Perioperative Care of Patients Undergoing Major Complex Spinal Instrumentation Surgery: Clinical Practice Guidelines From the Society for Neuroscience in Anesthesiology and Critical Care

Samuel N. Blacker, MD, FASA, Anita Vincent, MD,† Mark Burbridge, MD,‡ Maria Bustillo, MD,§ Sprague W. Hazard, MD,‖ Benjamin J. Heller, MD,¶ Jacob W. Nadler, MD, PhD,# Elaine Sullo, MLS, MAEd,** and Abhijit V. Lele, MBBS, MD, MS, FNCS;†† for On Behalf of the Society for Neuroscience in Anesthesiology and Critical Care*

Abstract: Evidence-based standardization of the perioperative management of patients undergoing complex spine surgery can improve outcomes such as enhanced patient satisfaction, reduced intensive care and hospital length of stay, and reduced costs. The Society for Neuroscience in Anesthesiology and Critical Care (SNACC) tasked an expert group to review existing evidence and generate recommendations for the perioperative management of patients undergoing complex spine surgery, defined as surgery on 2 or more thoracic and/or lumbar spine levels. Institutional clinical management protocols can be constructed based on the elements included in these clinical practice guidelines, and the evidence presented.

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From the *Department of Anesthesiology, University of North Carolina at Chapel Hill, NC; †Department of Anesthesiology and Critical Care Medicine, The George Washington University School of Medicine; **Himmelfarb Health Sciences Library, The George Washington University, Washington, DC; ‡Department of Anesthesiology, Perioperative, and Pain Medicine, Stanford Health Care, Stanford, CA; §Department of Anesthesiology, Weill Cornell Medicine, New York; #Department of Anesthesiology and Perioperative Medicine, University of Rochester Medical Center, Rochester, NY; ‖Penn State Hershey Anesthesiology and Perioperative Medicine, Hershey, PA; ¶Department of Anesthesiology and Pain Management, The University of Texas Southwestern Medical Center, Dallas, TX; and ††Department of Anesthesiology and Pain Medicine, Harborview Medical Center, University of Washington, Seattle, WA.

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Address correspondence to: Samuel N. Blacker, MD, FASA. E-mail: samuel_blacker@med.unc.edu.

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It is estimated that upwards of 400,000 patients undergo spinal fusions each year in the United States.[1,2] Spinal instrumentation surgeries continue to rise worldwide.[3] There has been a 15-fold increase in spine procedures between 2000 and 2007 alone; among this growth, primary lumbar fusion procedures had the largest increase compared with cervical and thoracic spinal fusions.[1] Major complex spine surgery (defined as surgery involving 2 or more levels of the spinal column) is associated with in-hospital cardiopulmonary events, stroke and wound complications, prolonged hospitalization, high 30-day hospital readmission rates, and often requires discharge to skilled nursing or rehabilitation facilities.[3] A retrospective review of 1,288,496 patients found that mortality for lumbar spine fusion was 0.2%, with over half of the fatalities occurring by postoperative day 9.[4] Major complex spine surgery alternatively defined based on associated comorbidities, such as data published from the Spine AdVerse Event Severity (SAVES) system,[5] is also associated with increased odds for revision surgery. There is a reported association between deep tissue infection and all-cause mortality.[5]

The perioperative care of patients undergoing complex spine surgery is a multidisciplinary team effort that incorporates the highest levels of evidence to design standardized patient-centric approaches. Concept and institutional implementation of evidence-based Enhanced Recovery After Surgery (ERAS) clinical pathways aim to incorporate best practice and improve measurable clinical outcomes, including pain, mortality, hospital length of stay, patient satisfaction, and costs.[6–9] ERAS pathways have been published to guide the management of patients undergoing different surgery types, including colorectal,[10] gynecologic,[11] and thoracic surgeries.[12] Also, outside of published institutional protocols,[9,13–24] the ERAS Society recently published evidence-based ERAS pathway recommendations for lumbar fusion.[25] For a specific

ERAS pathway, the individual elements of the pathway may not improve measurable outcomes. Rather, the improved outcomes associated with ERAS pathways are likely due to the combination and synergistic effect of all pathway elements and best practices.

A recent systematic review of 22 implemented adult spine surgery pathways[26] highlights the variability in outcome measures such as hospital length of stay, opioid consumption, postoperative pain, operative time, patient satisfaction, complication and readmission rates, and overall costs. The most commonly reported outcomes were reduction in hospital length of stay, opioid consumption, and costs. None of the 22 reviewed ERAS pathways were associated with worse outcomes compared with standard pathways.[26] Perioperative care encompasses prehospital, preoperative, intraoperative, and postoperative phases.

Although this document was initially intended to address ERAS for spine surgery, based on feedback from the membership of the Society for Neuroscience in Anesthesiology and Critical Care (SNACC), it now aims to provide evidence-based recommendations for the perioperative management of patients undergoing major complex spinal instrumentation surgery. In these guidelines, we have included anesthesia-specific and non–anesthesia-related elements relevant to prehospital, preoperative, intraoperative, and postoperative phases of care, all of which contribute to improved patient outcomes. Perioperative brain health and postoperative delirium reduction are also important but beyond the scope of these guidelines.

METHODS

In March 2019, all active SNACC members were invited to participate in a task force established to prepare clinical practice guidelines for major complex spine surgery. Eight SNACC members expressed interest in participating; each had clinical experience managing complex spine surgery patients, agreed to the project outline and evidence criteria, and independently examined peer-reviewed studies on complex spine surgery. The completed guideline document was placed on the SNACC Web site for 1 month, and the SNACC membership at large was invited to provide feedback and commentary. In addition, specific feedback was solicited from expert reviewers appointed by SNACC. The authors responded to the feedback from the SNACC membership and expert reviewers, and the final version of these clinical practice guidelines was approved by the SNACC Board of Directors.

Scope of Evidence Reviewed

Anesthesiologists play a vital role in maintaining perioperative anesthetic care standards, reducing practice variability and waste, and improving perioperative outcomes. Due to the heterogeneity and breadth of spine surgery, and to enable a relatively comparative study cohort, we focused on the perioperative management of thoracic and lumbar spine procedures conducted on 2 or more levels. Evaluation of supporting evidence and best practices, when combined, can facilitate the creation of an ERAS pathway for spine surgery patients. When considering perioperative care, we included all relevant care management areas from prehospital to postoperative phases of care. Recommendations are based on best practices, and postoperative outcome measures are stated for areas where data are available.

