Chapter 6
ERAS and Spine Surgery

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Introduction

A patient's surgical experience is comprised of different facets of perioperative care, including the preoperative, intraoperative, and postoperative phases, and is overseen by a multitude of practitioners. As such, postoperative recovery is a complex process that is not only influenced by a technically successful operation but also depends on the quality of perioperative care as coordinated by a multidisciplinary team. Such coordinated efforts are essential in reducing pain, morbidity, and recovery time. Indeed, a significant proportion of patients undergoing surgery will experience postoperative pain, with the majority reporting moderate or extreme pain [1]. Inadequate postoperative pain control has numerous adverse effects on the patient and healthcare system, including unwanted and harmful physiological side effects, poor patient satisfaction, and an increased overall cost of healthcare resource utilization [2].

Enhanced Recovery After Surgery (ERAS) protocols have thus been developed as a conceptual framework of optimizing surgical recovery. The core philosophy of ERAS consists of a multimodal approach to perioperative management, with the implementation of evidence-based approaches to treatment using a

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multidisciplinary team [3]. In 2001, the ERAS study group was founded by a group of European academic surgeons, who first developed a multimodal recovery protocol for colonic surgery based on the published literature [4]. Previously, the concept of "fast-track" surgery had been described in different specialties such as cardiac and general surgery [5–7] with an initial focus on expediting the speed of recovery, which then developed into a protocol for optimizing perioperative management to reduce complications and enhance recovery [8]. Subsequently, the ERAS Society was founded with a mission to "develop perioperative care and to improve recovery through research, education, audit and implementation of evidence-based practice" (http://www.erassociety.org).

Although the ERAS Society has published numerous guidelines and consists of multiple specialties, there is no neurosurgical representation, and no guidelines exist regarding the perioperative management of spinal surgeries; however, the Congress of Neurological Surgeons is currently developing perioperative spine surgery guidelines, which are expected to be published in 2021. Until recently, the literature lacked detailed studies outlining ERAS protocols and outcomes for spine surgery [9], and the past few years have seen a newfound enthusiasm in ERAS development for a variety of spinal procedures and pathologies [10, 11]. The purpose of this chapter is to outline the components of ERAS protocols as they relate to spine surgery, and to review the process of ERAS development and published outcomes in the literature.

Rationale for the Use of ERAS in Spinal Surgery

There is a compelling case for the implementation of ERAS into the routine management of spinal surgery. Some spine procedures are associated with long operative duration, extensive muscle retraction and dissection, and the implantation of hardware, which can lead to prolonged recovery, delayed mobilization, and significant pain. In particular, both lumbar fusion and complex spinal reconstruction procedures have been rated by patients as having the most significant pain on the first postoperative day [12]. Accordingly, postoperative pain influences several outcome measures, including length of hospitalization, time to mobilization, readmission rates, and opioid tolerance and dose escalation [13].

The complexity of pain management for spinal pathologies is derived from the diverse pain etiologies arising from nociceptive, neuropathic, and inflammatory mechanisms, with potential anatomical sources of pain including the paraspinal muscles, bone, facet joints, and the intervertebral discs [14]. In addition to delaying recovery and prolonging a patient's initial hospital admission, the intensity of pain experienced in the early postoperative period may lead to the development of chronic postsurgical pain [15]. Pain can also be associated with kinesiophobia, or the "fear of movement" following spine surgery, which can impair early mobilization, leading to even greater pain, disability, and adverse psychological effects [16, 17].

Previously, the liberal use of opioids was favored in the treatment of acute postoperative pain; however, the rise in morbidity and mortality associated with acute and chronic opioid therapy has encouraged the development of multimodal analgesia (MMA) paradigms to both reduce perioperative opioid use and improve postoperative pain control and patient recovery [18, 19]. It is important to recognize that a majority of patients presenting for major spine surgery are taking opioids and that higher utilization of preoperative opioid use and higher pain scores are associated with chronic postoperative opioid use [20]. Interestingly, the preoperative use of high-potency opioids has also been associated with an increased reoperation rate following lumbar decompression or fusion surgeries [21]. Furthermore, opioid use in the elderly can be fraught with complications, as these patients are at an elevated risk of developing complications due to their comorbidities and higher likelihood of polypharmacy [22]. In particular, one must take into account a potentially elevated fall and fracture risk [23]. Although data on opioid abuse for adults aged 65 years and older are largely lacking [24], a number of studies have reported increasing rates of misuse and addiction [25, 26].

In the United States, the rates of surgical procedures for degenerative spine disease have rapidly increased over the past few decades, in particular the use of fusion for lumbar stenosis and spondylolisthesis [27–29]. The increasing complexity of cases necessitating fusion has also been associated with increased cost and risk of major complications and mortality [30]. Interestingly, some studies have suggested that postoperative, but not intraoperative, events are more predictive of increased length of stay (LOS) following lumbar fusion [31]. There is significant diversity in the nature of postoperative care among institutions and individual surgeons, with differing practices regarding the prescribing of medications, mobilization, and instructions for return to activity or work. As such, implementation of an ERAS protocol following spine surgery could potentially streamline postoperative care and improve outcomes.

ERAS Components

A multimodal ERAS management strategy focuses on optimizing the preoperative, intraoperative, and postoperative periods (Fig. 6.1). The foundation of these strategies is in minimizing stressors from a variety of physiological, psychological, and economic sources [32, 33].

