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Preoperative Optimization and Intraoperative Enhanced Recovery Principles for Patients Undergoing Spine Surgery

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Preoperative Assessment for Primary Care Providers

Advanced age, diabetes, heart disease, and lung disease have been identified as comorbidities that increase operative risk [1]. Once the patient and surgeon have agreed to pursue spine surgery, a multidisciplinary, systematic approach to assessing and optimizing these risk factors should occur in order to achieve a successful outcome. This often involves collaboration between the internist, consulting specialists, surgeons, and anesthesiologists. The preoperative medical optimization visit should not only include a thorough review of the patient's medical history, vital signs, and physical exam but should also include a discussion of functional status and new or concerning symptoms. It is imperative to focus on the stability and severity of chronic medical conditions, including a detailed current medication list and medication adherence. The goal of this visit is not to "clear" a patient for surgery but instead to optimize these complex patients while applying guideline-driven recommendations and testing when applicable. The following sections will review a system-based risk assessment for patients undergoing spine surgery.

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Cardiovascular Risk Assessment and Recommendations

Patients undergoing non-cardiac surgery are at risk for major adverse cardiac events (MACE) [2]. Therefore, a meticulous approach to preoperative cardiac evaluation should follow the 2014 American College of Cardiology (ACC) and American Heart Association (AHA) guidelines. In August 2014, the ACC/AHA updated their guidelines for cardiovascular evaluation and care of the patient undergoing non-cardiac surgery [3]. The guidelines provide a step-by-step approach to preoperative risk assessment and management, including a discussion surrounding several surgical risk calculators. Based on the guidelines, determination of the urgency and risk of surgery is a critical first step in the evaluation. Emergency or urgent procedures have been shown to increase risk of complications [4].

Procedure-Specific Risks

Fluid shifts, blood loss, and the degree of hemodynamic compromise have been reported to increase the risk of surgical complications [5]. While previous versions of guidelines classified the risk of the procedure as low, intermediate, or high, the current guidelines recommend stratifying risk into two simple categories: low and elevated risk [3, 6]. Calculation of this risk is based on a combination of both patient and surgical characteristics. Low-risk surgery is characterized as a <1% risk of MACE, while surgery with a risk of MACE of ≥1% is classified as elevated risk [3].

Patient-Specific Risks

The value of a comprehensive history and physical examination in the preoperative evaluation cannot be overstated. By understanding a patient's medical history, including identifying and assessing factors that can influence outcomes, the clinician can use evidence-based guidelines to guide decision surrounding preoperative testing and also to predict post-operative complications. The patient should ideally be evaluated within a month of the planned surgery. An assessment of functional capacity is a crucial aspect of this evaluation, with metabolic equivalents (METS) representing the primary method used to assess functional status. Functional status is defined as excellent (>10 METS), good (7–10 METS), moderate (4–6 METS), and poor (<4 METS). METS >4 has been considered adequate to proceed with surgery in the absence of active cardiac conditions or concerning clinical symptoms [3]. Recently published trials have found the Duke Activity Status Index (DASI), a questionnaire used to determine a patient's ability to achieve an appropriate METS, to be a more accurate measurement of a patient's actual functional capacity compared to a clinician's subjective assessment [7–9]. Moreover, DASI performed better when compared to stress testing and cardiac biomarkers like brain natriuretic peptide [8]. The DASI score is calculated by tallying the points of all performed activities, with higher numbers indicating a higher functional status. The score can then be converted to METS. Based on a study from Wijeysundera et al., a DASI score of 34 or less means that the patient is at risk for MACE and post-operative complications [9].

Risk Calculators

Cardiac risk calculators have also been used to assess perioperative cardiac complications. The use of these calculators has evolved over time, and no single tool is perfect. The most cited and externally validated tool is the Revised Cardiac Risk Index (RCRI) [10]. The RCRI consists of six risk factors that increase a patient's risk of cardiac complications. These six risk factors include: history of congestive heart failure, history of cerebrovascular disease, history of ischemic heart disease, high-risk surgery, creatinine >2 mg/dl, and diabetes requiring insulin [10]. Per the 2014 ACC/AHA guidelines, a patient with 0 or 1 risk factor is considered low risk while ≥2 risk factors is considered elevated risk [3]. Other risk calculators include the Gupta Myocardial Infarction and Cardiac Arrest calculator and the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) surgical risk calculator. Using the NSQIP database, Gupta et al. identified five unique predictors of MACE [11]. These include type of surgery, functional status, abnormal creatinine, age, and American Society of Anesthesiologists (ASA) physical status classification. The ACS-NSQIP calculator, although cumbersome, has garnered considerable attention as it is a more comprehensive risk calculator that enables procedure-specific risk assessment [12]. Both of these calculators are available online. Based on review of the evidence, these newer risk indices may perform better but should be applied in the setting in which they were studied [13].

Cardiovascular Clinical Risk Factors

Coronary Artery Disease

Livhits et al. observed that patients with a history of coronary artery disease (CAD) are at risk for cardiac complications, with recent acute coronary syndrome associated with an especially greater risk [14]. They also noted the postoperative myocardial infarction (MI) rate decreased as the length of time from MI to operation increased (0–30 days = 32.8%, 31–60 days = 18.7%, 61–90 days = 8.4%, 91–180 days = 5.9%), as did 30-day mortality (0–30 days = 14.2%, 31–60 days = 11.5%, 61–90 days = 10.5%, 91–180 days = 9.9%). The risk was modifiable by how long from the planned surgical date the myocardial infarction occurred, if revascularization was performed, and the type of revascularization [15]. Analyzing the data, surgery within 1 month of an acute coronary syndrome is associated with a significantly increased risk of MACE. The 2014 ACC/AHA guidelines recommend delaying elective surgery for at least 2 months following an MI [3]. Patients with stable CAD, without recent acute MI, red flags, or worrisome clinical symptoms should be able to proceed to surgery without any further risk stratification.