Literature Review

These clinical practice guidelines present a broad overview of the evidence regarding various components related to overall anesthetic care of patients having major complex spine surgery. The writing group, with the assistance of a medical librarian (E.S.), created a strategy to perform a literature search in the MEDLINE (OVID), Scopus, and Cochrane Library databases using the keywords and relevant MeSH terms (Medical Subject Headings in MEDLINE) listed in the Supplementary Material (Supplemental Digital Content 1: List of MeSH, http://links.lww.com/JNA/A425). The search was limited to English-language articles, and search results were limited to studies performed on patients 18 years or older. Studies conducted in children and animals, case reports, book chapters, editorials, letters to the editor, studies including pooled nonspine surgical patients, studies describing only isolated neuromonitoring data, interventional pain therapies, single-level microdiscectomy/laminectomy or minimally invasive procedures, proof of concept studies and device trials were excluded. Studies including isolated cervical spine surgeries were also excluded because cervical spine surgery may differ among concepts, including airway management and perioperative complications, compared with thoracolumbar surgeries. The literature primarily focused on elective surgeries; however, appropriate parallels may be drawn for urgent or emergent procedures.

Three successive levels of the literature review were conducted using a publicly available web-based application (www.sysrev.com). The Level I screen included a review of article titles and abstracts, and Level II and III screening involved full-text reviews. Each article was independently reviewed by 2 authors responsible for respective sections. Any conflicts that could not be resolved were adjudicated by authors S.N.B. and A.V.L. to determine whether the article should be included in the subsequent level of screening or excluded.

The initial literature search was conducted for articles published between January 1, 2010, and July 31, 2019. A total of 3228 articles were included in the initial Level I review, of which 1315 articles were selected for Level II screening; finally, 675 articles were identified for Level III review (Fig. 1). Sixty-one additional articles meeting inclusion criteria were included following subsequent literature searches during the writing and editing of the manuscript through May 17, 2021, utilizing the same search criteria. The article count listed at the beginning of each section of these guidelines relates to the number (and nature) of spine-related articles identified by the literature search for that particular topic. Other spine and nonspine articles are included in the text for reference and narrative where relevant. The recommendations in these guidelines follow the American College of Cardiology/American Heart Association methodology for assessing the quality of evidence (Supplementary Table 1, Supplemental Digital Content 2, http://links.lww.com/JNA/A426).[27]

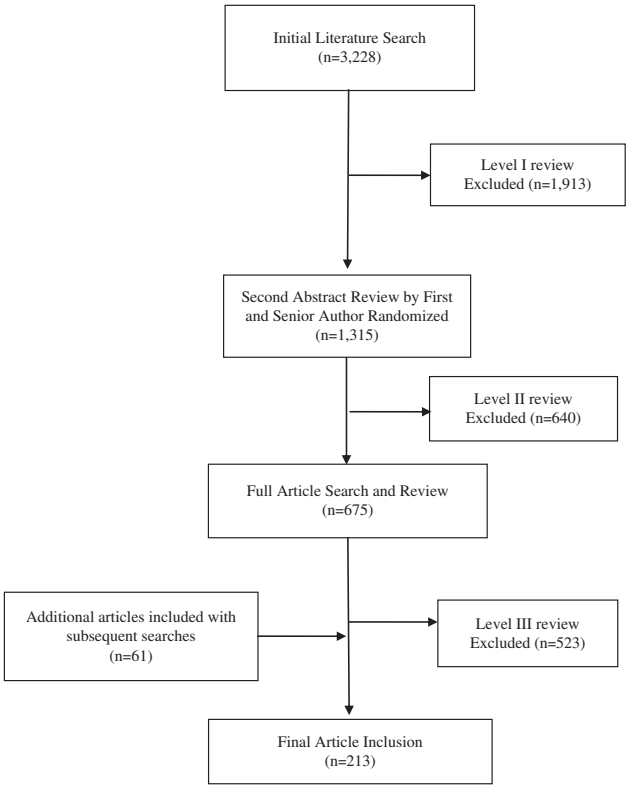

FIGURE 1. Flow diagram of the systematic review. The final number of references in the manuscript (n = 244), including both spine and nonspine articles, were added after the systematic review was completed to inform the narrative and the clinical practice guidelines.

EVIDENCE-BASED CLINICAL PRACTICE GUIDELINES AND RECOMMENDATIONS

The evidence related to the perioperative care of patients undergoing major complex spine surgery is summarized in Table 1 and discussed in detail in the following sections.

Preadmission and Preoperative Considerations

Articles reviewed (16): 6 meta-analysis/systematic reviews, 5 randomized control trials, 2 prospective observational studies, and 3 retrospective cohort studies.

Patients presenting for complex spine procedures may be at risk for adverse perioperative outcomes due to significant medical comorbidities, frailty,[28,29] nutritional deficiencies,[28,30] chronic uncontrolled pain, chronic opioid use,[31] substance abuse,[32] and physiological deconditioning.

Preadmission Assessment and Interventions

Preadmission evaluation has many potential benefits, including risk stratification, frailty assessment, identification of the need for postoperative resources in high-risk patients (eg, intensive care and pain services),[31] patient education regarding expectations for pain control and quality of life after the surgery, identification of patients who might benefit from prehabilitation and physiotherapy, and those at risk for postoperative delirium.[33–36] Commonly reported frailty assessment tools are the frailty index,[37] modified 5-item frailty index,[28] frailty-based score,[38] the clinical frailty scale,[39] the metastatic spinal tumor frailty index,[29,40] and the FRAIL scale.[34] It is hypothesized that the surgical procedure may improve postoperative frailty if deficits improve.[39] Prehabilitation has been shown to be feasible[41] with promising results,[41–43] and without complications in this patient cohort.[42] Protein supplementation may increase muscle mass[44] and improve physical performance in frail elderly patients.[45] Preoperative physiotherapy has decreased pain and risk of avoidance behavior and improved quality of life and physical activity levels.[46] Similarly, early rehabilitation can be safely implemented during the first 3 months after lumbar fusion and may include modifying psychological and motor functions.[43]

Surgeries of urgent or emergent nature may limit the routine use of preadmission multidisciplinary assessment.