Preoperative Period

Preoperative optimization begins even before the patient presents to the hospital for their procedure. Preparation begins with education, which can include the basic details of the surgical procedure, expected length of the procedure and LOS,

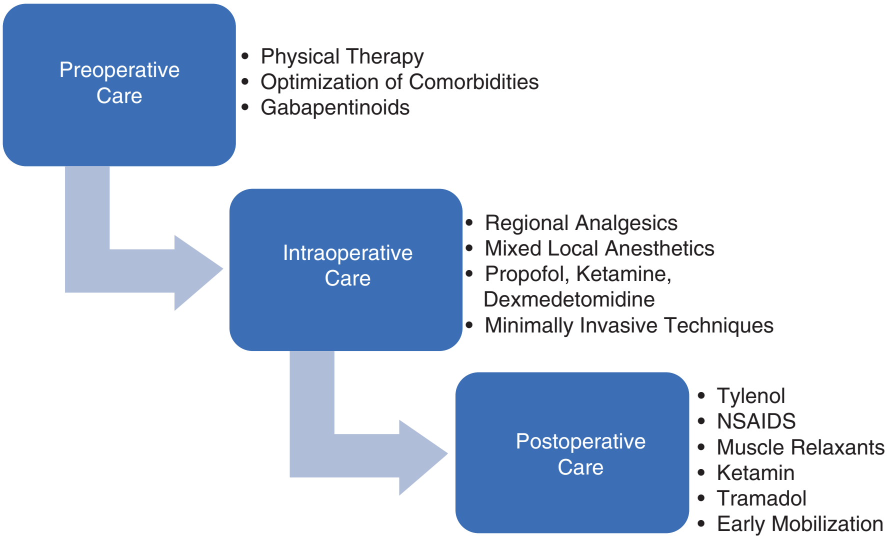

Fig. 6.1 Typical components of an ERAS pathway

postoperative expectations for discharge, potential restrictions on mobility and activity, and expected course of postoperative recovery. Despite the seemingly basic nature of this information, having a structured approach to providing education can empower patients. Indeed, there is evidence that such preoperative education sessions improve pain, function, and psychological outcomes following spine surgery [34, 35]. “Prehabilitation,” or the process of enhancing functional capacity prior to elective surgery, has also been researched in spine surgery [36]; however, there are few studies addressing this topic, and it is not clear if their implementation results in significant improvements in pain or function.

Additional preoperative considerations include the management and optimization of comorbidities, particularly in an elderly population with a higher incidence of heart disease and diabetes. The rising rates of obesity are concerning, and there is often an association with diabetes. Multiple studies have shown that patients with poorly controlled diabetes have a higher incidence of postoperative complications following spine surgery, including infection and poor wound healing [37, 38]. Similarly, tobacco use is associated with a higher rate of adverse events following spine surgery, including infection, fusion failure, and cardiopulmonary complications [39, 40]. Screening for such factors is essential to optimize preoperative health and function. Other considerations include the identification of nutritional insufficiency or malnutrition—this often unrecognized risk factor has been independently associated with adverse events following spine surgery including infection, increased LOS, and mortality [41, 42]. In addition to these modifiable factors, non-modifiable factors such as the use of anticoagulation medications may also contribute to the development of perioperative complications and should be managed appropriately.

As discussed, infection is an important complication in spine surgery. In addition to optimizing comorbidities, other critical considerations include the use of preoperative antibiotics, and appropriate sterile preparation and surgical technique. Preoperative bathing with chlorhexidine gluconate has received recent attention in the orthopedic literature as a means of reducing surgical site infections [43]. A recent analysis of 4266 spine surgeries reported that the implementation of a protocol requiring patients to shower at least 3 times prior to surgery with chlorhexidine significantly decreased the risk of developing an infection [44]. Interestingly, this decreased risk was only observed in patients undergoing spine surgery without fusion in univariate analysis, perhaps as a result of the increased complexity of cases requiring fusion [44].

“Preemptive” analgesia refers to the preoperative administration of pain medications to prevent postoperative pain. Mechanistically these medications inhibit or reduce autonomic reactivity and nociceptive signals generated through tissue damage and inflammation [13]. The use of gabapentinoids, including gabapentin and pregabalin in the preoperative setting, has been demonstrated to decrease opioid consumption and improve pain scores following lumbar surgery [45, 46], and both drugs may be equally efficacious [47]. The use of nonsteroidal anti-inflammatory drugs (NSAIDs) has also been demonstrated to improve pain scores and reduce opioid use in the postoperative period [48]. Although there have been concerns regarding the use of NSAIDs and the development of pseudoarthrosis or nonunion, numerous studies have reported their safety in the postoperative period when judiciously dosed [49, 50]. Many ERAS protocols will combine different agents based on institutional or provider preference, and common combinations include a gabapentinoid, NSAID, and/or acetaminophen [51–53]. Another consideration is timing of medication administration, as different protocols may initiate therapy on the morning of surgery and/or the night before surgery. For gabapentinoids, this may include administration of a single or divided oral dose of 300–1200 mg, 2–24 h before surgery [54]; one meta-analysis of multiple inpatient surgical procedures identified an association between the cumulative gabapentin dose and a total reduction in morphine consumption [54].

Intraoperative Period

There are numerous intraoperative considerations for ERAS implementation, including the choice of anesthetic agent, MMA with a focus on opioid-sparing medications, antimicrobial prophylaxis, and the maintenance of both normothermia and normovolemia.

A number of different anesthetic regimens have been described in conjunction with ERAS protocols. When general anesthesia is desired, propofol tends to be the agent of choice in multiple ERAS paradigms [52, 53, 55, 56]. The use of ketamine as both a pre-incisional bolus and intraoperative infusion has been reported to reduce opioid consumption and incisional hyperalgesia, and also improve the efficacy of neurophysiologic monitoring by reducing inhalational anesthetic requirements [14, 57]. Dexmedetomidine has also been investigated as a sedative and analgesic adjuvant in spine surgery, with notable reductions in both intraoperative and postoperative opioid use reported [58]. Intravenous glucocorticoids have been reported to reduce postoperative pain as well as nausea and vomiting [59], although some studies have reported a higher rate of postoperative infection [60]. The use of regional (neuraxial) anesthesia in spine surgery has also been described in a number of studies, commonly employing the use of spinal bupivacaine [61]. Compared to a general anesthetic, regional anesthesia may be associated with decreased blood loss, a lower incidence of nausea and vomiting, and reduced pain scores and LOS [61].

