciplinary meetings including anesthesiologists, neurosurgeons, orthopedic spine surgeons, ICU physicians, hospitalists, and acute pain management specialists. Trauma spine surgeries were not specifically addressed in the protocol, although anesthesiologists could utilize its intraoperative management component as required.

Creating and implementing the perioperative spine protocol allowed standardization of patient management during elective complex spine surgeries across all anesthesia providers in our institution. To evaluate the effectiveness of such standardized anesthetic care, we performed a retrospective cohort analysis before and after implementation of the complex spine surgery protocol. We hypothesized that instituting the protocol would decrease total hospital and ICU length of stay (LOS), and complication rates.

MATERIALS AND METHODS

Following institutional review board approval, a retrospective cohort study was performed to evaluate the effectiveness of implementing a high-risk spine surgery protocol (Supplemental Digital Content 1, http://links.lww.com/JNA/A192). The medical records of patients who underwent complex-risk/high-risk elective spine procedures at Keck Medical Center of the University of Southern California between January 2012 and March 2017 were reviewed. Inclusion criteria were ≥ 1 of the following: surgery involving >6 vertebral levels; expected surgery duration >6 hours; predicted blood loss >2 L; combined anterior and posterior approach (patients undergoing minimally invasive 1-level or 2-level fusion procedures were not included); staged procedure; procedure classified as high risk by the spine surgeon; patients with significant comorbidities, and; patients over 70 years of age. Significant comorbidities were defined as: coronary artery disease, pulmonary disease resulting in functional impairment (severe chronic obstructive pulmonary disease, pulmonary fibrosis), liver disease, end-stage renal disease, and preexisting coagulopathies. All patients with coronary artery disease were excluded except those who were symptom-free patients or had undergone revascularization within the last 5 years.[11] In addition to the above variables, data were also collected on: patient demographics, American Society of Anesthesiologists physical status class, number of spine levels operated upon, fusion, tumor, staged procedure, number of stages, and use of intraoperative and postoperative blood products. Trauma patients were not included in the study, and all surgeries were elective.

Patients were divided into 2 groups based on the date of their complex spine surgery. The before-protocol group included consecutive cases operated between January 2012 and March 2015; patients received individualized care at the discretion of the treating anesthesiologist. The protocol group included consecutive patients operated between April 2015 and March 2017 who received anesthesia care according to the complex spine surgery protocol. The same anesthesiologists cared for all patients in both groups, that is, before and after protocol implementation. Operating surgeons, ICU physicians, and hospitalist were also the same during the study period.

The primary outcome of the study was hospital LOS, which was measured from the day of the initial surgery to discharge regardless of the date of hospital admission. Secondary outcomes were ICU LOS, number of complications during the postoperative hospital stay and 30-day mortality. Postoperative complications were defined as any occurrence of postoperative hypotension requiring vasoactive medications (phenylephrine infusion ≥ 50 mcg/min or norepinephrine infusion of ≥ 3 mcg/min), hemorrhagic/hypovolemic shock, respiratory failure (unpredicted inability to extubate at the end of the case, prolonged intubation for >24 hours postoperatively, and unexpected postoperative reintubation in the ICU), pneumonia, sepsis, acute myocardial infarction, cardiogenic shock, cardiac arrest, significant arrhythmia (supraventricular tachycardia, atrial fibrillation, heart block), venous thromboembolism (deep venous thrombosis and pulmonary embolism), acute kidney injury, liver failure, ileus, delirium, or stroke.

Statistical Analysis

A power analysis for the primary outcome (hospital LOS) was calculated. For a 2-tailed Wilcoxon-Mann-Whitney test for equal groups with equal SDs, to detect 0.4 effect size at 5% significance level 104 patients per group were required to achieve 80% power. In our case we had 94 patients in the protocol group, however, the results of the study are positive, making the power analysis less of a concern.