Recommendations:

(1) Whenever possible, a comprehensive preadmission/preoperative assessment should be performed in patients undergoing complex surgeries to address the following areas (Class I, Level of Evidence C-EO):
   (a) Identification of significant medical comorbidities and a consultation with an internist/specialist for preoperative optimization. This includes but is not limited to cardiopulmonary workup and anemia screening and management.
   (b) Dietary consultation in a high-risk malnourished patient.
   (c) Consultation with acute/chronic pain services for high-risk patients.
   (d) Counseling for tobacco and other substance cessation.
   (e) Frailty assessment.
   (f) Prehabilitation/preoperative physiotherapy/early rehabilitation.
   (g) Identification of risk factors for postoperative delirium.

(2) Nil per os should follow American Society of Anesthesiologists (ASA) guidelines, and patients should consume a commercially available carbohydrate drink at least 2 hours before the planned procedure start time (Class I, Level of Evidence C-EO).

Intraoperative Considerations

Anesthetic Technique

Articles reviewed (25): 1 meta-analysis/systematic review, 13 randomized control trials/prospective studies, 10 retrospective cohort studies, 1 medical society guideline.

Total Intravenous Anesthesia (TIVA)

The potential benefits of TIVA include reduced postoperative nausea and vomiting (PONV) and facilitation of intraoperative neurophysiological monitoring (IONM) such as somatosensory-evoked potential (SSEP), motor-evoked potential (MEP), and electromyography monitoring.[47–53]

TABLE 1. Class of Recommendations and Level of Evidence for Elements to be Considered in Enhanced Recovery Pathway for Patients Undergoing Major Complex Spine Surgery

Phase of Care	Details	Class of Recommendation	Level of Evidence
Scope of the pathway	Define complex spine, clarify if applicable to adults or children	Class I	C-EO
Prehospital			
Preadmission/preoperative assessment	Identify significant medical comorbidities, internist consultation	Class I	C-EO
	Dietary consultation for high-risk malnourished patient	Class I	C-EO
	Acute/chronic pain service consultation for high-risk patients	Class I	C-EO
	Counseling for tobacco/substance cessation	Class I	C-EO
	Tobacco cessation, alcohol/substance abuse counseling	Class I	C-EO
	Frailty assessment	Class I	C-EO
	Prehabilitation/preoperative physiotherapy/early rehabilitation	Class I	C-EO
	Identify risk factors for postoperative delirium	Class I	C-EO
Preadmission (day of surgery)	Commercially available carbohydrate drink at least 2 h before procedure start time	Class I	C-EO
Intraoperative			
Anesthesia technique	If utilizing volatile agent and IONM, dose <0.5 MAC	Class I	B-R
	If utilizing IONM, avoid abrupt increase in anesthetic dose	Class I	B-NR
	Consider effects of TIVA and volatile effects on IONM	Class I	B-NR
	Informed consent should include IONM risks	Class I	C-EO
	Close communication with IONM team and surgeon	Class I	C-EO
	Dexmedetomidine > 0.8 mcg/kg/h may interfere with MEP	Class IIa	B-R
	Padding/secured bite blocks, frequent evaluation of intraoral integrity to prevent intraoral injuries	Class IIa	C-EO
	Lidocaine is likely compatible with IONM	Class IIb	B-R
	Volatile/TIVA/combination	Class IIb	B-NR
	Remifentanil <0.8 mcg/kg/min is compatible with IONM	Class IIb	B-NR
	Avoid NMBD when MEP or EMG are being monitored	Class IIb	C-EO
Perioperative analgesia	Methadone	Class IIa	B-R
	Wound infiltration	Class IIa	B-R
	Alpha-2 agonists (clonidine/dexmedetomidine)	Class IIa	B-R
	Cyclooxygenase inhibitors	Class IIb	B-R
	Lidocaine infusion	Class IIb	B-R
	Neuraxial (epidural), intrathecal opioids	Class IIb	B-R
	Liposomal bupivacaine	Class III (unclear benefit)	B-R
	Patient-controlled analgesia	Class IIb	B-R
	Acupressure	Class IIb	B-R
	Magnesium	Class IIb	B-R
	Multimodal analgesia regimen	Class IIb	B-R
	Ketamine infusion (bolus 0.1-1 mg/kg+infusion 0.1-0.25 mg/kg/h) intraoperatively and may continue postoperatively	Class IIb	B-R
	Remifentanil infusion as an adjunct without NMBD	Class IIb	B-R
	Remifentanil <0.8 mcg/kg/min for compatibility with IONM	Class IIb	B-NR
	Acetaminophen	Class IIb	B-NR
	Sufentanil/fentanyl infusion	Class IIb	C-EO
	Non-neuraxial blocks	Class IIb	C-LD
	Use of gabapentinoids	Class III (no benefit/ potential harm)	B-R
Threshold and risk of transfusion, blood conservation	Antifibrinolytic therapy (tranexamic acid)	Class I	A
	High-risk group for transfusion	Class I	B-NR
	Serial intraoperative monitoring of hemoglobin/hematocrit	Class I	C-EO
		Class I	C-EO

	Amount/rapidity of blood loss, concurrent fluid/acid-base/coagulation profile, systemic perfusion pressure/end-organ function determine perioperative transfusion threshold		
	No specific transfusion threshold/transfusion ratio	Class IIb	B-NR
	Preoperative blood donation	Class IIb	B-NR
	Cell salvage	Class III (no benefit)	A
Normothermia	Core temperature monitoring	Class I	C-EO
	Normothermia (36°C)	Class I	C-EO
	Acceptable techniques (higher ambient room temperature before patient arrival in the operating room, active body surface warmers, and intravenous fluid warmers)	Class IIa	B-R
Postoperative nausea and vomiting	Multimodal approach to prevent nausea and vomiting	Class I	B-R
Mechanical ventilation	Use of Jackson surgical table when prone positioning	Class I	B-R
	Higher levels of PEEP (9-12 cm H_2O) to prevent atelectasis in prone position	Class IIa	B-R
	Pressure-controlled ventilation	Class IIa	B-R
	Lung protection ventilation (Vt 6-8 mL/kg IBW)	Class III (no benefit)	B-R
Fluid management and hemodynamic monitoring	Intraoperative invasive/minimally invasive hemodynamic monitoring techniques consistent with institutional standards	Class I	C-EO
	Goal-directed fluid therapy	Class IIa	B-NR
	Balanced salt solution	Class IIa	B-NR
	Colloids and/or crystalloid use for fluid replacement	Class IIa	C-EO
	Invasive arterial blood pressure monitoring	Class IIa	C-EO
	Arterial waveform-based monitoring	Class IIb	B-NR
Blood pressure targets	Baseline blood pressure, the presence of neurological deficits, and preexisting end-organ injury may influence intraoperative mean arterial blood pressure targets	Class I	C-EO
Positioning-related complications	Informed consent should include positioning associated risks	Class I	C-EO
	Every effort made to prevent position-related complications	Class I	C-EO
	Periodic position checks during surgery	Class I	C-EO
Antibiotics	Intravenous antibiotics within 60 min before incision	Class I	A
Glycemic control	Serial intraoperative glucose monitoring for diabetic patients	Class I	C-EO
	Maintain glucose <180 mg/dL	Class I	C-EO
Venous thromboembolism (VTE) prophylaxis	Use of nonchemical VTE prophylaxis intraoperatively and postoperatively until appropriate for chemical VTE prophylaxis	Class I	C-EO
Postoperative			
Postoperative disposition	Preoperative and intraoperative factors may affect postoperative ICU/floor/ward admission	Class IIb	B-NR
Infection prevention	Remove Foley catheter when clinically appropriate to reduce catheter-associated urinary tract infections	Class I	C-EO
Postoperative nutrition	Early enteral nutrition	Class I	C-EO