Infiltration of the incision with local anesthetic is a widely utilized and efficacious technique [62], and is routinely infiltrated underneath the skin prior to incision and into the muscle prior to closure. Such measures may reduce postoperative pain scores and opioid use [63]. Although local anesthetics are generally limited by their relatively short duration of action, there has been recent enthusiasm in the use of multivesicular liposomes containing bupivacaine, which allows for sustained drug release that can last for a few days. Recent studies assessing the use of liposomal bupivacaine suggest improved mobility and reduced opioid consumption when either used as a sole intervention [64] or in conjunction with an ERAS protocol [65]. The use of intrathecal morphine has also been reported to reduce pain scores and postoperative opioid use following spine surgery [66]. Complications including pruritus and respiratory depression have been reported in some studies [66]. Although pain is improved in the immediate postoperative period, the efficacy tends not to persist after 48–72 h, and is not associated with a decreased LOS [66–68].

Spine operations can be associated with numerous homeostatic insults, particularly in those of longer duration and requiring more exposure and/or instrumentation. Longer operations are associated with potentially extended periods of hypothermia, which has been reported to increase the incidence of infection [69]; as such, maintaining overall normothermia and targeting a core temperature of 36 °C is considered essential. Major spine surgery can also be associated with elevated blood loss, resulting in hypotension and an increased risk of end-organ damage. In one study, patients requiring a blood transfusion during lumbar fusion were significantly more likely to develop a complication, including sepsis, pulmonary embolus, or infection [70]. The maintenance of normovolemia in spine surgery is therefore essential, and has been associated with reduced blood loss and lower rates of transfusion, as well as improved respiratory and bowel function [71]. The use of tranexamic acid has been reported to be effective in reducing perioperative blood loss and the need for transfusion [72], and may provide an especially useful adjunct when used in conjunction with thorough surgical hemostasis techniques [73].

An additional consideration is the avoidance or early removal of urinary catheters and surgical drains. Urinary catheters are associated with development of urinary tract infections, and there is mixed evidence in their association with the development of a surgical site infection following spine surgery [74]. The prolonged use of surgical drains has similarly been reported as an independent risk factor for developing a surgical site infection [75]. Minimally invasive surgeries (MIS) may be able to avoid the use of catheters and drains, although they may be necessary following major spine surgery with longer durations and larger exposures. Accordingly, many ERAS protocols specify early removal to facilitate mobilization [11].

Postoperative Period

The key postoperative considerations following spine surgery focus on pain control, mobilization and the path to discharge. Whereas early "fast-track" protocols may have focused exclusively on the speed of recovery and discharge, ERAS places greater emphasis on optimizing the patient experience.

One of the most important postoperative considerations is that of pain control and the appropriate medication regimen. If implemented judiciously, the use of preemptive and intraoperative MMA as described in previous sections can improve postoperative pain control through an opioid-sparing approach. Different agents are used in combination to synergistically treat pain, and common postoperative drugs include acetaminophen, gabapentin or pregabalin, NSAIDs, and muscle relaxants. The use of scheduled NSAIDs, as opposed to the as-needed administration, may act synergistically with opioids in the postoperative period [18]. This may enable an overall decreased dose of opioids, indirectly reducing postoperative nausea and sedation [18]. Such benefits may be of particular use to the elderly population, who are particularly susceptible to opioid-related side effects [22, 76]. Of course the use of perioperative NSAIDs must be measured with the risk of potential platelet dysfunction, gastrointestinal irritation, and/or renal impairment [18].

The use of NMDA agonists, such as ketamine, in the perioperative period may also be an effective approach to surgical pain. Different administration protocols have been described, including its use as a pre-incisional bolus, an intraoperative infusion, and postoperative use in combination with a patient-controlled analgesia (PCA) pump [77]. Given as infusions, they can lower the use of opioid therapy and decrease nausea and vomiting [18, 57, 77]. However, the administration of the agent in this manner may require a coordinated effort from pharmacy, the recovery unit nursing staff, and anesthesia, who will likely ultimately be overseeing its delivery. Furthermore, ketamine is a psychoactive drug, which could potentially contribute to the development of postoperative cognitive side effects in a vulnerable elderly population [78]. In a multicenter randomized trial of patients aged 60 years or older undergoing major surgery, the use of a subanesthetic ketamine dose during surgery did not reduce the incidence of postoperative delirium, and instead increased the incidence of postoperative nightmares and hallucinations [79].

It is difficult if not impossible to avoid the use of opioids altogether, and the judicious administration of short-acting opioids and/or tramadol may be necessary. Tramadol acts weakly at the μ-opioid receptors, but also acts at non-opioid receptors, resulting in inhibition of norepinephrine and serotonin reuptake. Consequently, there is a multimodal benefit of this single agent [18]. Tramadol's weak action at the opioid receptor also diminishes the risk of addiction and other systemic side effects seen with traditional opioids use [18]. One novel treatment strategy involves administration of pain medications based on NRS scores, with non-opioids administered for scores 4 or less, tramadol for scores between 5 and 7, and oxycodone for scores between 8 and 10 [55]. In this protocol, assessment by an anesthesiologist is required if pain is refractory and dose escalation is required [55].

PCA pumps are commonly used as postoperative adjuncts in the first 12–24 h. Following this initial period, the patient is transitioned to oral medications with dosing determined by the amount and frequency of PCA use [14]. However, PCA usage has been reported to be associated with increased total opioid use and increased adverse events [80]. Interestingly, PCA use has also been associated with equivalent or even worse postoperative pain control compared to MMA [80, 81], which suggests careful consideration for their inclusion in an ERAS protocol. When implemented, there should always be a plan for early discontinuation and transition to oral therapy [82].