Data are presented as mean and SD, median and range, or frequency as appropriate. LOS data are generally right skewed (as were ours) and ordinary linear regression cannot adequately handle such data. Alternative approaches to analysis of LOS data involve normality-improving data transformations, Poisson regression, or negative binomial regression.[18] No simple data transformations improved normality sufficiently for us to use linear regression in our analyses. Furthermore, besides being right skewed, LOS data can sometimes be overdispersed where Poisson may not sufficiently explain all of the variance. For those cases, negative binomial, a more general version of Poisson, is more commonly used because it generates more accurate results by explaining more of the variance. Therefore, because our data were right skewed and overdispersed we used negative binomial regression in our analysis; the negative binomial regression was truncated at 0 since no patients had a LOS of 0 days. We used multivariate negative binomial regression to assess how a number of independent variables, including the complex spine protocol, affected hospital LOS. Initially, a univariate negative binomial test was performed for each independent variable. Subsequently, we developed a multivariate model including all the significant predictors from the univariate analyses, as well as important demographic variables that were not significant in the univariate analysis (age, sex). All data analyses were performed using STATA, v14.2 (StataCorp LLC, College Station, TX).[19]

RESULTS

A total of 658 patients underwent spine procedures at Keck Medical Center between January 2012 and March 2017. Of these, 201 patients underwent a major spine surgery as defined by our inclusion criteria; 107 patients (mean age: 63 ± 12, 37.4% male) were included in the before-protocol group and 94 (mean age: 65 ± 15, 42.6% male) in the protocol group. Patient demographics, American Society of Anesthesiologists physical status score and comorbidities are shown in Tables 1 and 2. There were no differences between the 2 groups, except that tumor etiology was the indication for surgery in more patients in the before-protocol compared with protocol group (27 [25.2%] vs. 7 [7.5%], respectively; $P = 0.001$) (Table 1).

Mean (SD) hospital LOS was lower in the protocol than before-protocol group (10 ± 10.7 vs. 14.8 ± 10.8 d; $P < 0.001$) (Table 1 and Fig. 1). The factors significantly impacting hospital LOS are shown in Table 3. The spine surgery protocol was the primary factor decreasing hospital LOS (incidence rate ratio = 0.78, $P < 0.001$). Similarly, mean ICU LOS was lower in the protocol compared with before-protocol group (4.2 ± 6.3 vs. 6.3 ± 7.3 d; $P = 0.011$ (Table 1, Fig. 2). There were no significant differences in the rate of postoperative complications between the 2 groups ($P = 0.231$). However, there was a trend towards a reduction in the rate of some complications following protocol implementation. The incidence of pulmonary complications (8.4% vs. 3.2%), respiratory failure (7.4% vs. 4.2%), sepsis (5.6% vs. 0%), wound complications (10.3% vs. 6.4%), and postoperative delirium (3.7% vs. 1%) were (not significantly) reduced after introduction of the protocol. Of note, our study was not powered to detect differences in these secondary outcomes.

We also examined early mortality because previous studies have suggested that more than half of patients who die after spine surgery do so within the first 10 days.[20] The 30-day mortality rate was 4.7% in the before protocol group in our study; 2 patients died intraoperatively following cardiac arrest secondary to hemorrhagic shock and 3 postoperatively from respiratory arrest, septic shock, and massive bleeding with disseminated intravascular coagulation. No additional patients died after hospital discharge but within 30 days of surgery. Following implementation of the protocol there were no deaths within 30 days of surgery.

DISCUSSION

Since the implementation of Early Recovery After Surgery protocols in the 1990s,[21] multimodal perioperative care pathways have proven to be effective and safe strategies. There is strong evidence that implementation of such protocols is associated with improved outcomes,

TABLE 1. Summary of All Considered Independent Variables and the Dependent Variable Hospital Length of Stay