EMG indicates electromyography; IBW, ideal body weight; ICU, intensive care unit; IONM, intraoperative neurophysiological monitoring; MAC, minimum alveolar concentration; MEP, motor-evoked potential; NMBD, neuromuscular blocking drugs; PEEP, positive end-expiratory pressure; TIVA, total intravenous anesthesia; Vt, tidal volume.

Limitations of TIVA are lower titratalibilty compared with volatile agents, risking intraoperative hypotension and the need for vasoactive support, differential context-sensitive half-lives of propofol, remifentanil/sufentanil/fentanyl and their effect on emergence and extubation times, effects of bolus dosing, and possible effects of high-dose remifentanil (0.8 mcg/kg/min) on SSEPs,[54] and cumulative dose on neuromonitoring.[55–57]

Volatile Anesthesia

The potential benefits of volatile anesthetic agents include predictable emergence and extubation profiles. Limitations include PONV, the dose of minimal alveolar concentration[53,58–61] and maximal allowed dose to facilitate specific components of IONM safely,[62–65] and the effect of abrupt changes in the dose of volatile anesthetics on IONM.[66]

Patient Safety Concerns for Patients Undergoing MEP Monitoring

Attempts should be made to prevent MEP-associated non-neurological adverse events such as intraoral injury (including tongue lacerations,[67,68] lip, mucosal, mandibular,[69] or dental injuries[67,68]) or endotracheal tube rupture due to high extracranial current densities resulting in contraction of the temporalis muscle and forceful closure of the jaw.[70] While the incidence of injuries is low (0.63%),[68] some can be devastating and require surgical repair in the form of sutures or grafting. Other reported complications of MEP monitoring include seizures and cardiac arrhythmias.[69,71]

Strategies to prevent MEP monitoring–related injury include the use of padding or soft bite blocks.[70] Though bite blocks must be soft enough to prevent dental trauma (avoid rigid bite blocks), they must also be able to resist the force of the human bite. Careful placement of soft bite blocks ensures that the tongue is displaced medially and no part of the tongue sits between the molars. This may be achieved by placing 2 bite blocks, one on either side, with padding anteriorly to prevent tip-of-the-tongue injuries. Clinicians should be aware that bite blocks may shift during patient positioning or MEP stimulation, resulting in their failure.[68] Unsecured bite blocks may fall out of the oropharynx when the patient is in the prone position; hence, the anesthesiologist must confirm the secure placement of bite blocks before prone positioning. In addition, all efforts should be made to secure the bite block in place before the initiation of MEP acquisition. There is no high-quality evidence to endorse any commercially available preformed bite blocks.

Recommendations:

(1) Low-dose volatile agents (not exceeding 0.5 minimum alveolar concentration) are compatible with SSEP and/or MEP monitoring in patients without preexisting neurological deficits (Class I, Level of Evidence B-R).
(2) In patients undergoing IONM, a stable concentration of volatile or intravenous anesthetic should be maintained. Abrupt changes in the dose of intravenous and/or volatile agents can interfere with IONM (Class I, Level of Evidence B-NR).
(3) When IONM is performed, the effects of volatile and TIVA agents on IONM modalities should be considered (Class I, Level of Evidence B-NR).
(4) Closed-loop communication should always be maintained between anesthesiology, neuromonitoring, and surgical teams. Changes in anesthetic dose or IONM signal intensity, and significant changes in IONM data, should be promptly communicated between team members to ensure monitoring quality and patient safety (Class I, Level of Evidence C-EO).
(5) Informed consent must be obtained from the patient/legal next of kin regarding potential adverse events related to IONM (Class I, Level of Evidence C-EO).
(6) In patients undergoing MEP monitoring, padding/appropriately sized secured soft bite blocks and frequent evaluation of intraoral integrity can be useful in preventing intraoral injuries (Class IIa, Level of Evidence C-EO).
(7) Volatile anesthesia or TIVA, or a combination, may be utilized based on patient considerations when not utilizing IONM (Class IIb Level of Evidence B-NR).
(8) Caution must be maintained when using remifentanil as high doses ($\geq$0.8 mcg/kg/min) may affect the amplitude of SSEPs (Class IIb, Level of Evidence B-NR).
(9) Neuromuscular blocking medications should be avoided when MEPs or electromyography are being monitored (Class IIb, Level of Evidence, C-EO).

Analgesia

Complex spine surgery patients are at risk of significant postoperative acute and chronic pain and chronic opioid use.[72] Analgesia is a critical component of perioperative care.

Gabapentinoids

Articles reviewed (10): 6 meta-analysis/systematic reviews, 4 randomized control trials.

The potential benefits of gabapentinoids include reduction in pain scores and morphine consumption at 12 and 24 hours postoperatively,[73–76] reduction in preoperative anxiety,[77,78] synergistic effects with clonidine,[79] and additive effects with dexamethasone.[80] Some studies have reported no clinically relevant analgesic effect from the perioperative use of gabapentinoids, and no effect on prevention of postoperative chronic pain or risk of adverse events.[81]

Gabapentinoids have been associated with the potential for harm, including the risk of respiratory depression with concomitant use of opioids and other central nervous system depressants, in high-risk patients such as those with chronic obstructive pulmonary disease, and with advanced age (US Food and Drug Administration warning).[82] Unclear benefits on acute, subacute, and chronic pain have also been reported when gabapentinoids are included in an multimodal analgesia regimen.[81,83]

Recommendation:

(1) The usefulness of routine use of perioperative gabapentinoids in multimodal analgesic regimen is not well-established (Class III, Level of Evidence B-R).