An essential component of ERAS protocols is early mobilization, referring to mobilization on the day of surgery or the first postoperative day thereafter. The adverse effects of bed rest and immobilization are well-documented, in particular the elevated risk of deconditioning, cardiopulmonary events, and thromboembolism [83–85]. Across multiple disciplines, the benefits of early mobilization are apparent in reducing the postoperative LOS, and also as measured by an overall reduction in rates of infection, respiratory compromise, thromboembolic events, and sepsis [86]. Few studies have specifically investigated the impact of early mobilization following spine surgery; however, these studies have uniformly identified improvements in rates of perioperative complications and LOS [87–90]. Accordingly, they have been adopted with enthusiasm into spine ERAS protocols [91]. Equally important considerations are involvement with physical and occupational therapy during an inpatient admission [52, 55, 92], and to continue physical therapy on an outpatient basis.

Outcomes by Type of Spine Surgery

Few publications on ERAS and spine surgery were available prior to 2018, and the past few years have seen an exponential increase in interest and published protocols. These protocols are highly variable and tend to be institutional-specific, but have generally focused on providing improved education, early nutrition and mobilization, multimodal pain management, and a general trend toward a transition to minimally invasive techniques. These protocols have been studied in a variety of spine surgeries, from simple decompressive laminectomies to more extensive tumor and fusion surgeries. The majority of currently reported protocols are focused on lumbar surgeries. Regardless of the specific ERAS elements, nearly all studies have reported beneficial effects, often related to decreased LOS and reduced opioid usage, without an increase in complications or readmissions [93]. Table 6.1 comprehensively outlines selected studies that evaluate ERAS protocols compared to cohorts with conventional care.

Table 6.1 Selected ERAS studies in spine surgery with comparison to conventional care pathways

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Fletcher, 2014 [94]	Retrospective	ERAS 279, control 86	Open	AIS undergoing PSF	Postoperative: early oral meds, drain removal, PT, nutrition	2.92 days vs. 4.28 days			$1885 vs. $2779
Gornitzky, 2016 [95]	Prospective	ERAS 58, control 81	Open	AIS undergoing PSF	Perioperative: MMA Postoperative: early ambulation, nutrition	LOS 31% shorter	Decreased pain at POD 0,1,2	No difference	
Muhly, 2016 [96]	Prospective	ERAS 84, transition period 104, historic controls 134	Open	AIS undergoing PSF	Postoperative: MMA, early mobilization, nutrition, transition to oral medications, drain removal	4 days vs. 5.7 days	Decreased pain at POD 0 and POD 1	No difference	
Fletcher, 2017 [97]	Retrospective	ERAS 105, control 45	Open	AIS undergoing PSF	Postoperative: early mobilization, nutrition, transition to oral medications, drain removal	48% shorter LOS		No difference	

(continued)

Table 6.1 (continued)

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Rao, 2017 [98]	Retrospective	Pre-ERAS 51, first protocol 100, second protocol 39	Open	AIS undergoing PSF	First: early PCA discontinuation, epidural pain infusion until POD 3, full nutrition POD 2, drain removed on POD 2, cefazolin until drain removal, d/c Foley after epidural catheter is pulled, up to chair on POD 2 with short walks	84.3 h (second protocol) vs. 98.4 h (first protocol)	No difference		
					Second: full nutrition POD 0, d/c Foley if epidural drain still in place if able to stand				

Li, 2018 [99]	Retrospective	ERAS 114, control 110	Open	Cervical (laminoplasty)	Preoperative: education, antimicrobial prophylaxis	5.75 days vs. 7.67 days	POD 3 VAS score 2.72 vs. 3.35 (no difference in frequency of breakout pain)	Lower rate of urinary tract infections	
					Perioperative: reduced fasting time, MMA			Higher rate of nausea and vomiting	
					Postoperative: MMA, early drain/catheter removal, nutrition, mobilization				
Debono, 2020 [100]	Retrospective	ERAS 202, control 202	Open	Cervical (ACDF)	Preoperative: patient education	1.40 days vs. 2.96 days	No difference in levels of satisfaction	No difference	
					Perioperative: disinfection protocol,				
					preemptive analgesia, no routine drain, seated in recovery room without brace, early PT				
					Posthospitalization: trained nurse available for phone fast tracking, satisfaction survey, outcome metrics				

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Table 6.1 (continued)

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Carr, 2019 [53]	Retrospective	ERAS 620, traditional 183, non-ERAS after ERAS implemented 129	Open	Cervical, thoracic, lumbar	Preoperative: education, carbohydrate loading, MMA, temperature control, nasal povidone-iodine swab	LOS: 5.4 days vs. 8.2 days			Savings of $19.344 between traditional and ERAS pathways
					Perioperative: temperature control, MMA, TXA	ICU LOS: 1.8 days vs. 3.1 days			
					Postoperative: MMA, early nutrition, drain removal, mobilization				

Dagal, 2019 [101]	Controlled before and after study	ERAS 267, traditional 183, non-ERAS after ERAS implemented 108	Open	Cervical, thoracic, lumbar	Preoperative: optimization of comorbidities, patient education, carbohydrate loading, MMA, temperature control, nasal povidone-iodine swab	LOS: 6.1 days vs. 8.2 days		No difference	$62,429 vs. $53,355
					Perioperative: temperature control, antibiotic and antiemetic prophylaxis, MMA, fluid management	ICU LOS: 1.9 days vs. 3.1 days			
					Postoperative: MMA, early nutrition, mobilization catheter/drain removal				

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Table 6.1 (continued)

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Debono, 2019 [102]	Retrospective	ERAS 1920, control 1563	Both	Cervical and lumbar	Preoperative: patient education, reduced fasting time	ALIF: 3.33 days vs. 6.06 days		ALIF: no difference	
					Perioperative: MIS, limited drain/brace usage	ACDF: 1.3 days vs. 3.08 days		ACDF: no difference	
					Postoperative: MMA, RN on call for questions and mobile app (48 h pre-op to POD 15)	Posterior lumbar fusion: 4.8 days vs. 6.7 days		Posterior lumbar fusion: 10.9% vs. 14.8%	
Sivaganesan, 2019 [103]	Prospective	ERAS 151, control 1596	Open	Cervical and lumbar	Perioperative: MMA Postoperative: early mobilization	Cervical: no difference		Lower overall complication rate (4.6% vs. 11.3%)	
						Lumbar: 2.5 days vs. 2.9 days		Cervical: no difference	
								Lumbar: lower complication (3.8% vs. 12.8%)	

Ifrach, 2020 [104]	Prospective	ERAS 504, control 60	Open	Cervical, thoracic, lumbar (small cohort of peripheral nerve surgeries)	Preoperative: education, consults (e.g., pain management, sleep, endocrine, nutrition)	3.7 days vs. 4.3 days	Reduced 1 month (36.2% vs. 71.7%) and 3 month (33.0% vs. 80%) opioid use with no significant increase in pain scores		
					Perioperative: carb load, MMA				
					Postoperative: early ambulation, meals OOB in chair, limited Foley, dispo on oxycodone 5 mg, PCP follow-up within 2 weeks				
Bradywood, 2017 [82]	Controlled before and after study	ERAS 244, control 214	Open	Lumbar	Use of order sets (postoperative care/ medications, mobility/therapy, patient education), patient education with milestones/ expectations, multidisciplinary rounds with providers/nursing	3.4 days vs. 3.9 days, with greater discharge to home (75% vs. 64%)	No difference	No difference	

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Table 6.1 (continued)

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Wang, 2018 [105]	Retrospective	ERAS 38, control 15	MIS	Lumbar	endoscopic decompression, liposomal bupivacaine, no intubation	1.23 days vs. 3.9 days			$19,212 vs. $22,656
Ali, 2019 [106]	Controlled before and after study	ERAS 201, control 74	Open	Lumbar (small cohort of peripheral nerve surgeries)	Preoperative: patient education, consults (e.g., pain management, sleep medicine, primary care, endocrine, nutrition), phone app	No difference	No difference in pain scores (1 month decrease in use of opioids 38.8% vs. 52.7%)	No difference	
					Perioperative: carb load, MMA				

Tarikci Kilic, 2019 [107]	Retrospective	ERAS 60, control 60	MIS	Lumbar	Preoperative: counseling/education, reduced fasting time	26.52 h vs. 30.10 h	Pre-op: no difference	Decreased nausea (15% vs. 63.3%)	Anesthesia: ₺73.00 vs. ₺270.42
					Perioperative: MIS technique, prophylactic nausea prevention, temperature control, euvolemia, local bupivacaine		6 h: 1.68 vs. 4.03 (VAS)		
					Postoperative: early mobilization/nutrition, MMA		12 h: 1.12 vs. 3.08 (VAS)		Surgery: ₺1,258.67 vs. ₺1,991.67

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Table 6.1 (continued)

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Soffin, 2019 [55]	Retrospective	ERAS 18, control 18	MIS	Lumbar	Preoperative: premedication with acetaminophen and gabapentin, education on NRS pain scale	No statistical difference	No difference in NRS pain scores or PACU opioid consumption, but a decrease in total perioperative opioid consumption in ERAS patients (2.43 vs. 38.125 oral morphine equivalents)		
					Perioperative: MIS, opioid-free anesthesia				
					Postoperative: early nutrition, MMA				
Angus, 2019 [108]	Controlled before and after study	ERAS 214, control 412	Open	Lumbar	Preoperative: prehabilitation, vit D replacement, smoking cessation	Scoliosis: 8 days vs. 11 days		Reduced 30-day readmission (1.9% vs. 2.1% but not statistically significant)	
					Perioperative: carbohydrate load, MMA	Complex fixation: 5.2 days vs. 7 days			
					Postoperative: MMA, post-discharge day 1.3 phone call, post-op check at 6 days				

Brusko, 2019 [65]	Prospective	ERAS 57, control 40	Both	Lumbar	Perioperative: bupivacaine Postoperative: 1 g IV acetaminophen infusion, daily ERAS team visits	2.9 days vs. 3.8 days	POD 1 pain decreased: 4.2 vs. 6		
Smith, 2019 [109]	Retrospective	ERAS 96, control 123	Open	Lumbar	Preoperative: patient education, anesthesia consult, diabetes optimization Perioperative: MMA, prophylactic antiemetic regimen Postoperative: early mobilization, early removal of catheter	No difference	No difference in pain scores (reduction in use of long-acting opioids—5.2% vs. 14.6%)		
Feng, 2019 [110]	controlled, before and after	ERAS 30, control 44	MIS	Lumbar	Preoperative: patient education Perioperative: MMA, TXA Postoperative: early mobilization, nutrition support	5 days vs. 7 days		No difference	¥71,426 vs. ¥70,467

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Table 6.1 (continued)

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Heo, 2019 [111]	Retrospective	ERAS 23, control 46	MIS	Lumbar	Preoperative: emotional support, preemptive analgesic, TXA, antiemetics		VAS higher on POD 1 and 2 for non-ERAS group	No difference	
					Perioperative: MMA, TXA, MIS, vancomycin powder, Dermabond (no suture)				
					Postoperative: early nutrition/mobilization				
Wang, 2020 [112]	Retrospective	ERAS 96, control 96	Open	Lumbar	Preoperative: education/ counseling, reduced fasting time, carb load, SCDs, antibiotic prophylaxis	12.3 days vs. 15.5 days			
					Perioperative: MMA, TXA, temperature management				
					Postoperative: early mobilization, nutrition, drain removal				

Yang, 2020 [113]	Retrospective	ERAS 51, control 21	MIS	Lumbar	Preoperative: education, smoking/alcohol cessation, aerosol antibiotics 2 days prior to intubation, reduced fasting, preanesthesia visit, nutrition assessment, psychological eval from psychiatrist	Improved Barthel index at 3 days and 1 month (equivalent at 6 months), reduced OR time/blood loss/LOS/NSAID use/time to ambulation			
					Perioperative: MMA				
					Postoperative: antibiotics 24 h after surgery, early nutrition and drain removal				

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Table 6.1 (continued)

Author, year	Type of study	Study size	Open or MIS	Type of spine surgery	ERAS components	LOS (vs. traditional)	Pain	Complications/ readmissions	Cost reduction
Grasu, 2018 [52]	Retrospective, controlled, before and after	ERAS 41, control 56	MIS	Tumor	Preoperative: education, anxiety management, pain consult if patient on >5 opioid tablets/day with preoperative tramadol/gabapentin, reduced fasting time	No difference	Trend toward better pain scores and decreased opioid consumption (no statistical significance)	No difference	
					Perioperative: temperature management, MIS when able, IV anesthesia maximization				
					Postoperative: MMA, early mobilization/ nutrition, pain management consult				

ACDF anterior cervical discectomy and fusion, *AIS* adolescent idiopathic scoliosis, *LOS* length of stay, *MIS* minimally invasive surgery, *MMA* multimodal analgesia, *NRS* numeric rating scale, *POD* postoperative day, *PSF* posterior spinal fusion, *PT* physical therapy, *TXA* tranexamic acid, *VAS* visual analog scale

Surgery by Anatomical Level

ERAS protocols have been studied in cervical spine patients [53, 99–104], although many studies report their outcomes in mixed cohorts with other spine surgery procedures. In the study described by Soffin et al., 33 patients underwent with anterior cervical discectomy and fusion or cervical arthroplasty, with each receiving an average of 18 ERAS elements. Patients were found to have minimal complications and no readmissions after 90 days [114]. In another study reported by Debono et al., two groups of patients undergoing anterior cervical discectomy and fusion were compared before and after ERAS implementation, without increased complications and with a significantly decreased LOS [100]. Sivaganesan et al. reported on pre- and post-protocol implementation results in elective degenerative spine surgeries; although there was a significant reduction in LOS with fewer 90-day complications, a subgroup analysis of cervical spine patients showed no significant changes [103]. Venkata and van Dellen also described the implementation of an ERAS protocol centered on early mobilization, opioid use reduction, patient counseling, and reduction of drains. This was a mixed cohort of lumbar and cervical patients, with the majority having undergone non-instrumented lumbar decompression surgeries. Logistic regression models showed no influence on LOS by the type of surgery performed [115]. Other similar studies with mixed cohorts of anatomical levels reported overall cost reductions or improvements in LOS [53, 101].

Lumbar spine surgery accounts for the majority of published ERAS protocols [55, 65, 82, 105–113]. An early fast-track protocol for lumbar spine surgery was reported by Scanlon and Richards in 2004 [116]. In this "same day laminectomy program," patients aged 55 years or less without chronic comorbidities were subjected to a protocol that primarily involved a change in anesthesia from propofol for pentathol, the omission of long-acting muscle relaxants, and early postoperative mobilization. No preoperative changes were made. With their sample of 27 patients that were able to be discharged on the same day of surgery, they estimated an elimination of 54 hospital days and cost savings of $111,420 in costs for the hospital [116]. ERAS protocols have also been evaluated specifically in lumbar fusion surgeries. In a retrospective study, Bradywood et al. found that lumbar fusion patients who entered into a standardized care pathway had significantly decreased median LOS, with a higher percentage of patients discharged home compared to prior to implementation (75% vs. 64%) [82]. No significant differences were identified in pain scores, readmission rates, or falls between groups. In another retrospective study, Wang et al. evaluated their ERAS protocol in elderly patients undergoing one- or two-level lumbar fusions and also found an overall decreased LOS [68].

Opioid consumption following spine surgery is an important consideration that has been evaluated in a few studies. In a prospective controlled study of predominantly thoracolumbar elective spine surgery, Ali et al. compared opioid consumption, pain scores, LOS, and readmission rates [106]. The ERAS protocol that was used involved preoperative education and a carbohydrate load, as well as evaluation by various consultants including nutrition, endocrinology, sleep medicine, and pain management for evaluation and optimization if necessary. Although there was no change in the LOS, the ERAS group had significantly less opioid use immediately postoperatively and at 1 month [106]. This reduction was seen at 3 and 6 months in a follow-up publication [117]. Patients with opioid use disorders undergoing open lumbar surgery have been reported to have increased complications and overall hospitals costs, suggesting that this patient population could benefit from specialized ERAS protocols [118].

Some studies have looked at removing opioids entirely from the intraoperative period. This strategy, known as opioid-free anesthesia, does not allow for systemic, neuraxial, or tissue infiltration with opioids. In a single-surgeon series of MIS lumbar surgeries, patients who underwent such a protocol within an established ERAS pathway did not demonstrate an increase in postoperative pain compared to patients who were treated with a standard ERAS pathway using opioids [55]. Although this study is limited by its sample size, it represents a promising avenue for research and treatment.

Minimally Invasive Surgery

One of the most important innovations in spine surgery has been the proliferation of MIS techniques. Compared to conventional open spinal surgery, MIS techniques often involve smaller incisions, the use of the microscope, endoscope or tubular working channels, and implantation of expandable cages and percutaneous screws. Previous studies have demonstrated that posterior lumbar interbody fusion or transforaminal lumbar interbody fusion (TLIF) procedures done in a MIS fashion reduce both blood loss and LOS compared to open surgery [119, 120]. Despite these apparent benefits, clinical outcomes following MIS procedures are generally equivalent to open procedures [9, 121, 122]. However, multiple studies have reported clear advantages with MIS techniques including fewer postoperative infections [123], reduced opioid consumption [124], improved mobilization [125], and reduced hospital costs [105, 121, 122, 126]. As such, the true value of MIS techniques may be seen when incorporated into a rigorous ERAS framework.

Chang et al. compared endoscopic discectomy with an expandable cage to a standard MIS dissection using a microscope, and reported reduced opioid utilization and LOS in the endoscopic ERAS group [127]. Other major components of this ERAS protocol included IV sedation without intubation, and injection of liposomal bupivacaine. Similarly, Wang et al. found decreased LOS and blood loss in patients undergoing endoscopic MIS TLIF as compared to standard MIS TLIF [105]. There was also a significant cost reduction in the endoscopic ERAS group of 15.2%, approximately $3444, compared to the traditional group [105].

In ERAS protocols where MIS techniques are employed, much of the benefit is attributed to the change in surgical technique; however, that is not to say other ERAS elements are less influential. Feng et al. compared the implementation of an ERAS protocol for MIS TLIF to a historical cohort without an ERAS protocol, and without modification of the surgical technique used between groups [110]. Based on the implementation of 11 ERAS components, there was a significant reduction in LOS, blood loss, cost, and complications [110].

Deformity Surgery

ERAS pathways in fusion for the treatment of adolescent idiopathic scoliosis (AIS) have been studied by multiple groups [94–98]. These complex surgeries often lead to prolonged hospital courses, which is why ERAS protocols may be especially useful in this population. Muhly et al. formalized an accelerated recovery pathway with a focus on MMA, early mobilization and nutrition, and studied outcomes prior to protocol initialization, during the time of transition, and post-protocol [96]. Compared with pre-protocol patients, the LOS was significantly reduced without an increase in readmission rates, and pain in the early postoperative period was significantly reduced. Gornitzky et al. also emphasized the utilization of MMA in the perioperative and postoperative period, demonstrating a 31% reduction in inpatient hospitalization and a 34% decrease in PCA usage [95].

Sanders et al. employed a comprehensive ERAS protocol for AIS and noted a decrease in postoperative hospitalization costs [128]. This protocol utilized preoperative education, early mobilization, drain removal, and nutrition, along with early transition to oral pain medications. With this decrease in hospital usage, there was a decrease in average cost decrease by 22%, from $23,640 to $18,360. There was no increase in rate of complications despite the early discharge [128]. Fletcher et al. also emphasized early mobilization, nutrition, and drain removal following AIS surgery, and reported earlier discharge with a 33% decrease in average costs, and without an increase in the rate of complications [94]. However, the accelerated and standard discharge groups had some notable differences, including a significantly higher utilization of implants and pedicle screws in the standard group. The same group evaluated their pathway in a subsequent publication, reporting a 48% reduction in LOS [97].

Tumor Surgery

ERAS programs lend themselves to improving outcomes in high-risk populations, such as patients with cancer. Grasu et al. devised an ERAS protocol that focused on preconditioning, decreased fasting time, MMA, MIS surgical techniques, and early postoperative mobilization for patients with metastatic spinal tumors [52]. Surgeries ranged from simple decompressions to vertebrectomies. All surgeries were done in an elective manner, and emergency cases were excluded. Both control and ERAS groups had similar preoperative characteristics with similar pain scores, although the tumor location and primary tumor origin were heterogeneous. Patients in the

ERAS group trended toward better postoperative pain control and a decrease in opioid consumption; however, there was no difference in LOS, readmission rates, or complications between the two groups [52].

Outcomes in Elderly Patients

Spine surgery in the aging population is becoming an increasingly relevant topic for neurosurgery as the global population of geriatric adults increases. The United Nation's 2017 World Population Aging Report found that, from 1980 to 2017, the number of adults above age 60 doubled, to increase to an estimated 2.1 billion adults by 2050 [129]. These population trends are starting to be seen in elective spine surgery as well; population data from 2004 to 2015 indicate that the number of elective lumbar fusions increased by 138.7% in patients older than 65 years [27]. Though the literature is sparse, there are definite considerations and potential for specialized protocols, including ERAS protocols, to better address the needs of elderly patients undergoing spine surgery.

Important initial considerations when considering spine surgery in the elderly are to clarify the goal of surgery and perform the proper preoperative evaluation. It has been reported that the goals of the elderly patient are more focused on being pain-free, maintaining mobility, and maintaining the ability to live independently [130]. The preoperative evaluation of geriatric patients should take into consideration patient quality of life and the various "geriatric syndromes," and how they contribute to the overall health and ability to undergo spine surgery. Geriatric syndrome is a term used to describe a set of diseases that are common to geriatric patients although are not necessarily linked physiologically to a specific organ system [131], and include diverse pathologies such as osteoporosis, sarcopenia, malnutrition, disability, decubitus ulcers, delirium, cognitive impairment, and a propensity for falls [129].

There have been several attempts to provide a comprehensive geriatric assessment that incorporates geriatric syndromes and frailty, and can be used to aid preoperative assessment. One such assessment is the Canadian Study of Health and Aging Frailty Index (CSHA-FI) [132], which evaluates 70 variables to measure the accumulative deficits with regard to physical, cognitive, functional, and social domains—this is a comprehensive assessment and is thus time-consuming to administer. A modified version of the CSHA-FI assessment using less variables has been termed the "modified frailty index" [133], and has been applied to predicting morbidity and mortality from spine surgery [134, 135]. In the study reported by Leven et al., patients in the oldest age group (mean of 72 ± 8.3 years) were more likely to have a higher frailty index than younger patients—this was an independent predictor of postoperative complications (need for blood transfusions, thromboembolic events, etc.), mortality, LOS, and reoperations in patients that underwent spinal fusion procedures [134]. As such, it is clear from these studies that the elderly are a vulnerable surgical population and that the development of protocols geared toward their needs is increasingly necessary in spine surgery.

The goals of ERAS protocols are to reduce the surgical stress response and minimize postoperative complications for patients. Although the role of geriatric risk factors in spinal surgery is understudied, most data on elderly patients are intermixed with younger patients, and studies evaluating the effects of ERAS protocols on elderly spine surgery patients are lacking. Few such studies have been published [104, 112]; although the protocols have different specifications, there are many commonalities geared toward meeting the needs of geriatric patients, such as preoperative education and counseling, minimizing prolonged preoperative fasting, early ambulation and oral feedings, and using multimodal perioperative analgesia.

