Enhanced Recovery After Surgery (ERAS) for Spine Surgery: A Systematic Review

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Key words
- ERAS
- Enhanced recovery after surgery
- Fast-track recovery
- Laminectomy
- Spine surgery

Abbreviations and Acronyms
ERAS: Enhanced recovery after surgery
ERSS: Enhanced recovery after spine surgery
LOS: Length of stay
MIS: Minimally invasive surgery
NSAID: Nonsteroidal antiinflammatory drug
OFA: Opioid-free analgesia
POD: Postoperative day
TIVA: Total intravenous anesthesia
TLIF: Transforaminal lumbar interbody fusion

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■ BACKGROUND: **Enhanced recovery after surgery (ERAS) represents an evidence-based multidisciplinary approach to perioperative management after major surgery that decreases complications and readmissions and improves functional recovery. Spine surgery is a traditionally invasive intervention with an extended recovery phase and may benefit from ERAS protocol integration.**

■ METHODS: **We analyzed the use of ERAS in spine surgery by completing a search using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and the PICOS (Participants, Intervention, Comparison, Outcomes, Study Design) model through PubMed and Ovid databases to identify studies that fit our search criteria. We assess the outcomes and ERAS elements selected across protocols as well as the study design and internal validation methods.**

■ RESULTS: **A total of 19 studies met the inclusion criteria and were used in our analysis. Patient populations differed significantly across all 4 studies. Reduction in length of stay was reported in 7 studies using the ERAS protocol. Comparative studies between ERAS and non-ERAS show improved pain scores and reduced opioid consumption postoperatively, but no differences in complications or readmissions between groups. Complication rates under ERAS protocols ranged from 2.0% to 31.7%. Significant pain reduction in visual analog scale scores was observed with 3 ERAS protocols. Direct, indirect, and total cost decreases were also observed with implementation of ERAS protocols.**

■ CONCLUSIONS: **A limited cohort of studies with significant variability in patient population and ERAS protocol implementation have evaluated the integration of ERAS within spine surgery. ERAS in spine surgery may provide reductions in complications, readmissions, length of stay, and opioid use, in combination with improvements in patient-reported outcomes and functional recovery.**

INTRODUCTION

The surgical stress response associated with major surgery describes fundamental metabolic changes that lead to increased catabolism, immunosuppression, free radical production, and hypercoagulable states.[1] These physiologic alterations have been linked to changes in organ function resulting in undesirable postoperative morbidity, complications, pain, fatigue, and extended convalescence.[1] Enhanced recovery after surgery (ERAS) attempts to decrease the surgical stress response to minimize postoperative complications and improve surgical outcomes and functional rehabilitation after major surgery.[2,3] Implemented for a wide range of surgical procedures, including colorectal, breast, abdominal, and emergency orthopedic interventions, ERAS protocols consist of a multidisciplinary evidence-based approach to perioperative counseling and nutrition and alternative approaches to anesthesia and analgesia.[2-4] A hallmark of ERAS is coordination between care services before and after surgery and continual evaluation of postoperative course with attention toward pain control, functional recovery, and patient satisfaction to improve standards of care.[5,6] ERAS has been shown to lessen likelihood of complications,[4,7-12] decrease length of stay (LOS),[4,8,9,11,13] and improve pain scores postoperatively.[10] Decreased length of index hospital stay, complications, and readmissions show the economic benefit of ERAS regimens. Recent studies have reported individual payment reductions after colorectal surgery with ERAS versus non-ERAS protocols ranging from $920 to $2619[14] and €153 to €6537.[15]

Spine surgery represents a typically invasive intervention with a protracted recovery phase that often requires rehabilitation and intensive postoperative pain management. Given the benefits of ERAS to decrease complications and improve patient-reported physiologic and psychological states, its incorporation into spine surgery represents a natural transition. In addition, anticipated increases in annual cases of spine surgery from an aging population portends increasing volume of spine surgery.[16] Quantitative quality measures such as patient-reported outcomes have emerged as an objective and increasingly used metric to evaluate surgical success by way of measuring postoperative pain, functional ability, and quality of life after spine surgery.[17-19] Standardization of ERAS for spine surgery may benefit such patient-reported outcomes, enhance surgeon and patient decision making, and optimize the rehabilitative course.[20] In addition, complications after spine surgery have been reported to be present in 16.4%[21] to as high as 80% of cases for complex spine surgery.[22,23] Opportunities for improved outcomes and decreased complication rates also make spine surgery an appropriate setting for ERAS development.

The present study represents a systematic review of the implementation of ERAS in spine surgery. Because of the recent introduction of ERAS to neurosurgery, a consensus has not yet been reached for evidence-based recommendations of ERAS. The ERAS Society publishes guidelines for different disciplines and procedures but has yet to publish official proposals for spine surgery.[3,24] We report elements of traditional ERAS protocols and adapted techniques used across studies to evaluate potential features of future recommendations and standards of care. Further, we summarize comparisons, results, and metrics that describe the success of ERAS for intervention cohorts to describe the adaptation of ERAS to spine surgery.

METHODS

Data Extraction

We framed the search around a PICOS (participants, intervention, comparison, outcomes, study design) model to define the population of interest used for predictive model creation and study design performed to yield a comprehensive and reproducible topic search. We analyzed those articles that used intentional ERAS-directed methods in spine surgery with case series or comparative study. No reviews or meta-analyses were included.

PICOS Outline

Participants. Participants were operative adult patients ≥18 years of age undergoing spinal surgery including spinal fusion, laminectomy, laminoplasty, discectomy procedures for all indications including trauma, neoplasm, and degeneration.

Intervention. Interventions were cervical or thoracolumbar spine surgery for degenerative spondylosis, deformity, disc herniation, trauma, neoplasm, and infection with postoperative follow-up with intentional and specific incorporation of ERAS principles.

Comparison. Comparison included control, traditional surgical management, different surgical approaches, and traditional perioperative care regimens.

Outcomes. Outcomes comprised postoperative outcome measures including complications, pain scores, assessment of functional recovery, and financial assessments. Complications included major medical complications or procedure-specific complications such as wound/surgical site complications, nonwound infectious medical complications (e.g., urinary tract infection), major medical complications (e.g., stroke, myocardial infarction, and mortality), venous thrombotic events, return to operating room, and bleeding requiring a blood transfusion.

Study Design. The study design included prospective and retrospective observational studies.

Search Criteria

We followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (2009)[25] to construct the framework of the systematic review and conducted the search on June 1, 2019 using the PubMed and Cochrane databases between 1990 and 2019. Additional articles used in the references were incorporated from the references of those article identified in the searches. We used keyword and MeSH (Medical Subject Heading) terms for ERAS to include the following terms with numbered iterations for the 2 databases as follows:

1) PubMed: ((ERAS OR enhanced recovery OR fast recovery)) AND spine surgery: 242 (17 included)

Ovid: (ERAS or enhanced recovery or fast track) AND Adult/ or Postoperative Complications AND Spine/ or Lumbar Vertebrae/ or Spinal Fusion/ or spine surgery.mp. or Cervical Vertebrae): 46 (2 included, 15 redundant)

2) PubMed ((ERAS OR enhanced recovery OR fast track recovery)) AND spine surgery: 176 (17 redundant)

Ovid: Spine/ or Lumbar Vertebrae/ or spine surgery.mp. or Cervical Vertebrae/ AND ERAS or enhanced recovery or fast recovery): 55 (15 redundant)

Risk of Bias Evaluation

Conflict of interest, funding for study, and study design were assessed according to the QUADAS criteria (Table 1).