	Total (N = 201)		Before-protocol (N = 107)		Protocol (N = 94)		
Variables	**Mean, Median (SD, Minimum-Maximum)**	**n (%)**	**Mean, Median (SD, Minimum-Maximum)**	**n (%)**	**Mean, Median (SD, Minimum-Maximum)**	**n (%)**	***P***
Age (y)	62, 65 (13, 20-87)	—	61, 63 (12, 27-83)	—	63, 65 (15, 20-87)	—	0.403
Sex (male)	—	80 (39.8)	—	40 (37.4)	—	40 (42.6)	0.455
Race (white, vs. other)	—	169 (84.1)	—	90 (84.1)	—	79 (84.0)	0.989
Comorbidities	2.7, 3 (1.3, 1-6)	—	2.8, 3 (1.2, 1-6)	—	2.6, 3 (1.3, 1-6)	—	0.189
Fusion (yes)	—	177 (88.1)	—	91 (85.1)	—	86 (91.5)	0.160
Tumor (yes)	—	34 (16.9)	—	27 (25.2)	—	7 (7.5)	0.001
Stages	1.3, 1 (0.5, 1-3)	—	1.4, 1 (0.6, 1-3)	—	1.2, 1 (0.4, 1-2)	—	0.068
Spine structures	—	—	—	—	—	—	0.674
Cervical (reference)	—	14 (7.0)	—	7 (6.5)	—	7 (7.4)	—
Thoracic	—	16 (8.0)	—	9 (8.4)	—	7 (7.4)	—
Lumbar	—	32 (15.9)	—	14 (13.1)	—	18 (19.2)	—
Multiple	—	139 (69.1)	—	77 (72.0)	—	62 (66.0)	—
1 (not staged, reference)	—	142 (70.7)	—	70 (65.4)	—	72 (76.6)	—
No. complications	0.6, 0 (1.0, 0-4)	—	0.7, 0 (1.1, 0-4)	—	0.4, 0 (0.7, 0-3)	—	0.1869
ICU length of stay	5.3, 3 (6.9, 0-56)	—	6.3, 4 (7.3, 0-49)	—	4.2, 3 (6.3, 0-56)	—	0.011
Total hospital length of stay	12.6, 9 (11, 2-85)	—	14.8, 12 (10.8, 4-70)	—	10, 8 (10.7, 2-85)	—	< 0.001

P-values are from comparisons of all variables between the 2 protocols (Mann-Whitney test, *t* test, Fisher test, or χ^2 test as appropriate).
ICU indicates intensive care unit.

TABLE 2. Summary of All Postoperative Complications and ASA Classification

	n (%)	
	Before-Protocol	Protocol
ASA classification (N)		
ASA I	0	1
ASA II	19	21
ASA III	82	65
ASA IV	6	7
Complications		
Wound complication (CSF leak, infection, dehiscence, hematoma)	11 (10.3)	6 (6.4)
Respiratory failure	8 (7.4)	4 (4.2)
Pulmonary complications (pneumonia, pleural effusion, tracheal fistula)	9 (8.4)	3 (3.2)
Deep venous thrombosis/pulmonary embolism	6 (5.6)	5 (5.3)
Septic shock/hypovolemic shock	6 (5.6)	0 (0)
Delirium	4 (3.7)	1 (1)
Acute kidney disease	4 (3.7)	1 (1)
Cardiac arrhythmia (supraventricular tachycardia, arterial fibrillation, heart block, etc.)	4 (3.7)	4 (4.2)
Cardiopulmonary arrest	3 (2.8)	1 (1)
Gastrointestinal complications (ileus, percutaneous endoscopic gastrostomy)	3 (2.8)	2 (2.1)
Hardware-related complications	3 (2.8)	0 (0)
Electrolyte disbalance/fluid overload	3 (2.8)	2 (2.1)
Urinary tract infection	2 (1.9)	2 (2.1)
Anemia	2 (1.9)	0 (0)
Death	5 (4.7)	0 (0)
Intraoperative death	2 (1.9)	0 (0)
Stroke	1 (0.9)	0 (0)
Hypotension requiring vasopressors	1 (0.9)	0 (0)
Cardiogenic shock	0 (0)	1 (1)
Peripheral nerve injury (BUE weakness, L LFCN numbness, neuropraxia)	1 (0.9)	3 (3.2)
Liver failure	1 (0.9)	0 (0)
Urinary retention	0 (0)	1 (1)
CNS injury (subarachnoid hemorrhage, etc.)	1 (0.9)	1 (1)
Myocardial infarction	1 (0.9)	0 (0)
Gluteal myositis	0 (0)	1 (1)
Acute bilateral visual loss (resolved)	0 (0)	1 (1)

ASA indicates American Society of Anesthesiologists; BUE, bilateral upper extremities; CNS, central nervous system; CSF, cerebrospinal fluid; L LFCN, left lateral femoral cutaneous nerve.

including reduction in hospital LOS, decreased perioperative complications, and earlier return to normal activity.[12] Prior reviews in the high-risk spine surgery population also suggest the potential for perioperative protocols to decrease LOS[10,22] and postprocedure morbidity and mortality,[23] as well reduce costs and improve patient welfare.[10,22,24] Our study supports these previous findings.

When complex spine procedures were first undertaken at our institution the overall cancellation rate on the day of surgery was high (7.93% between 2012 and 2014 compared with 6.08% after protocol implementation), postoperative complications were common, and ICU and hospital LOS were high (median: 6.3 and 14.8 d, respectively). Recognizing the need to improve the care of patients undergoing complex spine procedures we created and implemented a perioperative management protocol. Implementation of the protocol led to a decrease in ICU and hospital LOS by a median of 2.1 and 4.8 days, respectively. Males tended towards a longer overall hospital LOS compared with females. Some of the factors that influenced hospital LOS in our study were unsurprising, including multistaged procedures and site of surgery (thoracic or multilevel). However, these findings should be interpreted with caution as the study was not powered to identify such differences. Implementation of the protocol did not reduce postoperative complications, although there was a nonsignificant trend towards lower rates of some complications following implementation of the protocol.

Although the 2 groups in our study were generally well-matched, the number of patients undergoing spine surgery for tumor resection was lower in the protocol compared with before-protocol group. Given the retrospective nature of our study, it was impossible to ensure parity between the 2 groups with regard to presurgical etiology. Further investigation is required to evaluate this particular group of high-risk spine surgery patients.

The protocol was initially created by neuroanesthesiologists and subsequently discussed with neurosurgeon and orthopedic spine surgeon, as well as other relevant specialists including acute and chronic pain physicians, ICU specialists and hospitalists. Once agreed by these stakeholders, the protocol was distributed among all participating anesthesiologists, residents, nurse-anesthetists, pain specialists, and ICU physicians before its implementation. When complex spine surgeries where scheduled, a spine team anesthesiologist was assigned to that operating room to ensure adherence to the protocol and effective communication within the team.

Initially, we experienced some difficulties with implementation of the protocol. For example, it was difficult to schedule visits in the preoperative clinic in a timely fashion. This was resolved by conducting an initial evaluation as soon as a decision to operate was agreed between surgeon and patient; this initial evaluation being undertaken by nurse practitioners in the preoperative clinic. In addition, collaboration with the blood bank was initially challenging because of previously established red cell transfusion triggers and blood product ratios to prevent potential coagulopathies. However, after discussions with hematologists and blood bank personnel the transfusion protocol was amended (Supplemental Digital Content 2, http://links.lww.com/JNA/A193); cryoprecipitate to thawed plasma ratios were increased to maintain adequate fibrinogen level[25–27] and decrease the volume of the transfusion.[28] Further modifications to the overall protocol have been implemented after completion of this study and based on its findings. These include, but are not limited to, broadening the inclusion criteria for protocol implementation to patients with estimated blood loss > 1 L or 25% of total blood volume, instead of 2 L. We have also implemented stricter time guidelines for preoperative evaluation, such as referring patients for nutritional screening and pain management review at least

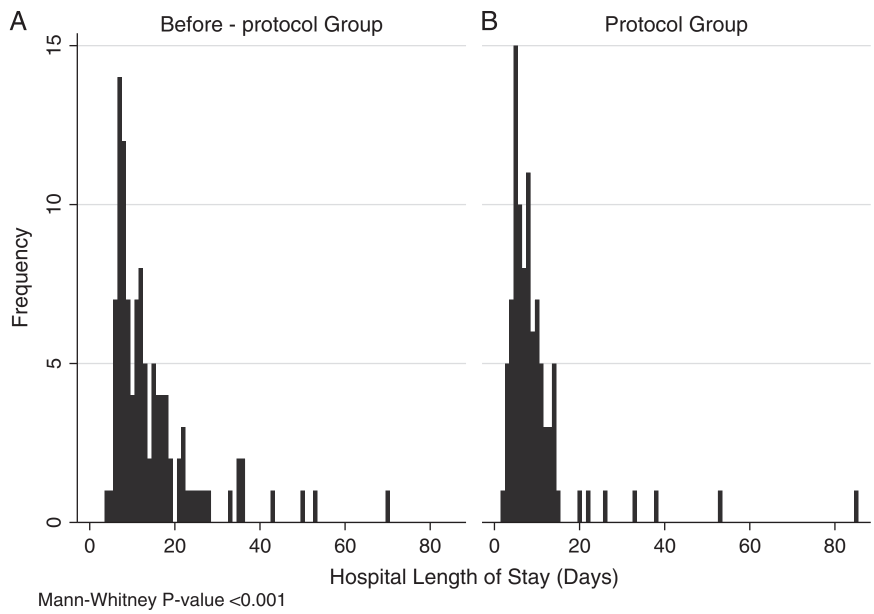

FIGURE 1. Hospital length of stay of 2 cohorts of patients who underwent complex spine surgeries between 2012 and 2017: median days before and after implementation of a perioperative management protocol. A: before protocol group versus, B: protocol group (n = 107); $P < 0.001$.

6 weeks before surgery, scheduling the visit to the preoperative clinic at least 4 weeks in advance, and discussing cases at the multidisciplinary conference at least 2 weeks before surgery. Patients are also prescribed an individualized preoperative multimodal analgesia regimen to begin 3 days before surgery.

It is important to highlight that the effectiveness of the spine protocol would likely be greatly reduced if patient care was delivered in a fragmented manner, with limited or poor communication between specialties. Previous studies have investigated implementation of Early Recovery After Surgery protocols for other surgical specialties and have shown adoption rates as low as 65%.[29] To maximize the effectiveness of perioperative protocols, complete buy-in by individuals in multiple specialties and across hospital departments is required. We believe that implementation of the spine protocol at our institution was successful in part because of continuous communication amongst all providers, especially at biweekly meetings and in the operating room.

TABLE 3. Results of Multivariate Negative Binomial Regression of Hospital Length of Stay on All Significant and Important Independent Variables (N = 201)

		95% CI		
Variables	**IRR**	**LL**	**UL**	***P***
Protocol	0.78	0.68	0.89	< 0.001
Length of ICU stay	1.05	1.04	1.06	< 0.001
Age	1.00	0.99	1.00	0.828
Sex (male)	1.15	1.01	1.32	0.038
Comorbidities	0.99	0.94	1.05	0.824
Tumor (yes)	1.06	0.89	1.27	0.507
Spine structures (cervical as reference)				
Thoracic	1.89	1.33	2.70	< 0.001
Lumbar	1.31	0.94	1.81	0.110
Multiple (thoracic and lumbar)	1.53	1.14	2.06	0.005
Stages (nonstaged as reference)				
2	1.24	1.06	1.45	0.006
3	2.70	1.81	4.02	< 0.001
No. complications	1.05	0.97	1.13	0.231

CI indicates confidence interval; IRR, incidence rate ratio; LL, lower level; UL, upper level.

Preoperative Management

The basis of our protocol, and ultimately the foundational elements for its outcomes, is a multidisciplinary perioperative care strategy and improved communication between providers. In the preoperative setting, in addition to surgical assessment, patients are evaluated by anesthesiologist and consulting specialists to assess for significant comorbidities. The patient is optimized medically, made aware of the surgical plan and risks, and evaluated for blood conserving strategies if appropriate (eg, embolization of hypervascularized lesions and blood salvage). Enhanced communication between specialties first takes place at the preoperative multidisciplinary high-risk spine conference, where individual cases are discussed and finalized; it is at this meeting where the decision is made to proceed with or reschedule surgery. Of note, surgeries were never cancelled because of a patient's medical condition although some were postponed to optimize it. This might have played a role in the decrease in ICU and hospital LOS that we observed following introduction of the protocol.

Intraoperative Management

Interdisciplinary communication also serves as the foundation of excellent intraoperative management. The

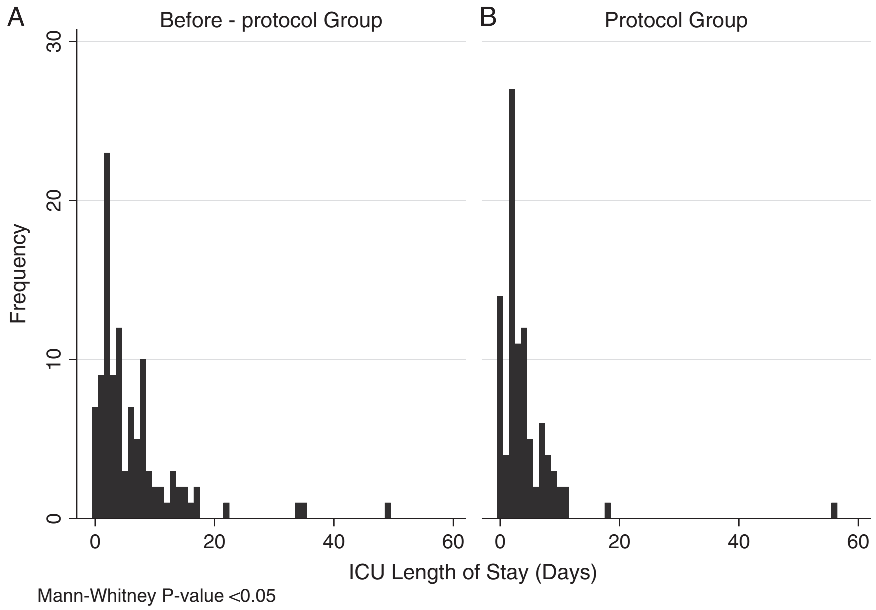

FIGURE 2. Intensive care unit (ICU) length of 2 cohorts of patients who underwent complex spine surgeries between 2012 and 2017: median days before and after implementation of a perioperative management protocol. A: before protocol group versus, B: versus protocol group (n = 107); $P < 0.001$.

anesthesiologist, surgeon, and neuromonitoring team communicate throughout the surgery with regard to changes in a patient's condition, expected blood loss, and management strategies. Anesthetic management for the majority of cases in this study involved general anesthesia with the avoidance of nondepolarizing neuromuscular blocking agents to preserve neuromonitoring capabilities. It has previously been shown that total intravenous anesthesia is superior to volatile anesthetics when neuromonitoring is required.[30] Although volatile agents are acceptable in concentrations <0.5 minimum alveolar concentration, total intravenous anesthesia provides more reliable evoked potential monitoring. In this study, methadone (10 to 20 mg), magnesium sulfate (2 g), lidocaine (1 to 2 mg/kg/h) and ketamine (0.5 mg/kg administered preincision, then 0.25 mg/kg/h) infusions were utilized in chronic opiate users, that is, those receiving long-acting opioid pain management (including fentanyl patch, oxycontin, etc.) and having pain for > 3 months.[31] Blood pressure goals were agreed with the surgical team. In general, mean arterial pressure was maintained > 85 mm Hg in patients with cervical stenosis or cord compression, whereas those undergoing other procedures were kept normotensive (within 10% of baseline mean arterial pressure).

Our protocol incorporates a proactive approach to blood transfusion and fluid management to maintain stable hemoglobin concentration, prevent coagulopathy, and minimize the risk of postoperative visual loss[32] which is a rare but potentially catastrophic complication of high-risk spine surgeries requiring significant volume resuscitation.[14] Fluid status is continuously assessed intraoperatively. Our goal for fluid resuscitation is to optimize end-organ perfusion and tissue oxygenation guided by clinical status, avoiding strict fluid administration guidelines. Crystalloids are restricted to balanced salt-solutions with low-chloride content; chloride-rich solutions are avoided because of the risk of hyperchloremia and potential for declining renal function.[15] Albumin (5%) is used if colloids are required. Cell salvage was utilized if significant blood loss (> 500 mL) was anticipated, except in patients with malignancy or active infection (white blood cell count <10 or ongoing wound/bloodstream infection). Patients with elevated white count receiving preoperative steroids were not excluded from cell salvage in the absence of clinical signs of infection. If massive transfusion was anticipated we considered the use of tranexamic acid, fibrinogen complex, desmopressin (in patients with Von Willebrand factor deficiency or platelet dysfunction), and cell salvage or acute normovolemic hemodilution in patients refusing blood products.[16,17] A massive transfusion protocol was initiated if anticipated blood loss was > 1500 mL. The massive transfusion protocol for these procedures (Supplemental Digital Content 1, http://links.lww.com/JNA/A192) was slightly different from the blood bank's protocol (Supplemental Digital Content 2, http://links.lww.com/JNA/A193) because we believe that proactive management of coagulation is a preventive approach which requires more aggressive transfusion of blood products. The use of cryoprecipitate has been suggested as a substitution for fresh frozen plasma, which can be associated with significant volume increase in cases of multiple transfusions in complex spine procedures.[13] As a result of collaboration with the blood bank, we were able to establish new guidelines for complex spine surgeries such that the trigger to transfuse was lower than the initial recommendations, and the ratio between packed red blood cells and other products was also modified.

Postoperative Management

After complex spine procedures, all patients were transferred to the ICU for postoperative management. The first communication between anesthesiologist and ICU physician was initiated while the patient was still in surgery, with final sign-out to the ICU attending/fellow and registered nurse assuming care of the patient on transfer to the ICU. An ICU proforma detailing the planned care of the patient was completed before handover to the ICU team. Following implementation of our protocol, communication between participating teams improved and this may have had a positive impact on our perioperative outcomes, as reported in the literature.[4] Despite postoperative management not being standardized at the time of the study, we maintained a consistent level of care following complex spine procedures according to standard practice.

Study Limitations

This study has several limitations. As with all retrospective database analyses ours is subject to measurement error and recall bias. We did our best to minimize these but it remains impossible to remove them entirely. As this was a retrospective study, adherence to the protocol was also not formally checked. Nevertheless, all complex spine procedures were discussed in bimonthly spine meetings, undertaken by a group of 4 anesthesiologists who created the protocol and followed it continuously. The ICU physicians and hospitalists caring for complex spine patients postoperatively also participated in the bimonthly spine meetings, and managed patients accordingly. Despite no official protocol for postoperative management being in place at the time of the study, we achieved a consistent level of immediate postoperative care which has led to the development of a postoperative protocol; this will be incorporated into the perioperative spine protocol when finalized. We were also unable to control for all institutional issues that might affect LOS. However, we believe that no relevant changes occurred during the study period; specifically there were no institutional changes to discharge planning, number of case workers, or social workers during the study. Finally, the study was underpowered. The power analysis determined that 104 patients were required in each group but, in the event, only 94 were included in the protocol group. However, since we identified a significant difference in the primary outcome the slight underpowering of our study is of less concern.

CONCLUSIONS

Implementation of a perioperative spine surgery protocol led to an overall decrease in hospital and ICU LOS, with trends towards reduced postoperative complications. The results of this study reinforce the notion that a multidisciplinary protocolized approach to the management of complex elective spine surgery reduces patient recovery time and allows for improvement in patient outcomes. Our findings have resulted in further modifications to our protocol. Perioperative management protocols require buy-in from multiple specialties, and active engagement between teams is essential to coordinate perioperative logistics and improve efficiency. Future studies should investigate whether, or to what extent implementation of the University of Southern California spine protocol at Keck Medical Center is adopted by anesthesiology and surgery providers on a large scale.

REFERENCES

1. Ali ZS, Ma TS, Ozturk AK, et al. Pre-optimization of spinal surgery patients: development of a neurosurgical enhanced recovery after surgery (ERAS) protocol. *Clin Neurol Neurosurg*. 2018;164:142–153.
2. Deyo RA, Mirza SK, Martin BI, et al. Trends, major medical complications, and charges associated with surgery for lumbar spine stenosis in older adults. *JAMA*. 2010;303:1259–1265.
3. McGlynn EA, Asch SM, Adans J, et al. The quality of health care delivered to adults in the United States. *N Engl J Med*. 2003;348: 2635–2645.
4. Zeeni C, Carabini LM, Gould RW, et al. The implementation and efficacy of the Northwestern High Risk Spine Protocol. *World Neurosurg*. 2014;82:e815–e823.
5. Sethi RK, Pong RP, Leveque J-C, et al. The Seattle Spine Team approach to adult deformity surgery: a systems-based approach to perioperative care and subsequent reduction in perioperative complication rates. *Spine Deformity*. 2014;2:95–103.
6. Kimmel J, Musco S. How a perioperative surgical protocol improves outcomes for spine patients. Advisory Board, Research Platform. The Growth Channel; 2018. Available at: www.advisory.com/research/market-innovation-center/the-growth-channel/2018/06/spine-patient-protocol. Accessed June 6, 2018.
7. Mayo NE, Feldman L, Scott S, et al. Impact of preoperative change in physical function on postoperative recovery: argument supporting prehabilitation for colorectal surgery. *Surgery*. 2011;150:505–514.
8. Lotzke H, Jakobsson M, Brisby H, et al. Use of the PREPARE (PREhabilitation, Physical Activity and exercise) program to improve after lumbar fusion surgery for severe low back pain: a study protocol for person-centered randomized controlled trial. *BMC Musculoskeletal Disorders*. 2016;17:349.
9. Moran J, Guinan E, McCormick P, et al. The ability of prehabilitation to influence postoperative outcome after intra-abdominal operation: a systematic review and meta-analysis. *Surgery*. 2016;1260:1189–1201.
10. Dagal A, Bellabarba C, Bransford R, et al. Enhanced perioperative care for major spine surgery. *Spine*. 2018. [Epub ahead of print].
11. Cohn SL, Fernandez Ros N. Comparison of 4 cardiac risk calculators in predicting postoperative cardiac complications after noncardiac operations. *The Am J Cardiol*. 2018;121:125–130.
12. Halpin RJ, Sugrue PA, Gould RW, et al. Standardizing care for high-risk patients in spine surgery: the Northwestern high-risk spine protocol. *Spine*. 2010;35:2232–2238.
13. Treede RD, Rief W, Barke A, et al. A classification of chronic pain for ICD-11. *Pain*. 2015;156:1003–1007.
14. Lobo DN, Awad S. Should chloride-rich crystalloids remain the mainstay of fluid resuscitation to prevent 'pre-renal' acute kidney injury? *Kidney International*. 2014;86:1096–1105.
15. Qureshi R, Puvanesarajah V, Jain A, et al. Perioperative management of blood loss in spine surgery. *Clin Spine Surg*. 2017;30: 383–388.
16. Carson JL, Guyatt G, Heddle NM, et al. Clinical practice guidelines from the AABB: red blood cell transfusion thresholds and storage. *JAMA*. 2016;316:2025–2035.
17. Pendi A, Field R, Farhan SD, et al. Perioperative ketamine for analgesia in spine surgery. a meta-analysis of randomized controlled trials. *Spine*. 2018;43:E299–E307.
18. Andrei AC. Modeling hospital length of stay data: pitfalls and opportunities. *Ann Thorac Surg*. 2016;101:2426–2432.
19. StataCorp. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP; 2015.

20. Kehlet H. Multimodal approach to control postoperative pathophysiology and rehabilitation. *Br J Anaesth*. 1997;78:606–617.
21. Melnyk M, Casey RG, Black P, et al. Enhanced recovery after surgery (ERAS) protocols: time to change practice? *Can Urol Assoc J*. 2011;5:342–348.
22. Stone AB, Grant MC, Pio Roda P, et al. Implementation cost of an enhanced recovery after surgery program in the United States: a financial model and sensitivity analysis based on experiences at a Quaternary Academic Medical Center. *JACS*. 2016;222: 219–225.
23. Pumberg M, Chiu YL, Ma Y, et al. Perioperative mortality after lumbar spinal fusion surgery: an analysis of epidemiology and risk factors. *Eur Spine J*. 2012;21:1633–1639.
24. Wainright TW, Immins T, Middleton RG. Enhanced recovery after surgery (ERAS) and its applicability for major spine surgery. *Best Pract Res Clin Anesthesiol*. 2016;30:91–102.
25. Ketchum L, Hess JR, Hiippala S. Indications for early fresh frozen plasma, cryoprecipitate, and platelet transfusion in trauma. *J Trauma*. 2006;60:S51–S58.
26. Ho AM, Dion PW, Cheng CA, et al. A mathematical model for fresh frozen plasma transfusion strategies during major trauma resuscitation with ongoing hemorrhage. *Can J Surg*. 2005;48:470–478.
27. Gonzalez EA, Moore FA, Holcomb JB, et al. Fresh frozen plasma should be given earlier to patients requiring massive transfusion. *J Trauma*. 2007;62:112–119.
28. Carabini LM, Ramsey G. Hemostasis and transfusion medicine. In: Barash PG, Cullen BF, Stoelting RK, Cahalan MK, Stock MC, Ortega R, eds. *Clinical Anesthesia*, 7th edition. New York, NY: Lippincott Williams & Wilkins; 2013:408–446.
29. Maessen J, Dejong CH, Hausel J, et al. A protocol is not enough to implement an enhanced recovery programme for colorectal resection. *Br J Surg*. 2007;94:224–231.
30. Tamkus AA, Rice KS, Kim HL. Differential rates of false-positive findings in transcranial electric motor evoked potential monitoring when using inhalational anesthesia versus total intravenous anesthesia during spine surgeries. *The Spine J*. 2013;14:1440–1446.
31. Cannesson M, Pearse R. Chapter 28: Perioperative hemodynamic monitoring and goal directed therapy. In: Cannesson M, Pearse R, eds. *Theory to Practice*. Cambridge, England: Cambridge University Press; 2014:237–245.
32. Lee LA, Roth S, Posner KL, et al. The American Society of Anesthesiologists postoperative visual loss registry analysis of 93 spine surgery cases with postoperative visual loss. *Anesthesiology*. 2006; 105:652–659.