Valvular Heart Disease

Patients with valvular heart disease undergoing non-cardiac surgery have an increased risk of MACE in the postoperative period [16]. This risk is dependent on the valve, the severity of the disease, and the type of non-cardiac surgery. The 2014 ACC/AHA guidelines recommend an echocardiogram for moderate-to-severe valvular disease if an echocardiogram has not been performed within 1 year or there is a change in the clinical status or physical exam [3]. For patients with moderate-to-severe valvular disease, a multidisciplinary preoperative discussion with the cardiologist, surgeon, and anesthesiologist is crucial to develop a perioperative plan as additional hemodynamic monitoring may be needed. If indicated, valvular intervention prior to surgery can reduce risk [16].

Heart Failure

Heart failure is a significant cardiac risk factor [17]. Although evidence is scarce on how asymptomatic heart failure impacts postoperative outcomes, the literature and guidelines specify that patients with decompensated heart failure should have surgery delayed unless the procedure is emergent [3]. Several studies have shown that patients with a left ventricular ejection fraction of <35% may also have an increased risk of postoperative complications [18]. For this reason, close hemodynamic monitoring in the perioperative period may be warranted. Optimal goal directed medical therapy for the treatment of heart failure can mitigate some of the risk [19].

Pulmonary Risk Assessment and Recommendations

Pulmonary complications are an underappreciated cause of perioperative mortality and morbidity [20, 21]. A thorough history and physical examination, including evaluation of tobacco history, remains the mainstay of the preoperative pulmonary assessment. Pulmonary risk assessment can be further divided into patient-related risk factors and procedure-related risk factors. Patient-related factors include asthma, tobacco use, heart failure, chronic obstructive pulmonary disease (COPD), obesity, and obstructive sleep apnea (OSA). Procedure-related risk is largely determined by the surgical site, with surgery closer to the diaphragm associated with greater risk [20, 21].

Several risk indices have been developed to predict the risk of postoperative pulmonary complications, including pneumonia and respiratory failure [22, 23]. Of note, many of these pulmonary risk indices exclude OSA. Although many cases likely go undiagnosed, the prevalence of OSA is increasing in the population. Patients with OSA require close monitoring in the perioperative setting because of their increased risk for complications [24, 25]. Consequently, all patients should be screened for OSA preoperatively. The most widely used OSA screening tool is the STOP-BANG questionnaire. Chung et al. demonstrated that the STOP-BANG questionnaire is a reliable and easy tool to screen for OSA. Each positive risk factor is scored one point, with a total score ≥3 indicating an increased risk for OSA [24, 25].

Pulmonary Risk Reduction

Chronic pulmonary conditions such as asthma and COPD should be optimized prior to surgery. Recent pulmonary function tests (PFTs) are helpful in assessing the degree of obstructive or restrictive lung disease. Pulmonary risk reduction can occur in several stages during the course of care. Preoperatively, the internist or pulmonologist should focus on patient education, including awareness of OSA risk, tobacco cessation when applicable, optimization of underlying disease, and the use of bronchodilators and steroids when indicated. Postoperative risk reduction measures include continuation of bronchodilators, incentive spirometry, analgesia, and the use of continuous positive airway pressure as needed [26].

Hematologic Risk Assessment and Recommendations

Preoperative Anemia

Approximately one-third of patients evaluated during their preoperative assessment will be diagnosed with anemia [27]. As such, this represents a commonly-encountered and modifiable risk factor in the presurgical patient. Preoperative anemia is often attributed to iron-deficiency anemia and anemia of inflammation (also known as anemia of chronic disease) [28]. While anemia has been classically defined by the World Health Organization (WHO) as a hemoglobin <13 g/dL in men and <12 g/dL in women, a universal threshold of <13 g/dL in all perioperative patients may be considered [28, 29]. A retrospective analysis of 227,425 patients undergoing major noncardiac surgery showed an increased 30-day risk of mortality (odds ratio 1.42, confidence interval 1.31–1.54) and morbidity (odds ratio 1.35, confidence interval 1.3–1.4) in patients with preoperative anemia after controlling for other confounding variables [27]. As a first step in the risk assessment, consideration should be given to the cause of the anemia. This should include a thorough medical history and physical exam. Spine surgery may be postponed depending on the severity of anemia, diagnostic workup required, and urgency of the planned procedure.

Causes of Preoperative Anemia and Management

The management of preoperative anemia should employ a Patient Blood Management (PBM) approach [30–32]. The WHO defines PBM as “patient-focused, evidence-based and systematic approach to optimize the management of patients and transfusion of blood products for quality and effective patient care. It is designed to improve patient outcomes through the safe and rational use of blood and blood products and by minimizing unnecessary exposure to blood products” [32]. The core principles of PBM include: management of anemia, multimodal approach to blood conservation, optimize hemostasis, patient-centered care and decision making [30]. By adhering to these principles, providers can minimize postoperative complications associated with anemia and the unnecessary use of blood transfusion. In most circumstances, anemia can be corrected with treatment prior to the planned surgery, which can also decrease the need for blood transfusion in the perioperative period [33, 34].