Inclusion and Exclusion Criteria

Inclusion criteria involved studies with adult patients ≥18 years of age who underwent elective spine surgery. Randomized controlled trials and prospective and retrospective studies were included. Spine surgery for infection, deformity, trauma, neoplasm, degenerative conditions resulting in discectomy, fusion, and decompression of cervical and/or lumbar vertebrae was included. Exclusion criteria involved studies with pediatric populations and those without full text or that were not available in English. Review articles and case reports were also excluded.

Data Evaluation

We followed the QUADAS tool to evaluate risk bias and result applicability of the studies according to 2003 guidelines as shown in Table 1. A total of 13 questions on the QUADAS survey were addressed for each study incorporated into the final analysis, covering patient selection, index test, reference standard, and timing.

RESULTS

A total of 19 studies met the inclusion criteria and were used in our analysis (Figure 1).[26-44] Patient populations

Table 1. QUADAS Criteria for All Studies

QUADAS Question	Yes	No	Unclear
Was the spectrum of patients representative of the patients who will receive the test in practice?	19	0	0
Were selection criteria clearly described?	9	10	0
Is the reference standard likely to correctly classify the target condition?	19	0	0
Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?	13	0	6
Did the whole sample or a random selection of the sample, receive verification using a reference standard of diagnosis?	19	0	0
Did patients receive the same reference standard regardless of the index test result?	0	0	19
Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)?	19	0	0
Was the execution of the index test described in sufficient detail to permit replication of the test?	13	0	6
Was the execution of the reference standard described in sufficient detail to permit its replication?	13	0	6
Were the index test results interpreted without knowledge of the results of the reference standard?	0	0	19
Were the reference standard results interpreted without knowledge of the results of the index test?	0	0	19
Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	19	0	0
Were uninterpretable/intermediate test results reported?	12	0	7
Were withdrawals from the study explained?	19	0	0

QUADAS criteria represented with tally of ratings for all 7 studies included in the final analysis. The index test was identified to be the enhanced recovery after surgery (ERAS) protocol developed for the case series or comparative analysis described in the study. The reference standard was determined to be a traditional non-ERAS protocol for perioperative management. Those studies without comparative analyses with a non-ERAS protocol did not score so highly on the questions regarding references standard comparison from index test.

differed significantly across all studies, including degenerative spondylosis, disc herniation, metastatic tumors, adult spinal deformity, and spondylolisthesis. Minimally invasive surgery (MIS) approaches were used in most studies; however only 7[27,33,34,36,41,42,44] required use of MIS as implemented in the ERAS protocol. The studies by Soffin et al.[27,28,36] used conscious sedation anesthesia methods when possible with ketamine and propofol infusion, whereas the other 16 used general anesthesia methods. Surgical indications were not specified in 10 of the studies. The most commonly occurring indication among those studies that reported patient population specifications was spondylosis and degenerative conditions, which were observed in 6 of the studies. The largest trial included 2592 patients consecutively enrolled in a 5-year study with 22 ERAS protocol elements.[33]

LOS was the most commonly assessed metric in comparative analyses. A comparative reduction in LOS was reported in most studies using the ERAS protocol.[26,30,31,33,34,39,40] Three studies reported no significant difference in LOS between ERAS and pre-ERAS cohorts.[32,35,37] Pain scores were monitored in 13 studies.[26-28,31-33,35-37,40,41,43,44] A significant pain reduction in visual analog scale scores was observed with ERAS protocols.[26,37,41] A comparative study between ERAS and non-ERAS showed improved pain scores and reduced opioid consumption postoperatively, with the morphine equivalent daily dose for the ERAS protocol being 372.2 mg compared with 521.5 mg for the non-ERAS cohort.[37] However, some studies have reported miniscule or no difference in pain scores between ERAS and pre-ERAS groups despite decreases in opioid use.[32,35,44] Complication rates under ERAS protocols ranged from 2.0% to 31.7% (Table 2). A decrease in adverse events associated with the ERAS protocol was reported.[31,33] No studies have reported an increase in complications associated with ERAS methods. A traditional preoperative ERAS protocol with acetaminophen and gabapentin was followed in 5 studies.[27-30,36] Evidence-based searches were followed in most studies. Iterative improvements were used in 8 studies to update and improve care models during study duration or from previous ERAS trials.[26-28,33,35-37,42] Direct, indirect, and total cost decreases were also observed with implementation of ERAS protocols.[30,33,34,39]

DISCUSSION

ERAS for spine surgery shows evidence for improved patient recovery with shorter LOS and decreased pain scores from changes to traditional anesthesia, an MIS approach, and inclusion of perioperative ERAS principles. Although distinct guidelines remain to be outlined, Wainwright et al.[5] have proposed opportunities for targeted ERAS implementation in spine surgery, including pain control and reduction of opioid use, with enhanced functional recovery for procedures with traditionally high morbidity and long recovery. Preoperative functional and physical status optimization with education may be improved with screening protocols to optimize outcome and recovery.[5,29,45] Elements of intraoperative technique seem most variable among studies investigated. Use of conscious sedation anesthesia instead of endotracheal general anesthesia and

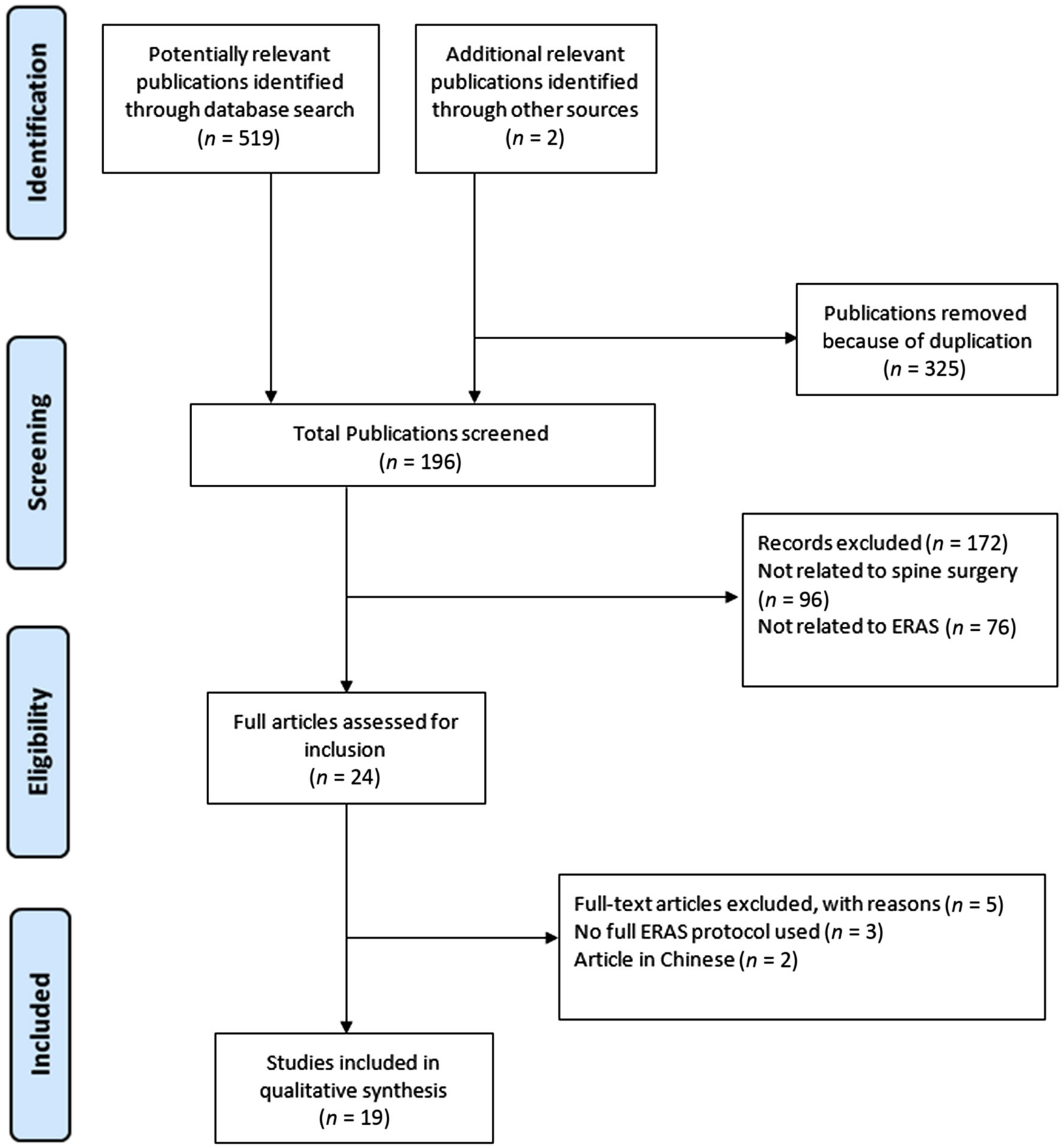

Figure 1. PRISMA flowchart of systematic search strategy. ERAS, enhanced recovery after surgery.

incorporation of MIS techniques are presented in the studies as opportunities to enhance ERAS for spine surgery guidelines, for example. Nonsteroidal antiinflammatory drugs (NSAIDs) with minimization of opioid use, early mobilization, and return to diet represent common goals among studies. Variability in operation, surgical indication, and ERAS protocol elements complicate standardization of ERAS in spine surgery.

Select Inpatient Study Summaries

Soffin et al.[36] described the development of an ERAS protocol for MIS lumbar surgery with LOS as primary outcome. After evidence-based review and committee discussion, 15 ERAS principles were selected to be incorporated into the final pathway and implemented for 61 consecutive patients undergoing lumbar decompression or microdiscectomy. An ERAS consultation team was also used to ensure the adherence to ERAS principles across surgeons, anesthesiologists, nurses, technicians, and other providers involved in perioperative aspects of care. A strength of

Table 2. Summary of Studies Implementing Enhanced Recovery After Surgery Protocol For Spine Surgery

Reference (Number of Patients)	Indication of Surgery, Surgical Operation	Type of Surgery/MIS Only (Yes/No)	Comparative Analysis (Yes/No)	Length of Stay	Pain Score Evaluation	Complications (n, %)	Compliance with Enhanced Recovery After Surgery Protocol (%)	Use of Preoperative or Intraoperative Acetaminophen, Gabapentin, or NSAID	Iterative Process	Evidence-Based Review	Key Enhanced Recovery After Surgery Elements
Brusko et al., 2019[26] (97)	NS	1-level to 3-level lumbar fusion, no	Yes	2.9 days	Yes	NS	100	Yes	Yes	Yes	Intraoperative liposomal bupivacaine, postoperative infusion of 1 g intravenous acetaminophen, frequent postoperative checkups
Soffin et al., 2019[27] (36)	NS	Lumbar decompression, microdiscectomy, yes	Yes	237 minutes	Yes	NS	91.4	Yes	Yes	Yes	(19 elements) TIVA with NSAIDs, opioid-free analgesia, early mobilization, tramadol rescue
Soffin et al., 2019[28] (33)	NS	Anterior cervical discectomy and fusion versus cervical disc arthroplasty, no	Yes	416 minutes	Yes	NS	85.6	Yes	Yes	Yes	(19 elements) TIVA with NSAIDs, opioid-free analgesia, early mobilization, tramadol rescue
Chakravarthy et al., 2019[29] (1770)	NS	Discectomy, microdiscectomy, laminotomies, degenerative scoliosis, no	Yes	NS	No	2% surgical site infection	NS	Yes	NS	Yes	Risk assessment and individualized perioperative risk mitigation, early mobilization, pain management, deep venous thrombosis prophylaxis
Carr et al., 2019[30] (932)	NS	Arthrodesis for deformity, anterior and posterior fusion, corpectomy, no	Yes	5.4 days	No	NS	NS	Yes	NS	Yes	Patient education, carbohydrate loading and perioperative nutrition, multimodal analgesia with acetaminophen and gabapentin
Angus et al., 2019[31] (626)	Degenerative scoliosis	Complex spinal deformity surgery, no	Yes	8 days	Yes	9.4%	NS	No	NS	Yes	Preoperative prehabilitation for muscle building, vitamin D optimization, carbohydrate loading, early mobilization, pain control, patient satisfaction surveys

Number of elements were included if specified in manuscript. Iterative process refers to continual feedback implementation to update and improve care models during study duration or from previous enhanced recovery after surgery trials.
MIS, minimally invasive surgery; NSAID, nonsteroidal antiinflammatory drug; TIVA, total intravenous anesthesia (i.e., intravenous ketamine, propofol); NS, not specified.
*100% compliance was observed for patient education, anitmicrobial prophylaxis, normothermia maintenance, postoperative early nutrition, and mobilization.
†78% compliance for gabapentin and 81% compliance of acetaminophen.
‡Complication rate did not include nausea and vomiting.
§Complication calculated at 6 weeks postoperatively as listed in manuscript, noting possible overlap among patients.

Continues

Table 2. Continued

Reference (Number of Patients)	Indication of Surgery, Surgical Operation	Type of Surgery/MIS Only (Yes/No)	Comparative Analysis (Yes/No)	Length of Stay	Pain Score Evaluation	Complications (n, %)	Compliance with Enhanced Recovery After Surgery Protocol (%)	Use of Preoperative or Intraoperative Acetaminophen, Gabapentin, or NSAID	Iterative Process	Evidence-Based Review	Key Enhanced Recovery After Surgery Elements
Ali et al., 2019[32] (275)	NS	Laminectomies, discectomy, foraminotomies, no	Yes	3.6 days	Yes	10.9%	NS	Yes	NS	Yes	Preoperative education, preoperative risk screening with nutrition optimization, metabolism management, safe early mobilization, wound care management
Staartjes et al., 2019[33] (2,592)	Degenerative diseases, lumbar disc herniation, spinal stenosis, spondylolisthesis, facet cysts	Tubular microdiscectomy, mini-open decompression, minimally invasive anterior and posterior fusion approaches, yes	Yes	1.1 days	Yes	4%	NS	Yes	Yes	Yes	(22 elements) Patient education, Minimally invasive techniques intraoperatively, early mobilization, early nutrition, frequent postoperative checks
Feng et al., 2019[34] (44)	Lumbar spinal stenosis, spondylolisthesis, degenerative lumbosacral spine conditions	Single-level MIS transforaminal lumbar interbody fusion, yes	Yes	5 days	No	2, 4.5%	100*	Yes	NS	Yes	(11 elements) Patient education, preoperative opioid-sparing medication, perioperative diet, early mobilization
Smith et al., 2019[35] (219)	NS	Single or double level open lumbar fusion, no	Yes	92.3 hours	Yes	3.3%	80†	Yes	Yes	Yes	Multimodal analgesia, preoperative acetaminophen and gabapentin, postoperative antiemetic regimen, and early mobilization
Soffin et al., 2018[36] (61)	Degenerative pathology	Lumbar decompression/ microdiscectomy, yes	No	279 minutes	Yes	4, 6.5%	85.03	Yes	Yes	Yes	(19 elements) TIVA with NSAIDs, early mobilization, tramadol rescue
Grasu et al., 2018[37] (41)	Metastatic tumors	Decompression, corpectomy, no	Yes	41 days	Yes	13, 41.7%	NS	Yes	Yes	Yes	Preoperative consultation with oncologic team, intraoperative ketamine, lidocaine, dexmedetomidine
Venkata and van Dellen, 2018[38] (246)	Degenerative disease	Open lumbar decompression, no	No	<24 hours	No	13, 4.6%	NS	No	NS	NS	Reduced hospital stay, noninstrumented, open intervention

Dagal et al., 2019[39] (558)	NS	Elective major spine surgery, no	Yes	6.1 days	No	28, 10.5%	NS	No	NS	NS	Patient education, perioperative nutrition with metabolic fitness assessment, carbohydrate loading, opioid-limited pain management
Li et al., 2018[40] (224)	Degenerative multilevel compression of spine and spinal stenosis	Laminoplasty, no	Yes	5.75 days	Yes	10.53%‡	93.7	Yes	NS	Yes	Patient education, early mobilization, early nutrition, postoperative NSAID regimen, early drain removal
Debono et al., 2017[41] (201)	Disc herniation	Lumbar microdiscectomy, yes	No	612 minutes	Yes	11.3%§	100	No	NS	Yes	Preoperative education with nursing staff on fast-track protocol, fasting minimized, early mobilization, postoperative pain and satisfaction measures
Wang and Grossman, 2016[42] (42)	Spondylolisthesis	Unilateral TLIF, yes	No	1.2 days	No	5, 11.9%	100	No	Yes	Yes	Sedation anesthesia, liposomal bupivacaine, MIS
Chin et al., 2015[43] (16)	Degenerative disease, spondylolisthesis	Direct open single-level lumbar interbody fusion, no	No	NS	Yes	1, 6.25%	NS	NS	NS	NS	Patient education, intraoperative ketorolac, postoperative follow-up with patient-reported outcomes and Oswestry Disability Index scores
Eckman et al., 2014[44] (728)	Stenosis, spondylolisthesis, disc herniation	Lumbar decompression/ microdiscectomy, yes	Yes	(73% same-day discharge)	Yes	NS	NS	NS	NS	NS	MIS technique, early mobilization with same-day discharge, postoperative pain monitoring with subjective visual analog scale scores

Number of elements were included if specified in manuscript. Iterative process refers to continual feedback implementation to update and improve care models during study duration or from previous enhanced recovery after surgery trials.
MIS, minimally invasive surgery; NSAID, nonsteroidal antiinflammatory drug; TIVA, total intravenous anesthesia (i.e., intravenous ketamine, propofol); NS, not specified.
*100% compliance was observed for patient education, anitmicrobial prophylaxis, normothermia maintenance, postoperative early nutrition, and mobilization.
†78% compliance for gabapentin and 81% compliance of acetaminophen.
‡Complication rate did not include nausea and vomiting.
§Complication calculated at 6 weeks postoperatively as listed in manuscript, noting possible overlap among patients.

the study was the standardization inherent in the use of a single surgeon for all patient participants and the same anesthesiologist for 91% of patients, potentially minimizing bias from surgical and technical experience. Preoperative preparation included education on goals of surgery and the expected rehabilitation process postoperatively and nutrition counseling with carbohydrate loading, solid food intake until 6 hours before the procedure and fluids until 4 hours before. Tylenol and gabapentin were administered preoperatively. General anesthesia with endotracheal intubation was selected to secure the airway with total intravenous anesthesia (TIVA) used intraoperatively with propofol, ketamine, ketorolac, lidocaine, antiemetics, and opioid with permission of inhaled agents to achieve up to 0.5 minimal alveolar concentration as needed. A minimally invasive technique was used for the surgical approach. Postoperatively, intravenous fluids were discontinued, and mobilization within 2 hours of the end of the procedure and an opioid-sparing regimen were followed, with tramadol used as rescue for analgesia. Patients were guided to maximize acetaminophen and NSAIDs before resorting to conservative tramadol prescription. Compliance was 85% of ERAS protocol, with most violation from use of gabapentin preoperatively, and minimal alveolar concentration was <0.5. The complication rate was 6.5%, but no complications required return to the operating room or readmission. Median LOS was 279 minutes, shorter than reports of average LOS after decompression of 2 days.[46] The same investigators conducted a study to analyze opioid-free analgesia (OFA) ($n = 18$) versus opioid-containing analgesia ($n = 18$) using an ERAS protocol,[36] as previously described.[27] Postoperative pain scores were recorded and opioid analgesics were offered to those with scores >4 on a numeric rating scale. LOS was 37 minutes shorter for the OFA ERAS group (237 minutes for OFA compared with 274 minutes for opioid-containing analgesia). There were no significant differences in postoperative maximal pain scores or opioid consumption between groups in the postanesthesia care unit. In a separate study, Soffin et al.[28] investigated ERAS for anterior cervical discectomy and fusion ($n = 25$) and cervical disc arthroplasty ($n = 8$). Compliance was 85.6%, with patients receiving 18 of 19 ERAS elements. LOS was 416 minutes on average and minimal complications were reported, with no patient requiring readmission in 90 days. Postoperative pain was a cause of extended LOS for each group.

Wang and Grossman[42] reported ERAS for spinal fusion in 42 patients, with a focus on the intraoperative approach to include a modified MIS transforaminal lumbar interbody fusion (TLIF). All patients had severe disc degeneration or spondylolisthesis with radiculopathy and back pain, requiring fusion. The ERAS MIS TLIF procedure was previously described[42] to include 6 modifications from a standard open approach, namely endoscopic access with recombinant human bone morphogenetic protein 2, a mesh expandable cage with allograft placement, and percutaneous pedicle screws with bupivacaine injections along tracts for local analgesia.[42] Conscious sedation anesthesia with ketamine and propofol was used to avoid the side effects of general anesthesia. In addition, the use of long-acting local analgesics with an MIS approach attempted to minimize tissue disruption and decrease pain at the surgical site to hasten recovery. Average LOS was 1.2 nights and Oswestry Disability Index scores were improved on early follow-up from 40 to 17, indicating substantial improvement in functional ability. The investigators noted that liposomal bupivacaine had a substantial effect on postoperative pain control, because those who received injections after pedicle screw placement had notably more pain than those who received injections under pressure before the screws broke the tissue plane. Five complications (11.9%) occurred, with a total of 3 patients requiring reoperation for cage misalignment and infections, and 2 others with medical complications of atrial fibrillation and thrombosis.

Staartjes et al.[33] conducted a 5-year study with ERAS implementation with 2592 consecutive patients from 2013 to 2018. Patients had to have had a 30-day minimum follow-up after surgery to be included in the study and to have completed patient-reported outcome questionnaires. The ERAS protocol implemented 22 features and included preoperative counseling, minimally invasive techniques intraoperatively, local analgesia, limited use of muscle relaxants, rare use of catheters and drains, and early mobilization and nutrition postoperatively. Intraoperatively, short-acting sufentanil was used to reduce opioid analgesia. LOS decreased over the course of the 5 years, with a reported average of 1.1 days. The rate of 1-night hospital stays increased from 26% to 85% with the ERAS protocol. Fusion procedures also had a decreased LOS of 1.5 days, compared with 2.4 days before the ERAS protocol was initiated. Nursing costs associated with the decrease in LOS across all participants were estimated to be 46.8%.[33] In addition, a decrease in adverse events was associated with the ERAS protocol over the 5 years, without increased readmission. Operative time was also shown to steadily decrease from 2013 to 2017 as the ERAS protocol was integrated. This study was the first to include anterior procedures in anterior lumbar interbody fusion. Similarly, Feng et al.[34] showed that incorporation of 11 ERAS elements for single-level MIS TLIF resulted in shorter length of hospital stay (5 days vs. 7 days, respectively), less operative time, less blood loss, fewer complications (4.5% vs. 13.3%, respectively), and less surgical drainage by postoperative day (POD) 1—3. Cost was also lower in ERAS at U.S.$70,467 versus U.S.$71,426.

Recently, Ali et al.[32,45] drafted an extensive ERAS protocol for 201 patients who underwent elective spine surgery or peripheral nerve surgery. Primary outcomes included postoperative opioid use and pain scores. The ERAS cohort included 201 patients and the non-ERAS cohort included 74. The ERAS protocol consisted of an extensive preoperative education process, which included surgical site care planning. Screening was conducted for patients at risk of impaired healing or comorbidity such as sleep apnea, low or high weight, and nutritional status. Sleep medicine was offered if the patient was at an increased risk of sleep apnea (STOP-BANG questionnaire score $\geq$2), nutrition counseling was given to those with body mass index <18.5 or >25.0 kg/m^2 or albumin<3.5 g/dL. Carbohydrate loading was also administered 2 hours before arrival at the hospital on day of surgery. Preoperative gabapentin and acetaminophen were also administered to reduce postoperative pain. Postoperatively, patients were instructed to get out of bed 3–5 times per day on POD 1. Meals were also eaten out of bed in a sitting chair. Catheter use was also limited. Postoperatively, a patient-controlled analgesia pump was used in 0.5% of the ERAS cohort and in 54.1% of the pre-ERAS cohort. Pain scores were not significantly different between groups by POD 1–3. At 1 month postoperative follow-up, 38.8% of the ERAS population were using opioids, whereas 52.7% of the pre-ERAS cohort were using opioids. Ambulation on POD was seen in 53.4% of the ERAS cohort and in 17.1% of the pre-ERAS cohort.

Chakravarthy et al.[29] focused on preoperative risk assessment and mitigation with individualized perioperative care was conducted with a focus on tobacco use, obesity, anemia, diabetes, and older age. If a patient had a glycated hemoglobin A_{1c} level >8%, for example, the patient was referred to endocrinology and surgery was postponed until 2 weeks after the visit. Procedures included in the analysis were categorized as minor (<100 mL blood loss), major (100–1000 mL blood loss), and complex cases (>1 L blood loss). Preoperatively, 300–650 mg gabapentin and 1000 mg acetaminophen were used to reduce narcotic need postoperatively. Ketorolac 15–30 mg intravenously, ketamine infusion, and epidural analgesia were administered during surgery as well to reduce narcotic use postoperatively. A total of 1770 patients were included in the analysis, with 799 receiving the ERAS protocol and 971 pre-ERAS. Surgical site infection was present in 2% of the ERAS cohort versus 4.12% in the pre-ERAS group. Transfusion rates in major or complex spine surgery decreased from 20.1% in the pre-ERAS protocol to 7.7% in the ERAS protocol.

Outpatient Studies

Incorporation of ERAS methods in spine surgery may also increase potential for transition to outpatient procedures. Less invasive surgery, decreased LOS, and alternative anesthesia methods are conducive to outpatient care centers.[47,48] Eckman et al. reported a same-day discharge after MIS TLIF in an outpatient setting for patients with degenerative lumbar conditions.[44] A total of 1114 patients were identified and 808 or 73% achieved same-day discharge. Analysis of 3 months follow-up showed no clinical changes pain or function between those who had same-day discharge and those who did not. In addition, Chin et al. described posterior lumbar interbody fusion or TLIF in 16 patients, with surgical time just more than 2 hours in an ambulatory surgical center.[43] After 15 months, the fusion success rate was 87.5%, with improvements in pain and Oswestry Disability Index scores. Chin et al.[43] further concluded that an MIS technique and specific medication regimen including ketorolac intraoperatively led to a more comfortable and immediate recovery.

In 2017, Debono et al.[41] evaluated lumbar microdiscectomies in the ambulatory setting in a series of 201 patients in France. An ERAS protocol was developed and included preoperative counseling and information about the fast-track method. Intraoperative techniques were minimally invasive with short-acting anesthetics and no use of drains. Postoperatively, patients received early nutrition and prompt mobilization, and follow-up measures of pain and satisfaction were performed at 6 months follow-up. At 6 months, 86% of patients had returned to activities with few or no limitations, and improvements in visual analog scale scores were 6.5 points in leg pain and 3.8 points in back pain. The ambulatory lumbar discectomy pathway with the ERAS philosophy used was shown to cost an average of €224.08 compared with €520.38 for the inpatient procedure.[41]

ERAS Guidelines in Spine Surgery

Although ERAS protocols have been established for other fields, there is not yet an official protocol for spine surgery. The ERAS philosophy focuses on patient experience, multidisciplinary teamwork (among surgeons, anesthetics, nurses, and physical therapists), evidence-based data gathering, and an iterative review process to improve protocol details[35,45] across preoperative, intraoperative, and postoperative phases (Table 3). Preoperative counseling is fundamental to ERAS, in which patients receive information to optimize physical and psychological function, which can reduce anxiety and prepare the patient to meet the milestones of the ERAS protocol.[45] Elements of counseling include orientation to protocol flow and pain reduction strategies,[40] prehabilitation[31] to promote muscle strength, surgical site management, vitamin D regulation for healing, insulin sensitivity, and smoking cessation.[32,45] Fasting is also limited to 6–8 hours before surgery, with carbohydrate or protein[32] loading, which may improve nutritional and metabolic status for the procedure.[34] Screening may identify those patients at risk of postoperative pain or impaired healing, such as chronic pain syndromes, sleep apnea, or nutritional disadvantages such as body mass index <18.5 or >25.0 kg/m^2, glucose level >180 mg/dL, glycated hemoglobin A_{1c} level>8.0%, hemoglobin level <11.5 g/dL, age >75 years, or albumin level <3.5 g/dL.[29,32] Individualized risk mitigation and tailored interventions may be implemented before surgery.[29] Consistent with traditional ERAS methods outside spine surgery, preoperative gabapentin and acetaminophen may also be used to reduce postoperative pain and narcotic use.[29,30,36]

Intraoperatively, efforts are made to reduce the surgical stress response, with a minimally invasive technique, local anesthesia, regional anesthesia, or TIVA[30,36,37] instead of general anesthesia, limited blood loss, and avoidance of opioids and urinary/oral tubing.[27,29,33] Normovolemia with goal-directed fluid management and normothermia remain integral to ERAS care in spine surgery to reduce perioperative morbidity and complications.[29] In cases in which opioids are used, efforts to include short-acting opioids such as sufentanil can be made.[33] Tranexamic acid has also been reported to reduce blood loss during surgery.[29,30,35] In addition, local anesthetics that are shown to have a longer duration may extend analgesia after surgery (e.g., liposomal bupivacaine [pain relief for ≤72 hours]).[26]

Postoperatively, goals are to assist the patient's return to normal function and activities through early mobilization, nutrition, and physical therapy.[26,34,45] Early mobilization may be introduced as

Table 3. Guidelines of Enhanced Recovery After Surgery in Spine Surgery

Preoperative	Intraoperative	Postoperative	Overarching Principles
Patient education and counseling	Minimally invasive techniques with small incision	Early mobilization (postoperative day 0 or as tolerated)	Multidisciplinary communication Iterative feedback process with compliance measures* Evidence-based evaluation of all elements Early reintroduction to preoperative function and activities
Risk assessment screening and intervention	Total intravenous anesthesia (i.e., intravenous ketamine or propofol) or regional anesthesia when possible	Prompt nutrition	
Carbohydrate loading	Emphasis on long-lasting local anesthetic (i.e., liposomal bupivacaine)	Cessation of intravenous fluids	
Shortened fasting 6–8 hours preoperatively	Normovolemia and normothermia maintenance	Nonopioid pain management	
Analgesia regimen with acetaminophen and gabapentin	Opioid-limited or opioid-free analgesia	Postoperative monitoring and follow-up with enhanced recovery after surgery team	
	Avoidance of urinary catheterization		

*Iterative process refers to continual feedback implementation to update and improve care models during study duration or from previous enhanced recovery after surgery trials.

early as 2 hours after spine surgery with guidance of physical therapy.[33] Chewing gum has been used to reduce the risk of postoperative ileus.[32] Dedicated ERAS teams play a larger role in postoperative settings, with drain removal, wound care, opioid-limited pain management, and bowel regimen in addition to early nutrition and mobilization.[31] Regular follow-up assessments on patient-reported outcomes including satisfaction, pain, and functional ability may also inform protocol modifications to improve outcomes.[35] Surveys may also increase adherence among providers and patients.[31,36] Compliance with key elements of a given ERAS protocol should be monitored and reported, with input from the dedicated multidisciplinary ERAS team.[27]

Synthesis and Future Directions

Certain elements of the ERAS protocol common to guidelines for other subspecialty surgeries such as preoperative analgesics have been independently shown to be beneficial in postoperative recovery in spine surgery.[49] Further, LOS is decreased and there are potential improvements in cost from outpatient centers.[47,48] Another benefit of ERAS for spine surgery is related to total cost savings, which accompany streamlined and less invasive methods.[30] Wang and Grossman[42] reported savings of $3442 or 15.2% per procedure with the application of ERAS methods, including endoscopic decompression versus traditional TLIF, the anesthetic technique, and liposomal bupivacaine in an acute care setting. In addition, Staartjes et al.[33] showed a reduction in nursing cost of 46.8% associated with ERAS protocol reduction in LOS. Operation time after the ERAS protocol was also decreased, showing further means of potential cost-saving.[33] Mathieson et al. reported that patients undergoing spine surgery who received an ERAS preoperative regimen of NSAIDs, acetaminophen, and gabapentin with incorporation of intraoperative intravenous ondansetron and ketamine and a postoperative NSAID course reported greater and earlier mobilization, less opioid use, and decreased nausea and sedation early postoperatively.[49] In addition, LOS was reduced by 2 days for the ERAS intervention group compared with the pre-ERAS cohort.[49] Other elements consistent with most postoperative ERAS protocols for other subspecialty surgeries include early mobilization and return to diet, which likely contribute to shorter recovery without increased complications.[50]

Although preoperative and postoperative management may seem more straightforward with an increasing body of evidence, further investigation is required regarding intraoperative proceedings. MIS represents a logical integration in the ERAS protocol because it has been shown to improve patient satisfaction and pain scores, minimize complications, and shorten recovery time.[5,51] Moreover, additions such as liposomal bupivacaine, incorporated in Wang and Grossman's study,[42] have been shown to provide patients with extended local analgesia after spine surgery compared with standard preparations of bupivacaine without impairing healing.[52,53] Alternatively, some protocols used short-acting opioids such as sufentanil to reduce opioid load.[33] OFA relies on nonopioid analgesic agents such as propofol, ketamine, and dexmedetomidine and local anesthetic agents to carry out analgesia and anesthesia.[27] Opioid use disorders in spine surgery are also associated with higher complication rates, extended hospitalization, and higher total costs.[54] Nonopioid drugs may achieve intraoperative anesthesia, with reduced postoperative nausea, pain, ileus, and LOS.[55] Such interventions may contribute toward reduced need for postoperative analgesia, minimizing opioid use.[26] Decreased complications without increases in readmissions also portend desirable outcomes with ERAS protocols in spine surgery.[33] Interesting additions to the TIVA regimen include dexmedotimidine, which decreases spinal cord edema, which may be specific to guidelines for spine surgery.[5] Variation in spine surgery and patient populations may differ sufficiently to warrant multiple ERAS protocols depending on indication and intervention. Staartjes et al.[33] reported the greatest discrepancy in LOS, for example, between the disc herniation, in which 98% were discharged after 1 day LOS and MIS TLIF, in which 22% were discharged after 1 day.

The studies analyzed show initial protocols for ERAS integration with spine surgery. Although the Grasu et al. study[37] did not show differences in LOS and readmission rates at 30 days between the enhanced recovery after spine surgery (ERSS) and pre-ERSS groups, the patient population may have influenced this metric in ways not seen in spine surgeries unrelated to neoplasm. Patients with metastatic lesions and possible comorbid health status may have an extended LOS, more frequent provider assistance, or reason for readmission unrelated to spine surgery, for example. In addition, most patients had $\geq$3 levels operated on: 87.8% in the ERSS and 80.4% in the pre-ERSS group. Elective procedures for decompression or discectomy are likely to have fewer confounding factors such as level of care and comorbidity, which may show a greater contrast in LOS and readmission from ERAS versus non-ERAS methods.

The ERAS philosophy stresses the benefits of iterative improvement of study protocols with compliance monitoring. One study[33] reported the benefits of the iterative improvement process, which saw an increase in same-day discharge after the first year. LOS decreased from 56.9 hours in 2013–2014 to 34.9 hours in 2018. Operative time also decreased steadily from 38.8 minutes in 2013 to 29.0 minutes in 2018. Continued improvement of study ERAS methods from patient and provider feedback and integration with evidence-based updates play an important role in ERAS evolution in spine surgery.

Strengths and Limitations

A paucity of literature regarding evidence-based ERAS methodology related to spine surgery represents a limiting factor that hindered study development and validity. As attention is directed to ERAS for spine surgery, with the development of guidelines from the ERAS Society and a more robust literature concerning its use in spine surgery, more investigation is required to address several elements of the protocol, such as use of NSAIDs intravenously, general anesthesia versus conscious sedation anesthesia with sole use of TIVA, and a minimally invasive versus an open approach to spine surgery.[30] Future studies may explore the elements of ERAS specific to spine interventions to optimize the protocol, as described previously.[5,45]

As Soffin et al.[27] outlined, monitoring of compliance with ERAS is an important factor in the evaluation of pathway consistency and external validity. Future studies may benefit from adopting similar checklists and adherence records to identify consistency and highlight variables of the pathway that may need modification. Studies may also benefit from longer follow-up times. Previous studies showed changes in patient-reported outcomes regarding pain and functionality after elective degenerative lumbar surgery that change throughout a 12-month follow-up.[56]

CONCLUSIONS

A limited cohort of studies with significant variability in patient population and ERAS protocol implementation have evaluated the integration of ERAS within spine surgery. Observations are mostly relevant to the use of MIS because this approach was most consistent across studies. Future studies may build on methods presented, with larger comparative studies to develop standards of care with ERAS guidelines for spine surgery. ERAS in spine surgery may provide reductions in complications, readmissions, LOS, and opioid use, in combination with improvements in patient-reported outcomes and functional recovery.

REFERENCES

1. Kehlet H. Multimodal approach to control postoperative pathophysiology and rehabilitation. *Br J Anaesth*. 1997;78:606-617.

2. Melnyk M, Casey RG, Black P, Koupparis AJ. Enhanced recovery after surgery (ERAS) protocols: time to change practice? *Can Urol Assoc J*. 2011;5:342-348.

3. Ljungqvist O, Scott M, Fearon KC. Enhanced recovery after surgery: a review. *JAMA Surg*. 2017;152:292-298.

4. Miller TE, Thacker JK, White WD, et al. Reduced length of hospital stay in colorectal surgery after implementation of an enhanced recovery protocol. *Anesth Analg*. 2014;118:1052-1061.

5. Wainwright TW, Immins T, Middleton RG. Enhanced recovery after surgery (ERAS) and its applicability for major spine surgery. *Best Pract Res Clin Anaesthesiol*. 2016;30:91-102.

6. Schifftner TL, Grunwald GK, Henderson WG, Main D, Khuri SF. Relationship of processes and structures of care in general surgery to postoperative outcomes: a hierarchical analysis. *J Am Coll Surg*. 2007;204:1166-1177.

7. Eskicioglu C, Forbes SS, Aarts MA, Okrainec A, McLeod RS. Enhanced recovery after surgery (ERAS) programs for patients having colorectal surgery: a meta-analysis of randomized trials. *J Gastrointest Surg*. 2009;13:2321-2329.

8. Ni TG, Yang HT, Zhang H, Meng HP, Li B. Enhanced recovery after surgery programs in patients undergoing hepatectomy: a meta-analysis. *World J Gastroenterol*. 2015;21:9209-9216.

9. Visioni A, Shah R, Gabriel E, Attwood K, Kukar M, Nurkin S. Enhanced recovery after surgery for noncolorectal surgery?: a systematic review and meta-analysis of major abdominal surgery. *Ann Surg*. 2018;267:57-65.

10. Sarin A, Litonius ES, Naidu R, Yost CS, Varma MG, Chen LL. Successful implementation of an enhanced recovery after surgery program shortens length of stay and improves postoperative pain, and bowel and bladder function after colorectal surgery. *BMC Anesthesiol*. 2016;16:55.

11. Liu VX, Rosas E, Hwang J, et al. Enhanced recovery after surgery program implementation in 2 surgical populations in an integrated health care delivery system. *JAMA Surg*. 2017;152:e171032.

12. Spanjersberg WR, Reurings J, Keus F, van Laarhoven CJ. Fast track surgery versus conventional recovery strategies for colorectal surgery. *Cochrane Database Syst Rev*. 2011:CD007635.

13. Ackerman RS, Hirschi M, Alford B, Evans T, Kiluk JV, Patel SY. Enhanced REVENUE after surgery? A cost-standardized enhanced recovery pathway for mastectomy decreases length of stay. *World J Surg*. 2019;43:839-845.

14. Thanh NX, Chuck AW, Wasylak T, et al. An economic evaluation of the enhanced recovery after surgery (ERAS) multisite implementation program for colorectal surgery in Alberta. *Can J Surg*. 2016;59:415-421.

15. Lemanu DP, Singh PP, Stowers MD, Hill AG. A systematic review to assess cost effectiveness of enhanced recovery after surgery programmes in colorectal surgery. *Colorectal Dis*. 2014;16:338-346.

16. Oresanya LB, Lyons WL, Finlayson E. Preoperative assessment of the older patient: a narrative review. *JAMA*. 2014;311:2110-2120.

17. Weldring T, Smith SM. Patient-reported outcomes (PROs) and patient-reported outcome measures (PROMs). *Health Serv Insights*. 2013;6:61-68.

18. McCormick JD, Werner BC, Shimer AL. Patient-reported outcome measures in spine surgery. *J Am Acad Orthop Surg*. 2013;21:99-107.

19. Variability in the utility of predictive models in predicting patient-reported outcomes following spine surgery for degenerative conditions: a systematic review. *Neurosurg Focus*. 2018;45:E10.

20. Graves C, Meyer S, Knightly J, Glassman S. Quality in spine surgery. *Neurosurgery*. 2018;82:136-141.

21. Nasser R, Yadla S, Maltenfort MG, et al. Complications in spine surgery. *J Neurosurg Spine*. 2010;13:144-157.

22. Yadla S, Maltenfort MG, Ratliff JK, Harrop JS. Adult scoliosis surgery outcomes: a systematic review. *Neurosurg Focus*. 2010;28:E3.

23. Carreon LY, Puno RM, Dimar JR 2nd, Glassman SD, Johnson JR. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. *J Bone Joint Surg Am*. 2003;85-A:2089-2092.

24. Sandrucci S, Beets G, Braga M, Dejong K, Demartines N. Perioperative nutrition and enhanced recovery after surgery in gastrointestinal cancer patients. A position paper by the ESSO task force in collaboration with the ERAS society (ERAS coalition). *Eur J Surg Oncol*. 2018;44:509-514.

25. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*. 2009;62:1006-1012.

26. Brusko GD, Kolcun JPG, Heger JA, et al. Reductions in length of stay, narcotics use, and pain following implementation of an enhanced recovery after surgery program for 1- to 3-level lumbar fusion surgery. *Neurosurg Focus*. 2019;46:E4.

27. Soffin EM, Wetmore DS, Beckman JD, et al. Opioid-free anesthesia within an enhanced recovery after surgery pathway for minimally invasive lumbar spine surgery: a retrospective matched cohort study. *Neurosurg Focus*. 2019;46:E8.

28. Soffin EM, Wetmore DS, Barber LA, et al. An enhanced recovery after surgery pathway: association with rapid discharge and minimal complications after anterior cervical spine surgery. *Neurosurg Focus*. 2019;46:E9.

29. Chakravarthy VB, Yokoi H, Coughlin DJ, Manlapaz MR, Krishnaney AA. Development and implementation of a comprehensive spine surgery enhanced recovery after surgery protocol: the Cleveland Clinic experience. *Neurosurg Focus*. 2019;46:E11.

30. Carr DA, Saigal R, Zhang F, Bransford RJ, Bellabarba C, Dagal A. Enhanced perioperative care and decreased cost and length of stay after elective major spinal surgery. *Neurosurg Focus*. 2019;46:E5.

31. Angus M, Jackson K, Smurthwaite G, et al. The implementation of enhanced recovery after surgery (ERAS) in complex spinal surgery. *J Spine Surg*. 2019;5:116-123.

32. Ali ZS, Flanders TM, Ozturk AK, et al. Enhanced recovery after elective spinal and peripheral nerve surgery: pilot study from a single institution [e-pub ahead of print]. *J Neurosurg Spine* https://doi.org/10.3171/2018.9.SPINE18681, accessed June 1, 2019.

33. Staartjes VE, de Wispelaere MP, Schroder ML. Improving recovery after elective degenerative spine surgery: 5-year experience with an enhanced recovery after surgery (ERAS) protocol. *Neurosurg Focus*. 2019;46:E7.

34. Feng C, Zhang Y, Chong F, et al. Establishment and implementation of an enhanced recovery after surgery (ERAS) pathway tailored for lumbar minimally invasive transforaminal lumbar interbody fusion surgery [e-pub ahead of print]. *World Neurosurg* https://doi.org/10.1016/j.wneu.2019.05.139, accessed June 1, 2019.

35. Smith J, Probst S, Calandra C, et al. Enhanced recovery after surgery (ERAS) program for lumbar spine fusion. *Perioper Med (Lond)*. 2019;8:4.

36. Soffin EM, Vaishnav AS, Wetmore D, et al. Design and implementation of an enhanced recovery after surgery (ERAS) program for minimally invasive lumbar decompression spine surgery: initial experience. *Spine (Phila Pa 1976)*. 2019;44:E561-E570.

37. Grasu RM, Cata JP, Dang AQ, et al. Implementation of an enhanced recovery after spine surgery program at a large cancer center: a preliminary analysis. *J Neurosurg Spine*. 2018;29:588-598.

38. Venkata HK, van Dellen JR. A perspective on the use of an enhanced recovery program in open, non-instrumented day surgery for degenerative lumbar and cervical spinal conditions. *J Neurosurg Sci*. 2018;62:245-254.

39. Dagal A, Bellabarba C, Bransford R, et al. Enhanced perioperative care for major spine surgery. *Spine (Phila Pa 1976)*. 2019;44:959-966.

40. Li J, Li H, Xv ZK, et al. Enhanced recovery care versus traditional care following laminoplasty: a retrospective case-cohort study. *Medicine (Baltimore)*. 2018;97:e13195.

41. Debono B, Sabatier P, Garnault V, et al. Outpatient lumbar microdiscectomy in France: from an economic imperative to a clinical standard—an observational study of 201 cases. *World Neurosurg*. 2017;106:891-897.

42. Wang MY, Grossman J. Endoscopic minimally invasive transforaminal interbody fusion without general anesthesia: initial clinical experience with 1-year follow-up. *Neurosurg Focus*. 2016;40:E13.

43. Chin KR, Coombs AV, Seale JA. Feasibility and patient-reported outcomes after outpatient single-level instrumented posterior lumbar interbody fusion in a surgery center: preliminary results in 16 patients. *Spine (Phila Pa 1976)*. 2015;40:E36-E42.

44. Eckman WW, Hester L, McMillen M. Same-day discharge after minimally invasive transforaminal lumbar interbody fusion: a series of 808 cases. *Clin Orthop Relat Res*. 2014;472:1806-1812.

45. 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.

46. Basques BA, Varthi AG, Golinvaux NS, Bohl DD, Grauer JN. Patient characteristics associated with increased postoperative length of stay and readmission after elective laminectomy for lumbar spinal stenosis. *Spine (Phila Pa 1976)*. 2014;39:833-840.

47. Koenig L, Gu Q. Growth of ambulatory surgical centers, surgery volume, and savings to medicare. *Am J Gastroenterol*. 2013;108:10-15.

48. Chin KR, Ricchetti ET, Yu WD, Riew KD. Less exposure surgery for multilevel anterior cervical fusion using 2 transverse incisions. *J Neurosurg Spine*. 2012;17:194-198.

49. Mathiesen O, Dahl B, Thomsen BA, et al. A comprehensive multimodal pain treatment reduces opioid consumption after multilevel spine surgery. *Eur Spine J*. 2013;22:2089-2096.

50. Lee TG, Kang SB, Kim DW, Hong S, Heo SC, Park KJ. Comparison of early mobilization and diet rehabilitation program with conventional care after laparoscopic colon surgery: a prospective randomized controlled trial. *Dis Colon Rectum*. 2011;54:21-28.

51. Tatsui CE, Stafford RJ, Li J, et al. Utilization of laser interstitial thermotherapy guided by real-time thermal MRI as an alternative to separation surgery in the management of spinal metastasis. *J Neurosurg Spine*. 2015;23:400-411.

52. Chahar P, Cummings KC 3rd. Liposomal bupivacaine: a review of a new bupivacaine formulation. *J Pain Res*. 2012;5:257-264.

53. Kim J, Burke SM, Kryzanski JT, et al. The role of liposomal bupivacaine in reduction of postoperative pain after transforaminal lumbar interbody fusion: a clinical study. *World Neurosurg*. 2016;91:460-467.

54. Martini ML, Nistal DA, Deutsch BC, Caridi JM. Characterizing the risk and outcome profiles of lumbar fusion procedures in patients with opioid use disorders: a step toward improving enhanced recovery protocols for a unique patient population. *Neurosurg Focus*. 2019;46:E12.

55. Lam KK, Mui WL. Multimodal analgesia model to achieve low postoperative opioid requirement following bariatric surgery. *Hong Kong Med J*. 2016;22:428-434.

56. Khor S, Lavallee D, Cizik AM, et al. Development and validation of a prediction model for pain and functional outcomes after lumbar spine surgery. *JAMA Surg*. 2018;153:634-642.

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