Ketamine

Articles reviewed (13): 1 meta-analysis/systematic review, 12 randomized control trials.

The potential benefits of ketamine include reduction in cumulative morphine equivalent consumption and reduced pain scores at 4, 8, 12, and 24 hours following spine surgery,[84] and reduced opioid requirements 6 to 12 months after surgery[85–87]; these effects are superior when ketamine is combined with methadone compared with methadone alone.[88] However, one study found no benefit in postoperative quality of recovery scores in the first 48 hours after ketamine use.[83] Ketamine is not generally associated with significant adverse events,[84] although there may be a risk of postoperative delirium.[89]

Ketamine dosing recommendations: bolus dose range of 0.1 to 1 mg/kg after intubation,[84,87,90,91] followed by infusion at 0.1 to 0.25 mg/kg/h.[85,92,93] Infusion rates <0.1 mg/kg/h have not been shown to effectively reduce postoperative opioid requirements,[94] especially in the opioid-naive patients.[95]

Recommendation:

(1) To reduce opioid consumption in the immediate postoperative period and considering the potential for long-lasting analgesic effects, an infusion of ketamine in the perioperative period (initiated in the intraoperative period and continued into the postoperative period) may be reasonable (Class IIb, Level of Evidence B-R).

Acetaminophen

Articles reviewed (2): 2 retrospective cohort studies.

There is conflicting evidence for benefit versus no benefit from acetaminophen use, including on reducing opioid consumption,[96] opioid-related side effects, and length of stay.[97] Generally, acetaminophen has a favorable risk/benefit profile.

Recommendation:

(1) The routine administration of perioperative acetaminophen for postoperative pain as a part of a multimodal analgesia regimen is not well-established (Class IIb, Level of Evidence B-NR).

Cyclooxygenase Inhibitors

Articles reviewed (2): 1 randomized control trial, 1 retrospective cohort study.

The effect of a single dose of a cyclooxygenase inhibitor on pain reduction is limited to the postanesthesia care unit.[98] Cyclooxygenase inhibitor use is associated with the potential for nonunion or failed spinal fusion in patients who smoke tobacco.[99]

Recommendation:

(1) After careful patient selection, cyclooxygenase inhibitors may be considered in the perioperative period to reduce postoperative pain (Class IIb, Level of Evidence B-R).

Intravenous Lidocaine Infusion

Articles reviewed (4): 3 randomized control trials, 1 retrospective cohort study.

The potential benefits of lidocaine infusion include reduction in verbal pain scores and opioid requirements at 48 hours postsurgery,[100] with no effect on SSEP or MEP monitoring.[101,102] Lidocaine infusion has no effect on hospital length of stay[100] or 72-hour pain scores.[103]

Intravenous lidocaine should be administered as a 1 to 1.5 mg/kg bolus followed by an infusion at 1 to 1.5 mg/kg/h.

Recommendations:

(1) Lidocaine may be considered in the intraoperative and postoperative periods to reduce verbal pain scores and opioid requirements at 48 hours (Class IIb, Level of Evidence B-R).
(2) Lidocaine may be safely used for spine surgery patients during IONM (Class IIb, Level of Evidence B-R).

Opioid Analgesics

In patients undergoing propofol-based TIVA, opioids are commonly administered as an infusion during surgery. The choice of opioid (remifentanil, sufentanil, or fentanyl) may depend upon the length of the procedure, concomitant use of neuromuscular blocking agents, and risk of perioperative pulmonary complications.

Remifentanil/Sufentanil/Fentanyl

Articles reviewed (6): 6 randomized control trials.

Concurrent infusion of remifentanil, sufentanil, or fentanyl facilitates propofol-based TIVA in the absence of neuromuscular blocking agents. Preincisional remifentanil infusion is linked to improved immediate postoperative pain scores.[104] Potential limitations of remifentanil include opioid-induced hyperalgesia with high doses,[105] and the previously highlighted effects of high-dose remifentanil (0.8 mcg/kg/min) on SSEPs.[54] Comparisons of remifentanil to other TIVA adjuncts, such as dexmedetomidine favor dexmedetomidine in reducing postoperative pain scores.[106,107] The relationship between the context-sensitive half-life of different opioids in relation to the use of propofol or volatile agents may affect the emergence and extubation times.

Remifentanil infusion maximum dose should be <0.8 mcg/kg/min (see Recommendation #8).[54] The addition of intraoperative ketamine infusion may blunt opioid-related hyperalgesia.[93,108] Remifentanil infusions of 0.16 to 0.3 mcg/kg/min when used as an adjunct to sevoflurane may not cause hyperalgesia.[109]

Recommendations:

(1) Remifentanil may be a reasonable adjunct to facilitate TIVA without a neuromuscular blocking agent (Class IIb, Level of Evidence B-R).
(2) To facilitate TIVA without a neuromuscular blocking agent, sufentanil or fentanyl may also be reasonable adjuncts (Class IIb, Level of Evidence C-EO).

Methadone

Articles reviewed (2): 1 randomized control trial, 1 retrospective cohort study.

The potential benefits of methadone include a reduction in pain scores and postoperative opioid requirements by 50%, lasting for up to 72 hours (dose 0.2 mg/kg).[110] Postoperative respiratory depression, hypoxemia,

need for reintubation, and cardiac complications such as arrhythmias or prolonged corrected QT interval (dose: 0.14 ± 0.07 mg/kg) are reported.[111] Methadone can be administered orally 0.2 to 0.3 mg/kg preinduction or as a single intravenous bolus (0.14 to 0.2 mg/kg) intraoperatively.

Recommendation:

(1) Methadone can be a useful adjunct to TIVA or inhalational anesthetic regimens to reduce pain and opioid requirements (Class IIa, Level of Evidence B-R).

Neuraxial and Regional Anesthesia

Articles reviewed (16): 14 randomized control trials, 1 prospective observational cohort study, 1 retrospective cohort study.

Epidural Analgesia

The potential benefits of intraoperative and/or postoperative epidural analgesia include increased patient satisfaction with decreased pain, lower opioid requirement, earlier mobility, reduced PONV, predictable neuraxial spread, and reduced inflammatory markers in the postoperative period.[112–115] There is no benefit in the reduction of inflammatory biomarkers when an epidural catheter is only used postoperatively.[114,116]

Spinal Anesthesia/Analgesia

Spinal anesthesia is associated with a reduction in visual pain scores[117,118] but has no benefit in reducing the duration of anesthesia, surgeon satisfaction, postoperative analgesic requirements, or anesthetic costs.[117,118] The use of spinal anesthesia is limited to shorter case times; published literature is restricted to its use in cases <2 hours duration.[117,118]

Intrathecal morphine (0.1 mg,[119] 0.3 mg,[120,121] or 0.4 mg[122]) has been shown to reduce the time to rescue opioids and dose of piritramide patient-controlled analgesia,[122] whereas intrathecal hydromorphone (0.5 mg)[123] is not associated with a reduction in pain scores and opioid dose in the immediate postoperative period. Both agents were found to be safe. Patients receiving intrathecal opioids must be monitored for respiratory depression in the postoperative period and should be admitted to a care area with the capability for end-tidal carbon dioxide and pulse oximetry monitoring.

Regional Anesthesia

Paravertebral blocks reduce postoperative narcotic medication use (50.1% lower on day 2 and 47.1% lower on day 3) but have no benefit on reducing hospital length of stay.[124] Thoracolumbar interfascial plane blocks reduce visual pain scores, fentanyl use, and patient-controlled analgesia doses.[125] Erector spinae plane blocks lowered pain scores immediately and 6 hours postsurgery, and improved patient satisfaction scores.[126,127] The LUMBES trial is investigating whether bilateral lumbar erector spinae blocks are effective in reducing 24-hour postoperative morphine consumption in patients undergoing lumbar interbody fusion surgery.[128]

Recommendations:

(1) To reduce postoperative opioid use and improve patient satisfaction, and with careful patient selection and appropriate postoperative neurological and respiratory monitoring, neuraxial techniques (epidural/spinal), or use of intrathecal opioids may be considered an adjunct (Class IIb, Level of Evidence B-R).
(2) The usefulness of non-neuraxial regional anesthesia is not well-established (Class IIb, Level of Evidence C-LD).

Patient-controlled Analgesia and Transdermal Analgesia

Article reviewed (3): 2 randomized control trials, 1 retrospective cohort study.

Patient-controlled analgesia allows patient autonomy. Bolus and maximal hourly doses may have to be individualized; thus, a universal dosing regimen may not be applicable.[129–131] Clinicians should account for the effects of demand-only patient-controlled analgesia, basal rate patient-controlled analgesia, and transdermal analgesia regarding effects on respiratory depression and the need for capnography and pulse oximetry. The side effects of transdermal analgesia include nausea/vomiting and erythema.[131]

Recommendation:

(1) Patient-controlled analgesia may be considered as part of a postoperative multimodal analgesic regimen (Class IIb, Level of Evidence B-R).

Wound Infiltration

Articles reviewed (7): 3 meta-analysis/systematic reviews, 3 randomized control trials, 1 retrospective cohort study.

Wound infiltration with an initial bolus followed by continuous infusion of ropivacaine is reported to reduce postoperative visual pain scores, medication requirements, length of hospital stay,[132,133] and PONV.[133] Limitations on the total dose of local anesthetic (safety established with appropriate dosing regimens),[134,135] and risks for infection (safe in published literature)[136] must be taken into account.

In a systematic review,[137] the use of liposomal bupivacaine in spine surgery, including pediatric, small and large spine surgeries, safely decreased opioid requirements, pain scores, and length of stay, although the level of evidence is of a low-quality; studies with moderate-quality evidence did not support the use of liposomal bupivacaine.[137] A retrospective study of large spinal fusion surgery patients found no difference in overall opioid consumption and no decrease in hospital length of stay with the use of liposomal bupivacaine.[138]

Recommendations:

(1) Wound infiltration with local anesthetic may be considered part of a multimodal pain regimen to reduce postoperative pain, PONV, and length of hospital stay (Class IIa, Level of Evidence B-R).
(2) The usefulness of liposomal bupivacaine to reduce pain scores, postoperative opioid use, early mobility, and length of stay is not well-established for major spine surgeries (Class III, Level of Evidence C).

Acupressure

Articles reviewed (1): 1 randomized control trial.

Acupressure may reduce postoperative pain intensity, analgesic consumption, and PONV.[139]

Recommendation:

(1) Acupressure point therapy may be considered as an adjunct in a multimodal analgesic regimen (Class IIb, Level of Evidence B-R).

Magnesium

Articles reviewed (1): 1 randomized control trial.

Magnesium has been reported to reduce postoperative analgesic requirements.[140] However, this evidence derives from a single study with a small sample size.

Recommendation:

(1) The usefulness of magnesium as an adjunct is not well-established (Class IIb, Level of Evidence B-R).

Alpha-2 Agonists

Articles reviewed (16): 1 meta-analysis/systematic review, 14 randomized control trials, 1 prospective observational study.

Dexmedetomidine may reduce the dose of hypnotic agents,[141,142] reduce heart rate responses to intubation and extubation,[143] reduce stress[144,145] and inflammatory responses,[146] reduce the incidence of PONV,[147] postoperative fatigue,[144] postoperative pain scores and analgesic consumption,[107] act as an adjunct to other analgesics for postoperative pain control,[148–150] and facilitate intraoperative wake-up testing.[151] Dexmedetomidine has not been found to affect SSEPs.[150,152–154] Limitations of dexmedetomidine include bradycardia, hypotension (especially with bolus dosing), and heterogenous effects on MEPs.[150,152–154]

Dexmedetomidine dosing: initial 0.5 to 1 mcg/kg bolus (caution: bradycardia and hypotension) followed by infusion at 0.3 to 1 μg/kg/h; a dose of 0.8 mcg/kg/h should not be exceeded if MEPs are being monitored.[150,152–154] Clonidine is administered in a dose of 150 mg (orally/intravenously).[155]

Recommendations:

(1) Alpha-2 agonists (clonidine/dexmedetomidine) can be useful analgesic adjuncts during TIVA or inhalational anesthesia to reduce dosing of other agents and opioids, improve postoperative pain, and to reduce PONV (Class IIa, Level of Evidence B-R).
(2) If MEPs are monitored, dexmedetomidine should be used in doses <0.8 mcg/kg/h to prevent interference with MEPs (Class IIa, Level of Evidence B-R).

Multimodal Analgesia Regimens

Articles reviewed (5): 1 randomized control trial, 2 retrospective cohort studies, 1 prospective study, 1 narrative review.

Mixed results for the potential benefit/no benefit for the use of multimodal analgesic regimens have been reported.[14,31,83,156,157]

Recommendation:

(1) A multimodal analgesic approach may be considered, but a specific regimen cannot be recommended from the literature (Class IIb, Level of Evidence B-R).

Transfusion Management and Antifibrinolytic Use

Risk Factors for Bleeding and Transfusion

Articles reviewed (4): 4 retrospective cohort studies.

Risk factors for intraoperative blood transfusion are anterior spinal instrumentation and fusion (25% to 29% transfusion rate),[158] spine deformity, tumor and trauma, multilevel (>3 levels) surgery,[159] prolonged operation times, involvement of the sacrum, and open posterior approaches.[160,161] Awareness of risk for bleeding and transfusion allows improved blood product resource utilization in the perioperative period.

Transfusion Thresholds and Risks of Transfusion

Articles reviewed (14): 2 meta-analysis/systematic reviews, 12 retrospective cohort studies.

Potential benefits of restrictive packed red cell transfusion strategies include reduced transfusion requirement, reduced transfusion-related adverse events[162] such as morbidity,[163,164] infectious complications,[165–167] and non-infectious complications, reduction in length of stay,[168] and reduced costs.[163] Restrictive perioperative transfusion policies have been associated with trends in worsening mortality, contrary to that observed in critical care patients.[169]

There is an unclear benefit of preoperative blood donation and its impact on the need for homologous blood[170,171] or on the effect of cell salvage on transfusion rates and total perioperative units of blood transfused.[172] Any benefits of balanced transfusion strategies incorporating plasma-reduced red cell: fresh frozen plasma (1:1) and plasma-reduced red cell: platelets (1:4) are also unclear,[173] as are any benefits of restrictive[174,175] (8 g/dL) versus liberal (10 g/dL) targeted transfusion strategies.

Recommendations:

(1) Preparation and allocation of resources for transfusion should be considered for the following high-risk groups: age over 50 years, preoperative anemia, multilevel/revision/tumor/deformity/trauma surgeries, and surgeries involving transpedicular osteotomy (Class I, Level of Evidence B-NR).
(2) Hemoglobin and hematocrit values should be monitored frequently (every 1 to 2 h or more often on a case-by-case basis) during complex spine procedures (Class I, Level of Evidence C-EO).
(3) Anesthesiologists should consider the amount and rapidity of blood loss, the concurrent fluid/acid-base/coagulation profiles, systemic perfusion pressure, and end-organ function in informing perioperative transfusion thresholds ratios (Class I, Level of Evidence C-EO).
(4) No specific recommendation can be made for transfusion thresholds or transfusion ratios (Class IIb, Level of Evidence B-NR).
(5) Preoperative blood donation may be considered for selected patients undergoing complex spine procedures (Class IIb, Level of Evidence B-NR).
(6) Cell salvage may be considered to reduce red blood cell transfusion requirement in patients undergoing complex spine procedures at risk for blood loss (Class III [*No benefit*], Level of Evidence A).

Antifibrinolytic Therapy

Articles reviewed (11): 5 meta-analysis/systematic reviews, 5 randomized control trials, 1 retrospective cohort study.

The potential benefits of antifibrinolytic therapy such as tranexamic acid include reduced intraoperative blood loss, transfusion needs, and operative times.[176–181]

When considering dosing schedules, the following factors should be considered: tranexamic acid is associated with dose-dependent reductions in perioperative blood loss,[182] and both low-dose and high-dose tranexamic acid use are beneficial.[176,183] A typical high-dose tranexamic acid regimen is a 10 mg/kg bolus followed by a 2 mg/kg/h infusion continued until 5 hours postoperatively.[182] A typical low-dose tranexamic acid regimen is a 5 mg/kg bolus followed by a 1 mg/kg/h infusion continued until 5 hours postoperatively.[182] Emerging data show uncertain benefit for the use of topical tranexamic acid.[180,184,185]

There is inconclusive evidence that tranexamic acid increases thromboembolism risk in spine surgery patients.[186] Seizure risk (cumulative risk = 2.7%, 95% confidence interval: 2.0%-3.3%),[187] is mostly described in cardiac surgery, with the use of higher doses, and in patients with renal insufficiency/failure.[187]

Recommendation:

(1) Intravenous antifibrinolytics such as tranexamic acid (bolus followed by an infusion) are beneficial in reducing intraoperative blood loss and are indicated in complex spine surgeries (Class I, Level of Evidence A).

Intraoperative Normothermia

Articles reviewed (5): 3 randomized control trials, 2 retrospective cohort studies.

Maintenance of intraoperative normothermia reduces blood loss and the incidence of adverse cardiac events and surgical site infections.[188] On the contrary, mild hypothermia (35 to 36.5°C) was associated with reduced acute kidney injury after spine surgery in a large (n = 6520) retrospective cohort study.[189] There is an unclear benefit regarding the type of warming method to maintain normothermia. Devices include electrically-heated humidifiers,[190] specially designed thermal gowns,[191] active surface warmers[192] underbody forced-air warming blanket versus a resistive heating blanket.

Recommendations:

(1) Core temperature should be monitored (Class I, Level of Evidence C-EO).
(2) Normothermia should be maintained (core temperature of > 36°C) in the perioperative period (Class I, Level of Evidence C-EO).
(3) Higher ambient temperature before the patient arrives in the operating room, active body surface warmers, and intravenous fluid warmers are reasonable techniques to maintain normothermia (Class IIa, Level of Evidence B-R).

PONV

Articles reviewed (6): 1 meta-analysis/systematic review, 4 randomized control trials, 1 retrospective cohort study.

Prevention and/or reduction of PONV is associated with improved patient satisfaction, faster hospital discharge, decrease in hospital resource utilization, and reduced risk of aspiration pneumonia, wound dehiscence, dehydration, electrolyte derangements, postoperative bleeding, and delayed early mobilization contributing to venous thromboembolic events.[193] Strategies to reduce PONV include dexamethasone (4 mg, every 8 h),[194,195] and use of nonopioid medications such as dexmedetomidine[147] and proparacetamol (prodrug of acetaminophen).[196] 5-HT3 antagonists such as ramosetron combined with dexamethasone have been specifically used for fentanyl patient-controlled analgesia-associated nausea and vomiting.[197] Amantadine can reduce intraoperative fentanyl and postoperative morphine requirements, as well as reduce the intensity of PONV.[198]

Recommendation:

(1) A multimodal approach to PONV prophylaxis is indicated in all patients undergoing complex spine surgeries (Class I, Level of Evidence B-R).

Mechanical Ventilation

Articles reviewed (8): 7 randomized control trials, 1 retrospective cohort study.

The Jackson surgical table reduces intra-abdominal pressure and increases oxygenation index compared with the general surgical table; these effects are more pronounced in overweight patients.[199] However, the Jackson table is associated with elevated peak inspiratory airway pressures.[200]

Pressure-controlled ventilation (compared with volume-controlled ventilation) has several benefits including lower peak airway pressure,[201] improved dynamic compliance,[202] higher postoperative partial pressure of oxygen levels,[202] reduced postoperative glucose and cortisol levels,[202] and reduced intraoperative blood loss.[203] Higher positive end-expiratory pressure (9 to 12 cm H_2O) is required to maintain compliance and regional ventilation in patients in the prone position.[204] No benefit of lung-protective ventilation strategies has been observed on reductions in perioperative inflammatory biomarkers[205] or on postoperative pulmonary function and oxygenation.[206] However, the use of lung-protective ventilation is not associated with harm.[205]

Recommendations:

(1) The Jackson surgical table should be used whenever possible to reduce intra-abdominal pressure and improve intraoperative oxygenation in the prone position (Class I, Level of Evidence B-R).
(2) Higher levels of positive end-expiratory pressure (9 to 12 cm H_2O) may be required to maintain compliance and regional ventilation in the prone position (Class IIa, Level of Evidence B-R).
(3) To lower peak airway pressure, improve oxygenation and reduce the risk of surgical bleeding, pressure-controlled ventilation may be considered rather than volume-controlled ventilation. No evidence was found

regarding the impact of the mode of ventilation on length of stay, or quality of recovery after spine surgery (Class IIa, Level of Evidence B-R).
(4) Lung-protective ventilation (6 to 8 mL/kg ideal body weight) has not been shown to confer benefit when in a prone position but is not harmful (Class III (No Benefit), Level of Evidence B-R).

Fluid Management and Hemodynamic Monitoring

Articles reviewed (15): 3 randomized control trials, 5 prospective observational studies, 5 retrospective cohort studies, 1 narrative review, 1 practice advisory.

Crystalloids

Balanced salt solutions reduce the risk of hyperchloremic metabolic acidosis and respiratory acidosis[207] but have unclear benefits on coagulopathy, cardiovascular and renal function,[208] ocular pressure,[209] as well as on total crystalloid volume use and intensive care unit (ICU) length of stay.[210]

Colloids Versus Crystalloids

Increased administration of crystalloid to colloid ratio is independently associated with delayed extubation.[211,212] Intraoperative infusion of balanced 6% hydroxyethyl starch (130/0.4) may result in clinically insignificant changes in postoperative blood loss and coagulation compared with crystalloid.[213] Colloid/crystalloid administration in itself may not affect intraocular pressure.[209] Colloids may be reasonable for intraoperative use in patients who have substantial blood loss.[214]

Goal-directed Fluid Therapy and Hemodynamic Monitoring

Hemodynamic monitoring and goal-directed fluid therapy allow optimization of circulatory volume with potential benefits including reduced risk of intraoperative hypotension,[215–217] avoidance of interstitial fluid overload (ie, maintenance of euvolemia), optimized cardiac output,[218] reduced intraoperative blood loss, reduced intraoperative blood transfusion rate, lower lactate levels, lower postoperative mechanical ventilation rates, faster return of bowel function, and reduced ICU length of stay.[219]

Pulse pressure variation, stroke volume variation, plethysmographic variability index, and dynamic arterial elastance[220,221] are all reasonable trending targets to maintain stroke volume in patients undergoing major complex spine surgery. The superiority of one hemodynamic monitoring technique over another has not been established.

Recommendations:
(1) Intraoperative invasive/minimally invasive hemodynamic monitoring techniques consistent with institutional standards may be used in patients undergoing complex spine surgeries (Class I, Level of Evidence C-EO).
(2) It is reasonable to use goal-directed fluid therapy for complex spine cases (Class IIa, Level of Evidence B-NR).
(3) It is reasonable to use a balanced salt solution, especially in procedures with anticipated significant blood loss and fluid resuscitation (Class IIa, Level of Evidence B-NR).
(4) To maintain euvolemia, it is reasonable to include colloids and crystalloids in patients with substantial blood loss (Class IIa, Level of Evidence C-EO).
(5) Invasive arterial blood pressure monitoring is reasonable for complex spine surgery (Class IIa, Level of Evidence C-EO).
(6) Arterial waveform-based monitoring may be useful to guide intraoperative fluid responsiveness (Class IIb, Level of Evidence B-NR).

Blood Pressure Targets

Articles reviewed (9): 7 randomized control trials, 2 retrospective cohort studies.

Blood pressure targets should be set to harmonize fluid and vasoactive medications to maintain systemic and spinal cord perfusion. No evidence was found regarding blood pressure targets during complex spine procedures. A meta-analysis of spinal cord injuries reported a low level of evidence for a recommended mean arterial pressure target ≥ 85 mm Hg.[222] An ongoing multicenter randomized control trial may inform future recommendations.[223]

The incidence of acute kidney injury after noncardiac surgery is reported to be between 3.9% and 9.8%.[224,225] Major risk factors for acute kidney injury include anemia, decreased glomerular filtration rate, elevated risk surgery, ASA physical status, and expected long duration of anesthesia and surgery.[224] In patients with the highest risk, mild hypotension ranges (mean arterial pressure 55 to 59 mm Hg) were associated with acute kidney injury (adjusted odds ratio = 1.34, 95% confidence interval: 1.16-1.56). Patients with medium risk demonstrated associations between severe range intraoperative hypotension (mean arterial pressure <50 mm Hg) and acute kidney injury (adjusted odds ratio = 2.62, 95% confidence interval: 1.65-4.16), while those with low baseline risk demonstrated no associations between intraoperative hypotension and acute kidney injury.[224]

Potential benefits of optimizing intraoperative blood pressure include maintenance of spinal cord perfusion, protection against acute kidney injury, and maintenance of ocular perfusion pressure. However, specific blood pressure targets for complex spine surgery are not defined. