Implementation of an Enhanced Recovery After Spine Surgery program at a large cancer center: a preliminary analysis

Roxana M. Grasu, MD,¹ Juan P. Cata, MD,^{1,5} Anh Q. Dang, MD,¹ Claudio E. Tatsui, MD,² Laurence D. Rhines, MD,² Katherine B. Hagan, MD,¹ Shreyas Bhavsar, DO,¹ Sally R. Raty, MD, MHA,¹ Radha Arunkumar, MD,¹ Yury Potylchansky, MD,¹ Ian Lipski, MD,¹ Benjamin A. Arnold, MD,¹ Thomas M. McHugh, MD,¹ Justin E. Bird, MD,³ Andrea Rodriguez-Restrepo, MD,⁶ Mike Hernandez, MS,⁴ and Keyuri U. Popat, MD¹

Departments of ¹Anesthesiology and Perioperative Medicine, ²Neurosurgery, ³Orthopedic Oncology, and ⁴Biostatistics, and ⁵Anesthesiology and Surgical Oncology Research Group, The University of Texas MD Anderson Cancer Center, Houston, Texas; and ⁶Department of Surgery, The University of Arizona, Tucson, Arizona

OBJECTIVE Enhanced Recovery After Surgery (ERAS) programs follow a multimodal, multidisciplinary perioperative care approach that combines evidence-based perioperative strategies to accelerate the functional recovery process and improve surgical outcomes. Despite increasing evidence that supports the use of ERAS programs in gastrointestinal and pelvic surgery, data regarding the development of ERAS programs in spine surgery are scarce. To evaluate the impact of an Enhanced Recovery After Spine Surgery (ERSS) program in a US academic cancer center, the authors introduced such a program and hypothesized that ERSS would have a significant influence on meaningful clinical measures of postoperative recovery, such as pain management, postoperative length of stay (LOS), and complications.

METHODS A multimodal, multidisciplinary, continuously evolving team approach was used to develop an ERAS program for all patients undergoing spine surgery for metastatic tumors at The University of Texas MD Anderson Cancer Center from April 2015 through September 2016. This study describes the introduction of that ERSS program and compares 41 patients who participated in ERSS with a retrospective cohort of 56 patients who underwent surgery before implementation of the program. The primary objectives were to assess the effect of an ERSS program on immediate postoperative pain scores and in-hospital opioid consumption. The secondary objectives included assessing the effect of ERSS on postoperative in-hospital LOS, 30-day readmission rates, and 30-day postoperative complications.

RESULTS The ERSS group showed a trend toward better pain scores and decreased opioid consumption compared with the pre-ERSS group. There were no significant differences in LOS, 30-day readmission rate, or 30-day complication rate observed between the two groups.

CONCLUSIONS An ERSS program is feasible and potentially effective on perioperative pain control and opioid consumption, and can expedite recovery in oncological spine surgery patients. Larger-scale research on well-defined postoperative recovery outcomes is needed.

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KEYWORDS enhanced recovery; spine surgery; length of stay; postoperative pain; opioid consumption; outcomes

THE concept of Enhanced Recovery After Surgery (ERAS) has emerged as a method for substantially improving postoperative outcomes.^{16–19} The principle of ERAS is modulating and minimizing the surgical stress response and the associated increases in insulin re-

sistance, hyperglycemia, and protein catabolism.^{2,5} ERAS integrates multimodal and multidisciplinary perioperative care protocols built on evidence-based perioperative care elements that individually have been shown to be beneficial in reducing the surgical stress response; when used

ABBREVIATIONS ASA = American Society of Anesthesiologists; AUC = area under the curve; DVT = deep vein thrombosis; ERAS = Enhanced Recovery After Surgery; ERSS = Enhanced Recovery After Spine Surgery; LITT = laser interstitial thermal therapy; LOS = length of stay; MEDD = morphine equivalent daily dose; MISS = minimally invasive spine surgery; NRS = numeric rating scale; POD = postoperative day; TIVA = total intravenous anesthesia.

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together in a single pathway, these individual elements can improve postoperative outcomes.²⁷ The successful implementation of an ERAS program depends on coordination between all perioperative services involved in patient care across outpatient, in-hospital, and postdischarge phases.^{11,18,40} Additionally, constant evaluation of postoperative outcomes, including pain control, length of stay (LOS), complications, readmissions, and patient satisfaction, is essential for the program's ongoing data-driven quality improvement strategies.^{1,3,6,20,25,29,32,34,40}

The volume and complexity of spine surgeries are rising worldwide.⁴⁰ Despite improvements in surgical techniques, anesthesia, and perioperative care, major spine surgery is still associated with significant morbidity and postoperative pain, decreased postoperative functional recovery, and prolonged LOS.^{3,7,15} There is increasing evidence of benefit from ERAS programs in gastrointestinal, pelvic, and orthopedic surgeries, such as hip and knee replacement, but there is little information on the development of an enhanced recovery pathway in spine surgery.^{28,40,41} Given the success of ERAS protocols in reducing morbidity and improving postoperative outcomes in other major surgeries, we hypothesized that an ERAS program tailored to patients undergoing spine surgery would have similar benefits. In our institution, we implemented a multimodal, multidisciplinary Enhanced Recovery After Spine Surgery (ERSS) program for patients undergoing spine surgery for metastatic tumors.

In this study, we reviewed postoperative outcomes before and after the implementation of ERSS. We hypothesized that the implementation of an ERSS program improved pain management, reduced postoperative LOS (a surrogate measure of postoperative inpatient recovery), and decreased the rate of postoperative complications.

Methods

ERAS Program Components

After reviewing the existing literature on successful ERAS programs and consulting with several national and international experts on ERAS, we formed a multidisciplinary ERSS committee comprising representatives in neuroanesthesia, neurosurgery, nursing, and other services, such as physical medicine and rehabilitation and nutrition. The committee developed a program built on an evidence-based approach to improve the perioperative care of patients undergoing spine surgery at The University of Texas MD Anderson Cancer Center. A standardized protocol was created to guide the perioperative management of spine surgery patients, and we prospectively collected perioperative data in a REDCap database.¹⁰

The ERSS program was introduced over several months and considered fully operational by April 2015. The committee met weekly to discuss, revise, and monitor adherence to the protocol. Although the ERSS protocol was provided to and discussed with members of all the perioperative services, the provider ultimately decided whether to deviate from the protocol if deemed necessary or clinically indicated.

The ERSS protocol (Table 1) is a comprehensive plan covering the continuum of care from preoperative prepa-

ration to intraoperative management to postoperative recovery. The preoperative protocol includes patient education, preconditioning exercise, optimization of comorbidities by the oncological primary care and specialty teams, and oral intake guidelines that allow patients to drink clear liquids up to 2 hours before the surgery. In the immediate preoperative period, patients receive oral analgesics consisting of acetaminophen (1000 mg), extended-release tramadol (300 mg), and either pregabalin (75–150 mg) or gabapentin (100–300 mg) unless administration is contraindicated. Intraoperatively, the protocol recommends 1) total intravenous anesthesia (TIVA) with bispectral index monitoring for guidance on anesthesia depth; 2) infusions of lidocaine, ketamine, and dexmedetomidine; 3) regularly scheduled intravenous acetaminophen; 4) epidural analgesia or liposomal bupivacaine for surgical wound infiltration; 5) goal-directed fluid therapy and hemodynamic optimization; 6) restrictive blood transfusion and the use of tranexamic acid; 7) risk-based antiemetic prophylaxis; 8) deep vein thrombosis (DVT) prophylaxis; and 9) maintenance of normothermia. The intraoperative surgery element evolved toward a change in practice with the development, improvement, and preferential use of minimally invasive techniques when clinically appropriate. The postoperative component includes specific guidelines for minimization of opioid consumption, DVT prophylaxis, early oral intake starting on postoperative day (POD) 1, early ambulation, and physical therapy.

Study Groups

After IRB approval, we conducted a retrospective study of consecutive patients at our institution who underwent spine surgery for metastatic tumor resection before (pre-ERSS group, or control group) and after (ERSS group) the implementation of the program in April 2015. We collected demographic and perioperative data from all patients in the study. We included patients ≥ 18 years old who underwent spine surgery for metastatic spine tumors under general anesthesia whose medical records had complete postoperative pain data. The surgery type included open surgery such as decompression, stabilization, and/or vertebrectomy, and minimally invasive spine surgery (MISS) such as transcutaneous vertebroplasty and/or stabilization. We excluded patients with primary spine tumors, emergency surgery, laser interstitial thermal therapy (LITT) procedures, or incomplete pain score data. Patients in the pre-ERSS group typically received conventional balanced general anesthesia using a combination of volatile agents, intravenous anesthetics, and infusion of opioids according to clinical judgment. Both groups had similar preoperative optimization of comorbidities, management of complications, and hospital practice/discharge criteria.

Outcome Measurement

The primary outcomes were postoperative pain scores, on a numeric rating scale (NRS) of 0–10, with 0 indicating no pain and 10 indicating the worst possible pain, and postoperative opioid consumption measured in oral morphine equivalent daily dose (MEDD). We assessed the primary outcomes for the postoperative periods of PODs

TABLE 1. ERSS versus conventional pathways

	ERSS Pathway	Conventional Pathway
Preop		
Education including guidance on prehabilitation when appropriate	General postop information (online video); additional ERSS education provided in the neurosurgery clinic, & handouts include specific information about enhanced recovery principles, patient & caregiver expectations, & opioid minimization pain management; emphasis on relevant preconditioning exercises	General postop information (online video)
Sedation & anxiety management	Consider consult for cognitive behavioral therapy, meditation, yoga, music therapy, &/or herbal/supplement use for consistently moderate MDASI, VAS, NRS scores 4–6; consider psychiatry consult first for MDASI consistently >6	Conventional anxiolytics
Pain management	Surgery preparation: Consider pain consult if anticipated difficult to control postop pain; patient on ≥ 5 opioid tablets/day; patient on long-acting opioid medication; rapidly increasing opioid requirements; pain not responsive to prescribed analgesics; patient treated by an outside pain physician; significant psychosocial distress related to pain &/or surgery; current or history of recreational drugs use. Consider starting w/ low-dose (e.g., 100 mg/daily) gabapentin for neuropathic pain & patient <65 yrs of age Day of surgery: tramadol ER 300 mg orally + gabapentin 300 mg (or pregabalin 75 mg) orally + acetaminophen 1000 mg orally upon arrival in preoperative holding area; consider decreasing dosage if patient ≥ 65 yrs old	Individual provider preference
Preop fasting	Clear liquids permissible up to 2 hrs before surgery except in cases in which there is a higher risk of aspiration (e.g., post-esophagectomy) up to 4 hrs before surgery; use carbohydrate loading guidelines	No oral intake for 8 hrs before planned surgery
Intraop		
Anesthesia & medications	IV anesthesia maximization: infusions of propofol, dexmedetomidine, ketamine, lidocaine (intent to get to TIVA); methadone (0.1–0.2 mg/kg) single upfront IV dose in opioid-tolerant patients; IV dexamethasone 10 mg every 6 hrs; consistent risk-based antiemetic, & DVT prophylaxis; emphasis on lung-protective mechanical ventilation strategies	Individual provider preference
Fluid management	Individualized goal-directed fluid therapy based on surgical & patient risk factors	Individual provider preference
Transfusion management	Minimize utilization of blood products; transfuse only if hemoglobin ≤ 9 –10 g/dl depending on comorbidities & hemodynamic stability; if utilized 2:1 prbc/ffp ratio or 1:1 for massive transfusion; consider tranexamic acid 1 g bolus over 30 min followed by 0.5 g/hr infusion; consider preop arterial embolization for high-risk bleeding tumors (renal, thyroid)	Individual provider preference
Temperature management	Constant body temperature monitoring throughout the surgery & actively attempt to keep temperature above 36°C using hot air blankets, warming mattresses, fluid warmers	Not performed w/ consistency
Surgical considerations	MISS techniques preferred when clinically feasible; emphasis on injection of liposomal bupivacaine at incision site or epidural placed under direct vision	Individual provider preference; rarely used MISS or liposomal bupivacaine
Postop		
Plastic surgery	Local flap, no restriction on ambulation	Individual provider preference
Early ambulation & PT/OT	Out of bed POD 1; movement 3 times daily, bed to chair, chair to bed at minimum assist level By discharge: ambulate at minimum assist level for 50 ft w/ or w/o an assistive device; if nonambulatory (i.e., wheelchair bound), bed to chair, chair to bed transfers at minimum assist level	Not consistently done w/ frequency
ICU/floor	Minimize ICU admissions; emphasis on extubation at the end of surgery; start incentive spirometry in PACU	Individual provider preference; patient not consistently extubated at end of surgery
Pain management (general protocol)	Gabapentin 300 mg orally every 8 hrs, celecoxib 200 mg orally every 12 hrs, tramadol ER 200 mg orally every 12 hrs, acetaminophen 1 g orally every 6 hrs, continue preop long-acting opioids plus IV PCA; cancer pain consult if pain poorly controlled, daily hydromorphone requirement >12 mg/day or morphine >60 mg/day, pain limits daily function/rehabilitation, significant psychosocial distress	Individual provider preference
Pain management (patient-specific needs protocol)	Engage pain consult service for patient-reported outcome approaching “unmanageable”; consider consult for cognitive behavioral therapy, meditation, yoga, music therapy, or herbal/supplement use for consistently moderate MDASI, VAS, NRS scores 4–6; consider psychiatry first for patient w/ MDASI consistently >6	Not traditionally used
Early oral intake	Patients allowed & begin clear liquids on day of surgery (POD 0); diet advanced as tolerated	Patients begin clear liquids on POD 1 & diet advanced as tolerated thereafter

ffp = fresh frozen plasma; ICU = intensive care unit; IV = intravenous; MDASI = MD Anderson Symptom Inventory Scale, a multi-symptom patient-reported outcome measure for clinical and research use; PACU = postanesthesia care unit; PCA = patient-controlled analgesia; prbc = packed red blood cells; PT/OT = physical therapy/occupational therapy; VAS = pain visual analog scale.

0–3 and the discharge day. The secondary outcomes were postoperative hospital LOS, hospital readmission rate, and postoperative complications. Postoperative LOS was defined as the time from completion of surgery to hospital discharge. Readmission was defined as hospital readmission for any cause within 30 days of discharge. Postoperative complications were defined as any medical or surgical complications within 30 days of surgery.

Statistical Analysis

Descriptive statistics such as the mean (standard deviation) and median (range) summarized continuous variables. Frequencies and percentages summarized categorical variables. An independent samples t-test, or Wilcoxon rank-sum test if more appropriate, was used to compare continuous variables between ERSS and pre-ERSS patients. A chi-square test, or Fisher's exact test if more appropriate, was used to compare categorical variables between ERSS and pre-ERSS patients.

Inpatient changes in pain scores were computed relative to POD 0. The absolute changes were categorized as favorable (for positive changes), neutral (for zero difference), and unfavorable (for negative changes). Because varying numbers of pain assessments were elicited from patients, both maximum and average pain scores were captured to better quantify patients' pain experiences. For pain scores and total oral MEDD measured longitudinally over time, the area under the curve (AUC) was computed for patients using the trapezoidal rule. Patients with complete information from PODs 0–3 and at discharge were used to compute the mean AUC, and mean AUCs were compared between ERSS and pre-ERSS patients. Spearman's rank correlation coefficient was used to assess the strength of association between the AUC for pain scores and the AUC for MEDD.

Because the distribution of LOS was highly skewed, a natural logarithmic transformation was applied to normalize the distribution. Linear regression was used followed by exponentiation of parameter estimates to acquire geometrical means associated with LOS. A *p* value < 0.05 was considered statistically significant, and analyses were performed using Stata software (version 13, StataCorp).

Results

Patient Population

Of the 97 patients included, 41 patients were in the ERSS group and 56 patients were in the pre-ERSS group. Relevant patient demographic characteristics are shown in Table 2. Additional surgical characteristics are displayed in Table 3. No significant differences between groups (Table 2) were identified with regard to age, gender, American Society of Anesthesiologists (ASA) class, comorbidities, or smoking status. The mean ($\pm$ SD) BMI (kg/m^2) was slightly lower in the ERSS group ($25.5 \pm 4.9 \text{ kg}/\text{m}^2$) than in the pre-ERSS group ($28.5 \pm 5.7 \text{ kg}/\text{m}^2$, *p* = 0.007). The ERSS group had a shorter surgical time (263.9 ± 128.0 min) than the pre-ERSS group (315.8 ± 152.1 min, *p* = 0.080). The percentages of patients with preoperative pain were similar between groups (90% in ERSS vs 93% in pre-ERSS, *p* = 0.644). The study surgery location and the

location of the primary tumor were heterogeneous (Table 3). With respect to surgery location, thoracic (41%), lumbar (22%), and thoracolumbar (15%) comprised the majority of locations observed. Kidney (21%), lung (18%), and breast (10%) were the most common primary tumors. The ERSS group had more breast (12% vs 8%) and lung (22% vs 16%) tumors, while the pre-ERSS group had more kidney (25% vs 15%, *p* = 0.698) primary tumors. The majority, and similar percentage, of patients in both groups had 1-stage surgery (96%) and 3 or more spine levels operated (84%). However, a significantly greater percentage of ERSS patients underwent MISS (27% ERSS vs 2% pre-ERSS, *p* < 0.001). The majority of open spine surgery categories observed included decompression only (19%), decompression/stabilization (14%), and decompression/stabilization/vertebrectomy (41%).

Adherence of Providers to the Program's Preoperative and Intraoperative Multimodal Analgesia

A higher percentage of patients in the ERSS group received preoperative nonopioid analgesics (39.0% vs 10.7%, *p* = 0.001), including gabapentinoids and tramadol. With regard to anesthetic technique, the ERSS group used TIVA at a greater rate than the pre-ERSS group (22.0% vs 7.1%, *p* = 0.050). The ERSS group also showed increased intraoperative rates of lidocaine (42% vs 14%, *p* = 0.003) and ketamine infusions (51% vs 29%, *p* = 0.023), while the frequency of dexmedetomidine use was only slightly higher in the ERSS group than in the pre-ERSS group. The percentage of patients receiving epidural analgesia was not significantly different (ERSS 9.8% vs pre-ERSS 8.9%, *p* = 1.000). However, we observed more use of liposomal bupivacaine for infiltration of the surgical wound in the ERSS group (54% vs 30%, *p* = 0.021).

Pain Scores and Opioid Consumption

Table 4 summarizes the results for the primary and secondary outcome measures. By POD 1, there was some separation between the mean pain scores of the two groups, although this difference was not statistically significant. At POD 2 (*p* = 0.065), POD 3 (*p* = 0.027), and discharge, the ERSS group had lower average pain scores than the pre-ERSS group (Table 4, Fig. 1). A similar trend was identified for maximum pain scores, but statistical significance was not achieved (Table 4, Fig. 2). The proportion of patients experiencing superior pain control was higher for the ERSS group than the pre-ERSS group. Additionally, examination of the AUC using a complete case analysis indicated that the mean AUC for the average pain score experienced was significantly lower for ERSS patients (*p* = 0.043; Table 4).

The median total MEDD (PODs 0–3) was 372.2 mg for the ERSS group and 521.5 mg for the pre-ERSS group (*p* = 0.507). Although the MEDD distribution was highly skewed and contained outliers, the ERSS patients received less total morphine. There was a significant Spearman's rank correlation (ρ = 0.47, *n* = 78, *p* < 0.001) between the AUC of average pain scores and total MEDD for PODs 0–3. Additionally, a significant Spearman's rank correlation (ρ = 0.42, *n* = 78, *p* < 0.001) between the AUC of

TABLE 2. Characteristics of study participants

Characteristic	ERSS (n = 41)	Pre-ERSS (n = 56)	p Value	Total (n = 97)
Age, yrs			0.591*	
Mean $\pm$ SD	58.8 $\pm$ 11.3	57.6 $\pm$ 10.5		58.1 $\pm$ 10.8
Median (range)	59 (28–80)	60 (31–78)		59 (28–80)
Sex, no. (%)			0.292†	
Female	19 (46.3)	20 (35.7)		39 (40.2)
Male	22 (53.7)	36 (64.3)		58 (59.8)
BMI, kg/m ²			0.007*	
Mean $\pm$ SD	25.5 $\pm$ 4.9	28.5 $\pm$ 5.7		27.2 $\pm$ 5.6
Median (range)	25.4 (15.7–38.6)	28.1 (18.8–43.9)		27.4 (15.7–43.9)
Surgical time, min			0.075§	
Mean $\pm$ SD	263.9 $\pm$ 128.0	315.8 $\pm$ 152.1		293.8 $\pm$ 144.0
Median (range)	227 (87–552)	321.5 (47–954)		275 (47–954)
Preop pain, no. (%)			0.644†	
No	4 (9.8)	4 (7.1)		8 (8.2)
Yes	37 (90.2)	52 (92.9)		89 (91.8)
ASA class, no. (%)			0.323‡	
2	1 (2.4)	1 (1.8)		2 (2.1)
3	38 (92.7)	55 (98.2)		93 (95.9)
4	2 (4.9)	0 (0.0)		2 (2.1)
Chronic cardiovascular disease, no. (%)¶			0.572‡	
No	39 (95.1)	55 (98.2)		94 (96.9)
Yes	2 (4.9)	1 (1.8)		3 (3.1)
Chronic pulmonary disease, no. (%)			0.393‡	
No	40 (97.6)	52 (92.9)		92 (94.8)
Yes	1 (2.4)	4 (7.1)		5 (5.2)
Diabetes mellitus, no. (%)			0.395†	
No	35 (85.4)	44 (78.6)		79 (81.4)
Yes	6 (14.6)	12 (21.4)		18 (18.6)
History of smoking, no. (%)			0.962†	
Current/past**	6 (14.6)	8 (14.3)		14 (14.4)
None	35 (85.4)	48 (85.7)		83 (85.6)

* t-test.

† Chi-square test.

‡ Fisher exact test.

§ Wilcoxon rank-sum test.

¶ Chronic cardiovascular disease includes myocardial infarction, congestive heart failure, peripheral vascular disease, and cerebrovascular disease.

** Past smokers were defined as those who had quit smoking within 1 year.

maximum pain scores and total MEDD for PODs 0–3 was noted. These analyses supported our finding that patients with higher pain trajectories characterized by the AUC also had higher total MEDDs (across PODs 0–3).

Length of Stay, 30-Day Readmission Rate, and 30-Day Complication Rate

Patients receiving ERSS had a geometrical mean LOS of 6.3 ± 2.2 days, while the pre-ERSS group had a slightly longer LOS of 6.8 ± 1.9 days ($p = 0.590$). The ratio of the pre-ERSS to ERSS geometrical means was approximately 1.08 (95% confidence interval 0.81–1.43) and suggests that pre-ERSS patients stayed 8% longer in the hospital on average (Table 4). ERSS patients had a slightly higher

30-day hospital readmission rate than pre-ERSS patients (14.6% vs 8.9%, $p = 0.381$; Table 4).

The 30-day complication rate was 31.7% for ERSS patients and 17.9% for pre-ERSS patients ($p = 0.113$; Table 4). The most common 30-day complications were cardiovascular (17%) and respiratory (9.7%) for the ERSS group and infectious (7.1%) and renal (5.4%) for the pre-ERSS group.

Discussion

To our knowledge, the present study is the first to report the implementation of a multimodal, multidisciplinary, enhanced recovery program for spine surgery and to describe its influence on several meaningful recovery out-

TABLE 3. Additional surgical characteristics

Characteristic	ERSS (n = 41)	Control (n = 56)	p Value	Total (n = 97)
Surgery location			0.322	
Cervical	2 (4.9)	8 (14.3)		10 (10.3)
Thoracic	17 (41.5)	23 (41.1)		40 (41.2)
Lumbar	8 (19.5)	13 (23.2)		21 (21.6)
Sacral	1 (2.4)	1 (1.8)		2 (2.1)
Cervical-thoracic	1 (2.4)	4 (7.1)		5 (5.1)
Thoracic-lumbar	9 (21.9)	6 (10.7)		15 (15.5)
Lumbar-sacral	3 (7.3)	1 (1.8)		4 (4.1)
Primary tumor location			0.698	
Breast	5 (12.2)	4 (7.8)		9 (9.8)
Lung	9 (21.9)	8 (15.7)		17 (18.5)
Kidney	6 (14.6)	13 (25.5)		19 (20.6)
Colorectal	1 (2.4)	3 (5.9)		4 (4.3)
Melanoma	3 (7.3)	2 (3.9)		5 (5.4)
Lymphoma	1 (2.4)	2 (3.9)		3 (3.3)
Malignant bone tumor	0 (0)	2 (3.9)		2 (2.2)
Other*	16 (39.0)	17 (33.3)		33 (35.9)
Staged procedure			0.636	
No	40 (97.6)	53 (94.6)		93 (95.9)
Yes	1 (2.4)	3 (5.4)		4 (4.1)
Spine levels operated			0.412	
1–2 levels	5 (12.2)	11 (19.6)		16 (16.5)
3 or more	36 (87.8)	45 (80.4)		81 (83.5)
Type of surgery			<0.001	
MISS	11 (26.8)	1 (1.8)		12 (12.4)
Open spine surgery	30 (73.2)	55 (98.2)		85 (87.6)
Decompression only	6 (14.6)	12 (21.4)		18 (18.6)
Stabilization only	0 (0.0)	1 (1.8)		1 (1.0)
Decompression/ stabilization	4 (9.8)	10 (17.9)		14 (14.4)
Decompression/ vertebrectomy	2 (4.9)	3 (5.4)		5 (5.2)
Stabilization/verte- brectomy	3 (7.3)	4 (7.1)		7 (7.2)
Decompression/ stabilization/verte- brectomy	15 (36.6)	25 (44.6)		40 (41.2)

All data given as number (percentage) unless otherwise indicated. The p value was based on Fisher's exact test.

* Of the 33, 2 were unknown and 1 was not available.

comes. We found that the patients who underwent ERSS had a trend toward better pain scores and decreased opioid consumption compared with the pre-ERSS patients. We conclude that an ERSS program is feasible and potentially effective in improving postoperative outcomes such as pain control and opioid use in oncological spine surgery patients.

In a 2016 literature review, Wainwright et al. examined the evidence to support the application of individual ERAS components and concluded that an ERAS program

could enable patients undergoing major spine surgery to recover more quickly with lower rates of morbidity and improved long-term outcomes.⁴⁰ Some recent studies^{28,41} mentioned the development of an enhanced recovery approach for spine surgery; however, they each introduced and described only one ERAS intervention, such as multimodal pain management or an improvement in surgical technique. In a retrospective study, Mathiesen et al. reported that the implementation of a comprehensive, standardized multimodal pain protocol reduced postoperative opioid consumption and opioid-related adverse events and improved mobilization after multilevel spine surgery.²⁸ In a recent case series, Wang et al. reported the development and implementation of a MISS approach as part of an action plan for the development of an ERAS spinal fusion protocol.⁴¹

Our enhanced recovery program included a multitude of perioperative interventions (Table 1). Preoperatively, patient education, defined expectations, and active patient participation were essential to the success of the program.³⁰ Additionally, we aimed to optimize preoperative pain management and reduce opioid consumption.^{4,9,14,21–23,31,35–37,39,42} Intraoperatively, anesthetic management included TIVA with propofol, dexmedetomidine, ketamine, and lidocaine infusions and scheduled intravenous acetaminophen for nonopioid analgesia.^{12,22,36,37} Other opioid-sparing pain management strategies included surgical wound infiltration with liposomal bupivacaine or epidural placement when indicated and scheduled high-dose intravenous dexamethasone to treat perioperative spinal cord edema.^{9,21,23,35,41}

To maintain intraoperative normovolemia, ERSS uses goal-directed fluid therapy.³⁹ Established guidelines for transfusion recommend only that providers avoid hemoglobin levels below 8–10 g/dl depending on comorbidities and baseline preoperative hemoglobin. Patients with vascular tumors of the spine (e.g., renal or thyroid carcinoma metastases) undergo preoperative arterial embolization as previously described^{8,24} and intraoperative tranexamic acid administration. The importance of perioperative DVT prophylaxis, timely and appropriate antibiotic administration, glucose and temperature management, and lung-protective ventilator strategies was repeatedly emphasized to the team. The technological advances and improvement in surgical techniques, and particularly the development and implementation of MISS techniques, can significantly decrease perioperative morbidity and accelerate recovery.^{38,40,41} Therefore, MISS was recommended and preferred when clinically feasible.

For postoperative analgesia, patients received intravenous patient-controlled analgesia with a gradual transition to oral analgesics as needed. Scheduled high-dose steroids were continued, and oral acetaminophen, gabapentinoids, and tramadol were administered as soon as oral intake was tolerated.³⁸ Early mobilization and diet advancement were implemented with strong support from physical medicine and rehabilitation services and from dietitians, respectively.²⁶

Our results indicated that a trend toward better postoperative pain control correlated with a downward trend in total opioid consumption in the ERSS group. Reduced

TABLE 4. Pain scores and morphine equivalent daily dose over time, LOS, 30-day hospital readmission rate, and 30-day postoperative complication rate

Variable	ERSS (n = 41)	Pre-ERSS (n = 56)	p Value	Total (n = 97)
Max pain experienced				
POD 0	n = 41	n = 52	0.832*	n = 93
Mean $\pm$ SD	5.4 $\pm$ 3.3	5.3 $\pm$ 3.2		5.3 $\pm$ 3.2
Median (range)	6 (0–10)	6 (0–10)		6 (0–10)
POD 1	n = 35	n = 54	0.456*	n = 89
Mean $\pm$ SD	4.5 $\pm$ 3.5	5.0 $\pm$ 3.3		4.8 $\pm$ 3.4
Median (range)	4 (0–10)	6 (0–10)		5 (0–10)
POD 2	n = 38	n = 54	0.216*	n = 92
Mean $\pm$ SD	4.0 $\pm$ 3.0	4.8 $\pm$ 3.1		4.5 $\pm$ 3.1
Median (range)	4 (0–10)	5.5 (0–10)		5 (0–10)
POD 3	n = 38	n = 53	0.286*	n = 91
Mean $\pm$ SD	4.0 $\pm$ 2.8	4.7 $\pm$ 3.3		4.4 $\pm$ 3.1
Median (range)	4 (0–10)	5 (0–10)		4 (0–10)
Discharge day	n = 37	n = 54	0.330*	n = 91
Mean $\pm$ SD	2.8 $\pm$ 2.9	3.5 $\pm$ 3.1		3.2 $\pm$ 3.0
Median (range)	4 (0–9)	4 (0–9)		4 (0–9)
Area under the curve	n = 34	n = 45	0.183†	n = 79
Mean $\pm$ SD	16.4 $\pm$ 9.6	19.4 $\pm$ 9.6		18.1 $\pm$ 9.7
Median (range)	15 (2–36)	20.5 (0–35)		20 (0–36)
Avg pain experienced				
POD 0	n = 41	n = 52	0.752*	n = 93
Mean $\pm$ SD	3.1 $\pm$ 2.0	3.0 $\pm$ 2.3		3.0 $\pm$ 2.1
Median (range)	3 (0–6)	3 (0–8)		3 (0–8)
POD 1	n = 35	n = 54	0.232*	n = 89
Mean $\pm$ SD	2.5 $\pm$ 2.2	3.1 $\pm$ 2.4		2.8 $\pm$ 2.3
Median (range)	2 (0–7)	3 (0–9)		3 (0–9)
POD 2	n = 38	n = 54	0.065*	n = 92
Mean $\pm$ SD	2.0 $\pm$ 1.8	2.8 $\pm$ 2.2		2.4 $\pm$ 2.1
Median (range)	2 (0–7)	3 (0–8)		2 (0–8)
POD 3	n=38	n=53	0.027*	n = 91
Mean $\pm$ SD	1.6 $\pm$ 1.7	2.6 $\pm$ 2.3		2.2 $\pm$ 2.1
Median (range)	1.5 (0–6)	3 (0–8)		2 (0–8)
Discharge day	n = 37	n = 54	0.311*	n=91
Mean $\pm$ SD	1.5 $\pm$ 1.9	1.9 $\pm$ 1.9		1.7 $\pm$ 1.9
Median (range)	0 (0–5)	2 (0–7)		1 (0–7)
AUC	n = 34	n = 45	0.043†	n = 79
Mean $\pm$ SD	8.1 $\pm$ 5.8	11.2 $\pm$ 6.8		9.9 $\pm$ 6.5
Median (range)	7.2 (0.5–21)	11 (0–27)		10 (0–27)
Total MEDD, mg				
PODs 0–3	n = 40	n = 55	0.507†	n = 95
Mean $\pm$ SD	678.9 $\pm$ 954.2	793.7 $\pm$ 727.6		745.4 $\pm$ 827.7
Median (range)	372.2 (6–5426.5)	521.5 (31–2520)		409 (6–5426.5)
LOS, days	n = 41	n = 56	0.590*	n = 97
Geometric mean $\pm$ SD§	6.3 $\pm$ 2.2	6.8 $\pm$ 1.9		6.6 $\pm$ 2.0
Median (range)	6 (1–42)	7 (1–35)		6 (1–42)
30-day readmissions, no. (%)			0.381†	
No	35 (85.4)	51 (91.1)		86 (88.7)
Yes	6 (14.6)	5 (8.9)		11 (11.3)

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TABLE 4. Pain scores and morphine equivalent daily dose over time, LOS, 30-day hospital readmission rate, and 30-day postoperative complication rate

Variable	ERSS (n = 41)	Pre-ERSS (n = 56)	p Value	Total (n = 97)
30-day complications, no. (%)¶			0.113‡	
No	28 (68.3)	46 (82.1)		74 (76.3)
Yes	13 (31.7)	10 (17.9)		23 (23.7)

Avg = average.

* t-test.

† Wilcoxon rank-sum test.

‡ Chi-square test.

§ Used owing to the skewness of the distribution of length of stay.

¶ Complications included cardiovascular, respiratory, neurological, infectious, gastrointestinal, and renal complications.

pain can increase participation in physical therapy and rehabilitation with preservation of muscle strength and decreased incidence of DVT.^{13,16} Decreased opioid use should diminish the side effects of nausea, vomiting, constipation, postoperative ileus, sedation, and respiratory depression and should render the patient more functional and willing to participate in physical therapy.^{16–19,22,28,31,42}

Postoperative hospital LOS, a secondary outcome, was chosen as a surrogate measure of postoperative inpatient recovery. In general, postprocedure recovery and early discharge are limited primarily by patient factors including age, comorbidities, severity of disease, complications, pain, opioid-related side effects, fatigue, and immobilization. LOS can also be influenced by medical facility factors, including practice style, availability of beds, and discharge policies. Thirty-day readmission rate was chosen as a measure to control for true readiness for discharge. The goal of an enhanced recovery program is to accelerate postoperative recovery by influencing all of the factors known to prolong LOS; therefore, LOS can serve as a surrogate measure for the effectiveness of such interventions.³³

Although the pre-ERSS and ERSS groups in our study had similar demographic characteristics, comorbidities, category of surgery for metastatic spine tumor, and hospital practice/discharge criteria, and despite the ERSS group having significant MISS, shorter surgical time, and better pain management, we were not able to demonstrate a significant reduction in the mean LOS, readmissions, or complications in the ERSS group. This result may be explained by several reasons. First, our study included small groups of patients. In particular, the ERSS group included only 41 patients because this represented the first assessment of our recently introduced ERSS program and patients with LITT procedures or incomplete pain score data were excluded. Second, metastatic cancer patients with advanced disease or terminal illness can have a prolonged LOS after surgery to continue cancer treatment unrelated to the surgical procedure they were admitted for; therefore it was difficult to capture the patient's true readiness for discharge after the procedure. Third, we were not able to study and control for the severity of the oncological disease. Fourth, although the minimally invasive surgical techniques, consistently applied after the development of the ERSS program, were captured in the study, we excluded the LITT

cases because the minimal invasiveness of this procedure could significantly influence the outcomes in our small-sized study. The potentially high impact of various types of MISS on the speed of recovery for these patients necessitates further research and larger-scale studies.

Success and sustainability of ERAS programs are based on level of compliance with an established protocol. Although our study indicated an increase in pre- and intraoperative multimodal analgesia in the ERSS group, the compliance rate for preoperative nonopioid analgesia (39%) and other intraoperative analgesia interventions (epidural placement) was quite low. Our preliminary data, which clearly showed differences in individual provider preference for analgesia interventions, were used to increase provider's awareness, improve communication, and reinforce group compliance with the protocol. In our institution, we have several ERAS programs in various stages of development for oncological surgery, including colorectal, pancreatic, thoracic, urological, brain, and spine. Strategies such as increased collaboration among all perioperative services, institutional leadership involvement, growing institutional electronic ERAS databases and research, periodic program assessments and newsletters, ERAS conferences, and grand rounds contribute to increase providers' awareness, participation, and compliance with the protocols. Our study served as a stepping stone for further improvement of the ERSS protocol and group compliance, identifying relevant patient and surgical variables, updating our ERSS database, and defining meaningful postoperative outcomes for future larger-scale studies.

Limitations of the Study

Due to our study's retrospective design, the results should be interpreted with caution, especially when considering the use of historical data in characterizing the pre-ERSS group. Because the ERSS program was evidence-based and directed toward constant quality improvement, we had to select our pre-ERSS group from patients treated before the implementation of the full ERSS protocol. Despite this selection criterion, some patients in the pre-ERSS group could have already received certain elements of the ERSS protocol before formalization and implementation. However, in both the pre- and postintervention groups, the metastatic type of spine surgery and

FIG. 1. Profile plots of the average pain scores across postoperative time by study cohorts (ERSS vs pre-ERSS). The pain was measured on an NRS (0–10) and postoperative time was defined across points in time, starting with day of surgery (POD 0), PODs 1–3, and day of discharge (D/C). In general, the trajectories of average pain scores display a decline on PODs 1–3 and by day of discharge. Although the findings were significant only on POD 3 ($p = 0.027$), the trajectories show more separation from POD 1 to POD 3 in favor of the ERSS group and the pain trajectory remains lower for ERSS patients from POD 1 to D/C. I bars indicate 1.96 times the standard error (SE) of the mean. Values below the graph indicate the number of patients remaining in the study at each time point.

discharge criteria in the department did not change, and the inconsistency of pain data was mitigated by our selection criteria and our ability to capture opioid consumption.

Our original query of the institutional database yielded 300 consecutive patients who had spine surgery for metastatic tumors. However, only a small number of patients within each study cohort met the inclusion criteria and provided analyzable data. Furthermore, the study describes only the first assessment of a recently implemented ERSS program. Although the number of ERSS patients was limited, patients on average were similar demographically between study cohorts. With a BMI lower than 30 kg/m² in both groups, the difference, although statistically significant, was considered too small to be clinically relevant. However, general surgical characteristics, such as type of primary tumor and magnitude of surgery, were heterogeneous. For example, more renal cancer spinal metastases in the pre-ERSS group can potentially increase the risk for bleeding and complications, and prolong LOS. Additionally, the shift in our surgical practice and emphasis on minimally invasive techniques when clinically indicated resulted in a significant percentage of ERSS patients having MISS, which can explain the decrease in magnitude of surgery and surgical time in ERSS versus the pre-ERSS group. Unfortunately, the small sample size in this study restricted our ability to conduct propensity score matching and rigorous analyses to measure the effects of ERSS while adjusting for covariates of interest.

We did not track other outcomes of enhanced recovery, such as early mobilization, recovery of bowel and urinary bladder function, or patient satisfaction, because information about specific mobilization steps, time to first meal,

FIG. 2. Profile plots of the maximum pain scores across postoperative time by study cohorts (ERSS vs pre-ERSS). The pain was measured on an NRS (0–10) and postoperative time was defined across points in time, starting with day of surgery (POD 0), PODs 1–3, and day of discharge (D/C). In general, the trajectories of maximum pain scores show slow decline over PODs 1–3, and more decline by day of discharge. Although the findings were not significant and the trajectories show little separation in ERSS vs pre-ERSS groups, the pain trajectory remains slightly lower for ERSS patients from POD 0 to day of discharge. I bars indicate 1.96 times the standard error (SE) of the mean. Values below the graph indicate the number of patients remaining in the study at each time point.

duration of urinary catheterization, and patient experience was not consistently available. Our future studies will aim to assess not only patient satisfaction and patient-reported outcomes, but also the financial impact of our accelerated recovery program compared with traditional care. We believe that the ever-changing healthcare landscape and pressure to move toward high-quality value-based care will drive the impetus for advancing programs such as ERAS, which are aimed at accelerating patients' recovery while preserving or increasing quality of care.

Although we have shown a trend toward improvement in postoperative outcomes such as pain scores and opioid use, we were unable to demonstrate a significant reduction in LOS or postoperative complications or to measure the specific impact of individual components of the program, such as the MISS. The constant quality improvement and multiinterventional nature of an ERAS program constitutes one of the most challenging aspects of research on postoperative outcomes. Larger-scale studies on individual components and well-defined postoperative recovery outcomes are needed to assess the benefits of an ERAS program for spine surgery.

Conclusions

The implementation of a multidisciplinary, evidence-based ERAS program can be associated with improved analgesia and decreased opioid consumption in the perioperative care of patients undergoing spine surgery for metastatic tumors. Although retrospective, this study represents the first evaluation of a newly developed enhanced recovery program in oncological spine surgery and serves

as a roadmap for further initiatives. More research aimed at capturing meaningful, reportable, patient-specific, and patient-reported outcomes, and larger-scale studies are needed to strengthen and validate our findings and demonstrate the benefits of the program. Our experience suggests that an enhanced recovery standardized protocol can be implemented system-wide in spine surgery. The adoption of such programs in spine surgery is feasible, can be beneficial, and should be encouraged.

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Disclosures

Dr. Rhines reports being a consultant to Stryker and Medtronic.

Author Contributions

Conception and design: Grasu, Cata, Dang, Popat. Acquisition of data: Grasu, Cata, Dang, Hagan, Bhavsar, Raty, Arunkumar, Potylchansky, Lipski, Arnold, McHugh, Rodriguez-Restrepo, Popat. Analysis and interpretation of data: Grasu, Cata, Dang, Tatsui, Rhines, Bird, Hernandez, Popat. Drafting the article: Grasu. Critically revising the article: Grasu, Cata, Dang, Tatsui, Rhines, Hagan, Bhavsar, Raty, Arunkumar, Potylchansky, Lipski, Arnold, McHugh, Bird, Popat. Reviewed submitted version of manuscript: Grasu, Cata, Dang, Tatsui, Rhines, Hagan, Bhavsar, Raty, Arunkumar, Potylchansky, Lipski, Arnold, McHugh, Bird, Rodriguez-Restrepo, Popat. Approved the final version of the manuscript on behalf of all authors: Grasu. Statistical analysis: Hernandez. Administrative/technical/material support: Rodriguez-Restrepo, Hernandez. Study supervision: Grasu, Popat.

Correspondence

Roxana M. Grasu: The University of Texas MD Anderson Cancer Center, Houston, TX. rgrasu@mdanderson.org.