Ifrach et al. examined the efficacy of an ERAS pathway in elderly patients undergoing elective laminectomy, discectomy, foraminotomy, thoracolumbosacral fusion, cervicothoracic fusion, and anterior cervical discectomy and fusion [104]. Relevant pain outcomes included self-reported opioid use at 1 and 3 months and patient-reported pain scores. The preoperative ERAS phase included written educational materials, smoking cessation, and the incorporation consults focused on nutrition, sleep medicine, pain, and endocrinology. Perioperative initiatives included a carbohydrate drink and gabapentin therapy. Postoperative medications included acetaminophen, ketorolac, and muscle relaxants, and limiting opioids for breakthrough pain to only postoperative day 1. Other initiatives included early ambulation, starting thromboembolism prophylaxis on day 1, and follow-up with the patient's primary care physician within 2 weeks. These patients had a significant reduction in 1-month and 3-month self-reported narcotic use without an increase in patient-reported pain scores. Reduction of opioid use in elderly patients is an important topic, as these patients are often subject to polypharmacy due to their multiple medical comorbidities.

Wang et al. studied the efficacy of an ERAS protocol in patients 65 years and older who had lumbar disc herniations or spinal stenosis, requiring one- or two-level lumbar fusion [112]. This retrospective study examined whether such protocols affected complications, LOS, postoperative pain scores, and 30-day readmission rates, compared to a historical cohort of patients who did not receive an ERAS protocol. Preoperative initiatives included patient education and counseling, limiting preoperative fasting, fluid and carbohydrate loading, antibiotic therapy, and antithrombotic stocking. Intraoperative initiatives included the use of tranexamic acid to decrease blood loss, maintaining normothermia, and the use of local analgesia. Postoperative initiatives included early ambulation, transition to oral feeding, early removal of urinary catheters, and multimodal analgesia. Compliance rates to the ERAS protocol were 92.1%, with the poorest compliance reported with discontinuation of the urinary catheter (52.6% of patients). Overall, no differences were identified between ERAS and non-ERAS protocol patients in the number of complications or mortality rates, nor were there differences in validated outcome metrics including the Japanese Orthopaedic Association score, visual analog scale, or Oswestry Disability Index. However, there was a significant decrease in the LOS for patients in the ERAS group (12.30 ± 3.03 days vs. 15.50 ± 1.88 days). Compliance with an

ERAS protocol is closely associated with prognosis; in one retrospective study of elderly patients undergoing lumbar fusion, older patients were less compliant with the protocol, and had a higher incidence of complications and a longer LOS [136].

Elderly patients represent an increasing proportion of patients with degenerative spine disease who will require surgical treatment when conservative measures fail. Their goals of surgery are often different than their younger counterparts, and are focused on their ability to maintain independence and mobility. Chakravarty et al. described an ERAS protocol used at Cleveland Clinic that included referral of all elective spine surgery patients over the age of 75 to geriatricians for frailty assessment and adequate time for optimization and prehabilitation [92]. Further study into the benefits of tailored preoperative optimization and surgical treatments aimed toward the geriatric population is needed, such as MIS procedures which generally have less blood loss and shorter LOS. Elderly patients are a vulnerable population that could benefit from tailored, multidisciplinary ERAS protocols to optimize their surgical treatment, including involvement of geriatricians, nutritionists, pain management specialists, and anesthesiologists.

ERAS Implementation

Ultimately, thoughtful delivery of an ERAS protocol for perioperative spinal surgery requires a multidisciplinary, team-based approach. This should be specific to each institution to appropriately address the needs of the patient population by incorporating readily available resources. For instance, employing a preoperative ERAS protocol with "prehabilitation," optimization of medical comorbidities, and timely administration of gabapentinoids may necessitate the involvement of departmental nurses, nurse practitioners, physical therapists, and referring physicians. Similarly, open dialogue with the anesthesia team and operating room staff may be critical for intraoperative ERAS strategies. Postoperative ERAS implementation using pain management algorithms and early mobilization may require the development of a detailed postoperative order sets for residents, physician extenders, and hospitalists. Additionally educational materials, team-based meetings, and open communication with patients, nurses, nutritionists, physical therapists, and consulting physicians will reduce errors and unify messaging. All of this is essential to enhance both recovery after surgery and the patient experience.

Despite the general consensus that ERAS protocols are beneficial in spine surgery, they are not universally embraced. In a multinational survey of spine surgeons, less than half of respondents were familiar with ERAS as a concept, with only about one-third utilizing ERAS protocols in their own practice [137]. Spine surgery is heterogeneous and multiple options are available for even a single pathology; therefore, no single protocol is universally applicable, making widespread utilization difficult to achieve. As the spine-specific ERAS literature becomes more robust, protocols will become more established and utilization will undoubtedly increase.

Conclusion

Due to the high level of variability and the number of simultaneous changes made in implementing ERAS protocols, the direct effect of any specific change is difficult to ascertain. A recent systematic review of the published literature from 2004 to 2019 regarding multimodality ERAS in adult elective spine surgery identified a variety of protocols, with the most common implementation being preoperative education and peri- and postoperative MMA [11]. Half of the included studies found a significant reduction in LOS, with no study identifying a worse outcome after implementation of an ERAS protocol [11].

The principle of ERAS is based on the synergistic effects of a multimodal approach in caring for a patient from the preoperative to the postoperative phase, with a focus on a multidisciplinary approach in improving surgical outcome and patient satisfaction. A single change alone would not necessarily qualify as an ERAS framework. In general, despite the wide variability in protocol elements and patient populations, ERAS protocols are associated with decreased LOS without any additional complications or readmission rates. Future research and implementation should focus on optimizations that may benefit specific surgical procedures or patient populations.

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