Iron Deficiency Anemia

Both oral and intravenous (IV) iron therapy are treatment options for iron deficiency anemia. Oral iron is often the first treatment choice provided there is sufficient time prior to surgery to replete iron stores and raise the hemoglobin value. Nonetheless, the efficacy of oral iron compared to IV iron in the presurgical patient with iron deficiency anemia has been debated [35]. Poor gastrointestinal absorption, patient intolerance, and an acute or chronic inflammatory state (referred to as anemia of chronic disease) may alter the efficacy of oral iron [34, 36]. Whichever approach is chosen, sufficient time must be given for either oral or IV iron to optimize hemoglobin and iron stores [33].

Anemia of Chronic Disease

Anemia of chronic disease, as seen in chronic renal insufficiency, is often driven by a decrease in erythropoietin production and iron metabolism [33, 34, 36]. Directed therapy involves not only addressing the chronic disease but also replenishing erythropoietin [36]. Erythropoiesis-stimulating agent (ESA) is the driver to produce red blood cells and works in synergy with iron, highlighting the importance of appropriate iron stores. There is growing evidence that the use of ESA in the preoperative management of anemia can decrease the need for allogenic blood transfusion [37–40]. However, the use of ESA in the presurgical patient has been a source of contention, particularly surrounding the matter of thrombosis. Evaluating the use of preoperative ESA in patients undergoing knee or hip arthroplasty, Alsaleh et al. found no significant difference in the risk of thromboembolism in patients who received ESA compared to patients who did not [37]. Additionally, the authors observed that there was a decreased rate of blood transfusion in the group of patients who received ESA. With appropriate patient selection, attention to the degree of blood loss for the planned surgery, and the use of a strong PBM program, ESA can decrease the need for blood transfusion in the perioperative period [32, 37–40].

Endocrine Risk Assessment and Recommendations

There is a significant amount of evidence linking hyperglycemia to poor outcomes in patients undergoing surgery [41, 42]. Poorly-controlled diabetes, regardless of the duration, can have detrimental effects in the postoperative period. Hyperglycemia is known to impair leukocyte function [43]. Unsurprisingly there is an association between poorly-controlled diabetes with hyperglycemia and an increased risk of surgical site infection [43, 44]. When a patient arrives for a preoperative visit, it is important to determine their level of glycemic control, including their most recent hemoglobin A1C level. This value is not only useful for diagnosing diabetes (≥6.5% being diagnostic of diabetes) but is also an essential tool for assessing glycemic control. The ideal hemoglobin A1C for elective surgery has been a source of contention in the literature. Although there is no defined threshold preoperative hemoglobin A1C to proceed with surgery, a value <8% appears to correspond to a decrease risk of postoperative complications [45]. Achieving this goal requires timely referral to the managing clinician for optimization, which may include titration of existing medications or the addition of other agents. Additionally, the preoperative visit will include a discussion of the management of both oral and injectable diabetic medications on the day prior to surgery and the day of surgery. Although hemoglobin A1C and blood glucose have their limitations, they remain valuable indicators of a patient's glycemic control.

There is a growing body of literature describing the use of other markers that reflect glycemic control in the perioperative period [46]. One of these markers is serum fructosamine, which measures the level of glycated serum proteins like albumin. Fructosamine reflects mean glucose levels over 14–21 days and may be a better marker for poor glycemic control than hemoglobin A1C [46]. In a large prospective multicenter study, it was shown to be an excellent predictor of adverse outcomes in patients following total knee arthroplasty. In this same population, fructosamine better reflected glycemic control, possessed greater predictive power for complications, and responded faster to treatment compared to hemoglobin A1C [46].

Regardless of which screening tool is used, improving outcomes in the diabetic patient undergoing surgery starts with optimal glucose control. In general, it is recommended to stop oral hypoglycemic medications on the morning of surgery, stop prandial insulin, and continue basal insulin with dose adjustments based on individual patient needs.

Introduction to the Anesthesia Preoperative Evaluation

In addition to the preoperative assessment by primary care providers, further patient optimization and risk stratification can occur in the immediate preoperative setting by anesthesiology providers. Perioperative anesthesia evaluation and education of spine surgery patients not only helps to improve patient satisfaction but also allows the anesthesia team guide medical optimization in collaboration with patients' primary care providers, consulting specialists, and surgical team [47]. Furthermore, evaluation in an anesthesia preoperative clinic allows for a thorough medical assessment, laboratory and cardiac testing prior to the day of surgery, focused conversations regarding anesthetic risks, and an introduction to Enhanced Recovery after Surgery (ERAS) protocols.

The anesthesia preoperative clinic evaluation may begin by triaging patients based on complex vs simple spinal surgery and surgical urgency. Simple spine surgery includes microdiscectomy and laminectomy for degenerative disease, while more complex surgery consists of spinal instrumentation, trauma, and tumor surgery [48]. While spinal surgeries are usually elective and thus allow time for adequate optimization, surgery for oncologic indications may be more time sensitive. Urgent procedures to address acute myelopathies or cauda equina syndrome mandate rapid evaluation [48].

System-Based Approach to the Preoperative Anesthesia Evaluation

Anesthetic preoperative evaluation usually follows a system-based approach. Special attention should be paid to preoperative vital signs to ensure not only that systemic blood pressure is optimized, but also well documented so that intraoperative hemodynamic goals can target 20% of the preoperative baseline. Even stricter blood pressure control may be required in patients with myelopathy or trauma to the spine [49]. The preoperative clinic is an ideal setting to discuss preoperative medication administration. Many clinics have established guidelines to instruct patients on which medications to continue perioperatively and which medications to hold. Depending on comorbidities, certain medications such as beta-blockers, pulmonary hypertension agents, and antiepileptics should be continued uninterrupted. Other medications like angiotensin converting enzyme (ACE) inhibitors and anticoagulants will likely need to be held. Discontinuation of anticoagulation or antiplatelet agents is advised only after consultation with the prescribing provider, especially in patients with recent cardiac stents or surgery.

Airway

A detailed airway evaluation is critical in spine surgery patients, especially those presenting for cervical or upper thoracic spine surgery. Careful documentation of the extent of mouth opening, neck range of motion, and symptoms such as pain or paresthesia elicited with neck movement should all be included. Many of these patients have disease pathology, such as rheumatoid arthritis or ankylosing spondylitis, that may limit neck mobility or distort airway anatomy. Preoperative airway evaluation will help the anesthesia team decide upon an appropriate intubation technique. For those patients with myelopathy or evidence of an unstable cervical spine, the anesthesiologist may choose to alter the intubation technique and perform an awake fiberoptic intubation [50].

Pulmonary

As mentioned above, chronic pulmonary conditions such as asthma or COPD should be optimized as much as possible prior to surgery. Recent PFTs are helpful in assessing the degree of obstructive or restrictive lung disease. Patients presenting for spine surgery often have restrictive lung disease related to their spinal pathology or curvature, which can decrease their vital capacity and total lung capacity. Special consideration should be given to patients with severe restrictive lung disease, as this can progress to pulmonary hypertension [50]. When appropriate, the anesthesia preoperative clinic should work in conjunction with the patient's primary care provider and/or pulmonologist to optimize their pulmonary medication regimen and compliance prior to surgery. Major thoracic spine surgery may require one lung ventilation, and careful preoperative assessment and optimization is critical for these patients.

Cardiovascular

Approach to the preoperative cardiac evaluation should follow the updated ACC/AHA guidelines as discussed above. The decision to obtain a preoperative electrocardiogram (ECG), echocardiogram, stress testing, and even coronary angiography should be directed by evidenced-based protocols for non-cardiac surgery. However, specific to spine surgery, special consideration should be given to patients with significant restrictive lung disease as this may result in pulmonary hypertension or cor pulmonale. Preoperative assessment of functional activity may also be limited in these patients secondary to pain or myelopathy, therefore cardiac risk stratification based activity level (or METS achieved) may be more difficult to discern.

Spine surgery is usually performed in the prone position. This can lead to decreased venous return and left ventricular compliance, which can subsequently cause a reduction in cardiac output [50]. Therefore, a thorough documentation of prior cardiac history should be pursued, noting any structural or valvular defects. Prior ischemic heart disease and/or history of arrhythmias is also important to investigate. Many of these diagnoses have implications for perioperative anticoagulation, therefore a clear history should be obtained. Complex heart disease may also change the anesthetic plan, increasing the need for more invasive monitoring, vascular access, or even requiring the assistance of anesthesia teams specializing in cardiac anesthesia. Arranging this ahead of time, along with a thorough discussion of anesthetic risks can help ensure there is no day of surgery delay. Specific conditions, such as pulmonary hypertension and congestive heart failure can be especially associated with increased perioperative morbidity and mortality [51]. Gathering medical records and engaging with a patient's primary care provider, cardiologist, or pulmonologist preoperatively to ensure optimization is critical, especially for more complex or high-risk spine surgeries.

Neuromuscular

Meticulous evaluation of preexisting neuromuscular symptoms is important in the preoperative evaluation of the spine patient. Existing motor or sensory deficits should be clearly documented. This ensures that care can be taken during operative positioning and that the postoperative exam can be compared to preoperative exam. The presence of existing motor deficits, such as weakness, immobility or paralysis may change the anesthetic plan. For example, the anesthesiologist may choose to avoid the use of succinylcholine as these patients may have upregulation of acetylcholine receptors. The use of succinylcholine may precipitate a dangerous episode of hyperkalemia.

Positioning Considerations

Most spinal procedures are performed in the prone position and as such, special considerations should be evaluated preoperatively. Attention to preoperative skin bruising or limited neck or extremity mobility should be noted so that care can be taken intraoperatively. The anesthesiologist performing the case may choose to provide extra padding to sensitive areas and avoid manipulation of the neck or extremities that may cause pain when patient is awake. For lumbar and lower thoracic surgery in the prone position, the arms may be tucked at the sides or placed in the "prone superman" position [50].

As above, prone positioning can also have effects on cardiovascular physiology. Abdominal compression can cause a decrease in venous return, resulting in decreased cardiac output and intraoperative hypotension. Preoperative screening should be sought to identify patients more at risk for intolerance of decreased venous return (e.g., those with valvular disorders, hypertrophic cardiomyopathy, etc.). Attention should also be given to patients with implantable devices such as pacemakers or implantable cardioverter defibrillators (ICDs). Depending on the underlying indication for placement, pacing dependency, and make/model, a coordinated plan should be developed with the patient's cardiologist. Magnet placement may be difficult or susceptible to malposition in the prone position. Preoperative reprogramming with a device representative may need to be coordinated prior to surgery. Prone positioning is also a risk factor for perioperative vision loss (POVL) [52]. This risk should be discussed with patients during their preoperative visit. An overview of the intraoperative considerations for POVL is provided later in this chapter.

Blood Bank Coordination

Complex spine surgery can be associated with significant blood loss. As previously mentioned, preoperative evaluation should include anemia screening and optimization with oral or IV iron as needed. For most spine surgery, a type and screen sample should be sent at their preoperative visit. If blood antibodies are identified during the preoperative type and screen, coordination with the blood bank should ensure that an adequate supply of type-specific blood is available. Certain types of spinal tumors are especially high risk for hemorrhage, (e.g., renal cell, melanoma, and sarcoma metastasis) and consideration should be given to preoperative tumor embolization [48]. Cell saver may also be requested preoperatively. Preoperative autologous blood donation is not routine in all surgical centers; however, it may be considered for patients having complex spinal procedures where estimated blood loss is anticipated to be at least 500–1000 mL [53].

Pain Assessment

Attention should also be paid to chronic pain medication use and its effectiveness. Since spinal surgery can be associated with an increased need for postoperative analgesia, documenting baseline preoperative opioid use can be important in calculating perioperative opioid requirements. Evaluating the preoperative analgesic regimen effectiveness can also be done by using the Visual Analogue Score (VAS) Pain Assessment [54]. If ineffective pain control is noted, preoperative referral to a pain specialist may be helpful. For patients receiving chronic opioids, there should be consideration given to weaning and titration of non-opioid agents in conjunction with a pain specialist. If there is any concern for addiction, placing a preoperative referral to an addiction specialist is recommended.

Preoperative Testing

Preoperative testing should be deliberately ordered based on a patient's medical history, comorbidities, and the complexity of the planned surgery. Establishing a formalized set of guidelines or laboratory testing grid helps to ensure appropriate studies are performed and avoids the ordering of unnecessary tests [55]. Usually a baseline hemoglobin level, platelet count, and serum chemistry panel (including creatinine and electrolytes) are obtained on most spine surgery patients. Besides simple spine procedures, most spinal surgery requires a preoperative type and screen as well. As above, cardiac testing such as ECG, echocardiogram, and stress test should only be obtained based on the updated ACC/AHA guidelines. Women of childbearing age should be screened with a preoperative pregnancy test. An example of a preoperative testing order grid is shown in Table 15.1.

Informed Consent and Discussion of Anesthetic Risks

Discussion of the anesthetic plan and informed consent should be included in the preoperative clinic visit [48]. Patients should be informed of potential plans for extra vascular access, such as additional peripheral IVs, arterial lines, or possibly central venous catheters. The risks of anesthesia and spine surgery-specific risks should be discussed thoroughly. Albeit rare, prone positioning carries a unique set of risks including pressure or nerve-related injuries and POVL. The preoperative clinic visit is also an appropriate time to ensure the patient has capacity to consent and that advanced directives have been arranged [48].

Table 15.1 Sample preoperative testing order grid

	CBC	PTT/ PT/ INR	BMP	Heparin assay (UFH)	Type & screen	Preg test	ECG
Patient-specific factors							
Cardiovascular disease (other than well-controlled HTN) Poorly-controlled HTN is >140/90 OR <140/90 on ≥2 medications)	X		X				X
Pulmonary disease (other than mild-moderate asthma)	X		X				
Cerebrovascular disease (CVA, TIA)	X		X				X
History of bleeding disorders	X	X					
Diabetes mellitus (POC glucose always checked on DOS)			X				X
History of renal dysfunction/failure	X		X				
History of liver dysfunction/cirrhosis	X	X	X				
Pacemaker/defibrillator							X
AGE >65 for intermediate or high-risk procedure							X
Female pts ≤60 unless hysterectomy or post-menopausal for 1 year						X	
Medications							
Chemotherapy within last 6 months or any anticoagulant	X						
Use of diuretics, digoxin, potassium, ACEI or ARB			X				
Coumadin therapy (INR only, PTT not necessary)	X	X					
Heparin therapy (PTT no longer needed, heparin assay preferred)	X			X			
Procedure-specific factors							
Neurosurgery procedures-all except shunts, rhizotomy, DBS, intrathecal pumps	X		X		X		

Preoperative Introduction to Enhanced Recovery After Surgery

ERAS pathways are evidence-based, integrated, multidisciplinary protocols used to guide the perioperative management of surgical patients. Originally designed to speed recovery and minimize the surgical stress response in patients undergoing colorectal surgery, ERAS pathways have since been developed for several surgical specialties [56, 57]. The preoperative clinic visit is an excellent time to introduce the concept of ERAS. In accordance with these pathways, patients should be advised on smoking and alcohol cessation, postoperative pain expectations, and the overall pain management plan. Institutional preoperative fasting policies should also be discussed. Usually patients are asked to abstain from eating solids for 6–8 hours preoperatively; however, many ERAS protocols advocate for hydration and encourage consumption of a carbohydrate-loaded clear liquid 2–3 hours prior to surgery.

ERAS protocols often incorporate multimodal analgesia to minimize opioid requirements, and it is common to administer analgesics by mouth on the day of surgery. The preoperative clinic visit is an ideal time to discuss the preoperative administration of these agents and screen for any contraindications. Furthermore, providing patients with a written copy of the ERAS plan can improve compliance and satisfaction with the perioperative experience [47]. The remaining sections will review intraoperative anesthetic management principles for spine surgery in the context of ERAS.

Tenets of Anesthetic Intraoperative Management and Spine ERAS Pathways

Background

Despite a growing interest in enhanced recovery, the application of ERAS principles to spine surgery has only recently gained popularity. Given that spine surgery is often associated with a prolonged recovery period requiring intensive rehabilitation and pain management, the adoption of ERAS initiatives has the potential to improve outcomes and decrease rates of complications [58]. Because spine surgery includes procedures of varying degrees of complexity and invasiveness, there are different levels of surgical stress response activation and thus several options for surgical and anesthetic techniques. This heterogeneity has likely contributed to the delay in developing a "one size fits all" ERAS pathway for spine surgery [59]. Acknowledging this, there are some common intraoperative elements of ERAS pathways that can be applied to spine surgery. Namely attempts to reduce the surgical stress response with minimally invasive techniques, goal directed fluid management strategies, preservation of normothermia, and the use of multimodal analgesia including non-opioid agents [58, 60]. Separate from ERAS, there are unique considerations in spine surgery that require special attention from anesthesia providers. These include the choice of anesthetic technique, management of massive blood loss, and risk for POVL. The following sections will review the intraoperative components of ERAS relevant to spine surgery and highlight examples of published pathways.

Anesthetic Technique

There is no consensus on the optimal anesthetic technique for patients undergoing spine surgery. Available options include general anesthesia, monitored anesthesia care (MAC), or neuraxial (spinal or epidural) anesthesia. Each of these techniques is associated with advantages and disadvantages. While general anesthesia allows for a secure airway and motionless operating environment, it may be associated with more hemodynamic changes and higher rates of postoperative nausea and vomiting (PONV). Alternatively, MAC and neuraxial anesthesia can be performed without manipulating the airway but may be associated with patient movement. Because of patient comfort, a neuraxial technique may be more appropriate in shorter, minimally invasive procedures. In high-risk patients undergoing lumbar spine surgery, performance of the procedure under spinal anesthesia is associated with better perioperative hemodynamic stability, shorter duration of surgery, and lower PONV rates than when performed under general anesthesia [61]. Similarly, a meta-analysis of randomized controlled trials comparing perioperative outcomes in lumbar spine surgery under spinal anesthesia versus general anesthesia concluded that spinal anesthesia offers several hemodynamic advantages in this patient population [62]. Despite these results, there remains heterogeneity in the anesthesia technique recommended in published ERAS pathways.

Fluid Management

The goal of intraoperative fluid management is maintenance of euvolemia. The application of goal directed fluid therapy strategies has been associated with improved perioperative outcomes [63–65]. While dynamic assessment of fluid responsiveness with stroke volume variation or pulse pressure variation may allow for an individualized fluid strategy, this has not been universally adopted. In general, it has been recommended to administer a maintenance rate of balanced crystalloid at 2–3 mL/kg/h with additional boluses of fluid as needed to treat hypovolemia [64]. A fluid strategy including both crystalloids and colloids may minimize the development of tissue edema.

Perioperative Vision Loss

POVL is a feared complication of spine surgery. It occurs with a frequency of 0.013–1% of cases [66]. The etiology of POVL is multifactorial and is variously attributed to ischemic optic neuropathy, central retinal artery occlusion, central retinal vein occlusion, cortical blindness, direct compression, and other causes [66]. Risk factors for the development of POVL include male gender, prolonged operating times, prone positioning, anemia, hypotension, obesity, use of the Wilson frame, and greater blood loss [66, 67]. To minimize the development of POVL, it is recommended to periodically monitor hemoglobin or hematocrit values in high-risk patients with substantial blood loss and transfuse as appropriate. If possible, high-risk patients should be positioned so that the head is level or higher than the rest of the body. Additionally, treatment of hypotension and evaluation of the patient's face and neck is warranted [68]. Direct pressure on the eyes should be avoided, and deliberate hypotension should be employed only if the anesthesiologist and surgeon agree that its use is essential.

Analgesia

Multimodal Analgesia

As introduced in the preoperative section, multimodal analgesia strategies are important components of many ERAS programs. The principle behind multimodal analgesia is achievement of pain management without a large reliance on opioids. This is often accomplished by administering several medications with different mechanisms of action and pharmacologic effects. In theory, such a strategy allows for effective analgesia and minimizes the negative effects of opioids, such as oversedation, ileus, nausea, respiratory depression, and addiction [69]. While a single best regimen has not been identified, acetaminophen, nonsteroidal anti-inflammatory drugs (NSAIDs), gabapentinoids, ketamine, muscle relaxants, local anesthetics, and neuraxial anesthetic techniques are often included in multimodal protocols [70–73]. These agents may be especially efficacious in patients with chronic pain who have previously been exposed to opioids.

Within spine surgery, acetaminophen, NSAIDs, gabapentinoids, neuraxial anesthesia, ketamine, and long-acting local anesthetics have all been found to reduce narcotic requirements and postoperative pain [70, 71]. A meta-analysis of 10 RCTs assessing the efficacy of preoperative gabapentin in spine surgery concluded that gabapentin was effective in reducing postoperative opioid consumption, VAS scores, and several postoperative side effects [74]. A meta-analysis of 14 randomized controlled trials concluded that supplemental perioperative ketamine reduces postoperative opioid consumption up to 24 hours following spine surgery [75]. Administration of a perioperative IV lidocaine infusion reduced pain scores and resulted in significantly improved quality of life scores at 1 and 3 months postoperatively in patients undergoing complex spine surgery [76]. Ketorolac is an NSAID that is commonly used to treat postoperative pain. As it has been implicated in inhibiting osteogenesis, the use of ketorolac in spine surgery is limited. Notably the results of a meta-analysis of five retrospective comparative studies concluded that short-term (<14 days) exposure to normal-dose ketorolac (<120 mg/day) was safe after spinal fusion while short-term exposure to high-dose ketorolac (>120 mg/day) increased the risk of nonunion [73, 77]. A large prospective randomized controlled trial designed to evaluate the effect of ketorolac on fusion rates is ongoing [78].

While there is high quality evidence that supports the administration of many of the individual medications included in multimodal regimens, there seems to be insufficient or conflicting evidence on the effectiveness of these medications when included within a multimodal pathway [70]. For example, Maheshwari et al. performed a randomized controlled trial to examine the effectiveness of a combination of four non-opioid analgesics versus placebo on Quality of Recovery scores, postoperative opioid consumption, and pain scores in adults undergoing multilevel spine surgery who were at high risk for postoperative pain [71]. In their study, an analgesic pathway based on preoperative oral acetaminophen and gabapentin, combined with intraoperative infusions of lidocaine and ketamine did not improve day 3 Quality of Recovery scores, reduce pain scores, or reduce 48-hour opioid consumption. The results of this study suggest that further investigation into the effectiveness of multimodal analgesic strategies within spine surgery is needed.

Opioid-Free Analgesia

The complete elimination of opioids may represent the next frontier in spine surgery analgesia. Soffin et al. retrospectively evaluated an opioid-free analgesic regimen within an established ERAS pathway for lumbar decompressive surgery [79]. The authors compared perioperative opioid requirements in a matched cohort of patients managed with traditional analgesic regimens that included opioids. Their opioid-free regimen included preoperative oral acetaminophen, oral gabapentin, and midazolam. Intraoperatively, the patients received infusions of propofol, ketamine, and lidocaine in addition to inhalational anesthesia up to 0.5 minimum alveolar concentration (MAC). Dual antiemetic therapy with dexamethasone and ondansetron were administered, and ketorolac was given during surgical closure. All patients received subcutaneous infiltration with 10 mL of 0.25% bupivacaine following fascial closure and immediately prior to skin closure. Patients in the opioid-free analgesia group had a significant reduction in their total perioperative opioid consumption and did not have any adverse effects on postoperative pain scores, opioid requirements, or recovery [79].

Bleeding During Spine Surgery

Spine surgery has the potential for substantial blood loss. Effective planning and communication among all members of the care team can reduce perioperative bleeding, morbidity, and mortality [80]. Significant blood loss causes anemia, coagulopathy, hypotension, and organ dysfunction [81]. Furthermore, excessive bleeding requires allogenic blood transfusion, which has been associated with surgical site infections, lung injury, hypersensitivity reactions, immune modulation, and increased hospital length of stay (LOS) [80, 82, 83]. Perioperative bleeding in spine surgery increases the risk for spinal epidural hematoma formation, which can cause spinal cord compression [82]. Adopting a liberal perioperative blood transfusion strategy ($\geq$10 g/dL intraoperatively or $\geq$8 g/dL postoperatively) is associated with increased costs in patients undergoing spine surgery [84].

Monitoring for Blood Loss

Rotational thromboelastometry (ROTEM) is a rapid, real-time viscoelastometic method for hemostasis testing in whole blood. ROTEM allows for evaluation of the interaction between multiple coagulation factors and cellular components during both the coagulation and lysis phases [85]. In this way, providers can identify the specific deficiency in the coagulation pathway and provide an individualized treatment [80]. In major spine surgery, the use of ROTEM-guided transfusion allows for standardization of transfusion practices [85]. Furthermore, the use of ROTEM during thoracolumbar deformity correction is associated with lower transfusion requirements [86].

Pharmacologic Agents to Mitigate Blood Loss

Excessive fibrinolysis has been implicated as a factor exacerbating blood loss in spine surgery. Antifibrinolytic agents work to decrease bleeding via inhibition of clot breakdown [87]. Antifibrinolytics such as aprotinin, tranexamic acid (TXA), and epsilon-aminocaproic acid have been shown to reduce perioperative blood loss and transfusion requirements in patients undergoing spine surgery [82, 88]. According to the results of a recently published meta-analysis of randomized control trials, TXA may be the most efficacious agent in reducing total blood loss, intraoperative blood loss, and blood transfusion [82]. Furthermore, there was no evidence from this analysis that the use of these agents was a risk factor for thromboembolism in spine surgery. While the optimal dosing and duration is still unclear, it is recommended that all patients undergoing major spine surgery receive a loading dose of TXA at incision followed by a maintenance infusion during the case [64, 88].

Hypotensive Anesthesia for Reducing Blood Loss

It is thought that controlled hypotension reduces blood extravasation and local wound blood flow [89]. While this technique may help reduce bleeding from soft tissues, both epidural venous plexus pressure and intraosseous pressure are more important determinants of blood loss during spine surgery, and these are both independent of arterial blood pressure [80, 89]. The major risks associated with controlled hypotension are impairing end-organ perfusion, especially the optic nerve and the spinal cord [80, 89]. This technique should only be performed if agreed upon by both the surgeon and anesthesiologist.

Bleeding and Temperature Management

Intraoperative hypothermia is a multifactorial clinical entity, caused by a low operating room (OR) temperature, administration of room-temperature IV fluids, evaporation from surgical wounds, and impaired thermoregulation from induction of general anesthesia [80]. Hypothermia is known to impair the function of platelets and enzymes of the coagulation cascade. Reductions in body temperature may also disrupt thrombin and fibrinogen synthesis [90]. In a pooled population of surgical patients undergoing several procedures, even mild hypothermia (34–36 °C) significantly increased surgical blood loss and the relative risk for transfusion [91]. Despite this, the association between intraoperative hypothermia and increased bleeding in spine surgery is less clear. The results of some studies support this association while others do not [90, 92, 93]. Although further evaluation of this relationship is warranted, maintenance of normothermia is recommended as hypothermia is associated with an increased rate of mortality and complications in surgical patients [94].

Positioning Strategies for Minimization of Blood Loss

The prone position often required during spine surgery can be associated with increased bleeding. The epidural veins are connected to the inferior vena cava through a valveless venous system. When prone, intraabdominal pressure increases and causes compression of the vena cava. This will result in an increase in the epidural venous system pressure and increase the risk for intraoperative bleeding [89]. The reverse Trendelenburg position decreases central venous pressure (and subsequently epidural venous pressure) and can potentially reduce intraoperative blood loss [80]. In a study of 108 healthy patients undergoing elective prone spine surgery, the use of a Jackson table, compared with the Wilson frame or chest rolls, was associated with a significantly lower intraabdominal pressure [95]. In patients using a Wilson frame, both intraabdominal pressure and intraoperative blood loss were significantly less when using a wide pad support versus a narrow pad support [96].

Examples of Published Spine ERAS Protocols

As discussed previously, there is no generally accepted single ERAS pathway for spine surgery. Published protocols vary in their choice of anesthetic technique, multimodal analgesic regimen, and approach to fluid management. The following section highlights some of these pathways.

Dagal et al. developed an enhanced perioperative care (EPOC) pathway for patients undergoing major spine surgery [97]. Intraoperative anesthetic elements of their pathway included standardized OR temperature management, total intravenous anesthesia (TIVA) with propofol, remifentanil, and ketamine infusions, multimodal analgesia, goal directed fluid administration with stroke volume variation or pulse pressure variation-guided resuscitation, and routine administration of TXA. The establishment of their EPOC program was associated with a reduction in mean hospital LOS, intensive care unit LOS, and average cost. Wang et al. implemented a "fast track" program for patients undergoing minimally invasive transforaminal lumbar interbody fusion [98]. Intraoperative elements of this program included the use of endoscopic decompression, injections of liposomal bupivacaine for long-acting analgesia, and performing the surgery under sedation. Although supplemental oxygen was administered, patients' airways were not manipulated. Patients were sedated with IV infusions of propofol and ketamine; no opioids were administered. Compared with patients undergoing conventional minimally invasive transforaminal lumbar interbody fusion, patients in the ERAS group had less intraoperative blood loss, a shorter hospital LOS, and lower total cost for the acute care hospitalization. Ali et al. conducted a prospective cohort study comparing outcomes of patients undergoing elective spine or peripheral nerve surgery following implementation of an ERAS protocol compared to a historical control cohort [99]. Pathway elements include multimodal analgesia with gabapentin, acetaminophen, muscle relaxants, NSAIDS, infiltration of long-acting local anesthesia at the time of surgical closure, and minimization of opioids. In this study, the ERAS protocol improved postoperative mobilization and reduced opioid use in both the perioperative period and at 1-month after surgery.

Soffin et al. performed a retrospective cohort study examining the impact of an ERAS pathway on 61 patients presenting for microdiscectomy or lumbar laminectomy/laminectomy [59]. Patients received multimodal analgesia with acetaminophen and gabapentin. Although a TIVA technique using propofol and ketamine infusions was preferentially used, up to 0.5 MAC of inhaled agent was permitted to achieve the desired depth of anesthesia. Additional non-opioid analgesia with ketorolac and IV lidocaine was administered. The choice and dose of intraoperative opioids was left to the discretion of the anesthesiologist. Infiltration of the surgical incisions with local anesthesia was performed at the end of the procedure. Implementation of their pathway was associated with a short LOS, minimal complications, and no readmissions within 90 days of surgery. Grasu et al. reviewed the postoperative outcomes before and after the implementation of an enhanced recovery after oncologic spine surgery program [100]. Their pathway advocated for multimodal analgesia with acetaminophen, tramadol, and gabapentinoids along with a TIVA technique using infusions of propofol, lidocaine, ketamine, and dexmedetomidine, epidural analgesia or liposomal bupivacaine for surgical wound infiltration, goal directed fluid therapy, maintenance of normothermia, and a restrictive blood transfusion trigger with TXA administration. In this study, patients in the enhanced recovery group had a trend toward better pain scores and decreased opioid consumption compared with patients in the pre-enhanced recovery group.

In another study, Soffin et al. designed an enhanced recovery pathway for 1- and 2-level open lumbar fusion [101]. As with other pathways, patients received multimodal analgesia with oral gabapentin and acetaminophen. A TIVA technique using propofol, dexmedetomidine, and ketamine infusions was preferentially used, and up to 0.3 MAC of isoflurane was permitted to achieve the desired depth of anesthesia. Additional non-opioid analgesia with ketorolac, ketamine, and IV lidocaine was administered. Opioid administration was permitted at the discretion of the anesthesiologist, with a suggested limit of 2 mg of hydromorphone. This pathway did not include goal directed fluid administration or a formal assessment of volume status. Versus usual care, patients in the enhanced recovery group achieved statistically significant gains in early recovery, although a significant clinical impact was not demonstrated.

Finally, Smith et al. evaluated the impact of their ERAS program for 1–2 level lumbar spine fusion surgery [102]. In this pathway, patients received preoperative acetaminophen and gabapentin and standard antiemetic prophylaxis intraoperatively. Patients with chronic pain or those receiving opioids received IV ketamine with induction of anesthesia; however, there were no specific guidelines for intraoperative opioid use. The protocol did not include intraoperative fluid or hemodynamic parameters. Authors found no impact on hospital LOS or postoperative pain scores but noted a significant decrease in the use of postoperative opioids and rescue antiemetics. Overall, while ERAS programs are being increasingly applied to spine surgery, further research is required to identify the optimal care pathway in this heterogenous patient population.

Conclusion

Patients undergoing spine surgery are at risk for significant morbidity and mortality. Providers must carefully consider both patient-specific and procedure-specific risk factors. A system-based approach to preoperative optimization is recommended. Although the widespread application of ERAS principles to spine surgery is in its early stages, these strategies have the potential to improve several clinical outcomes.

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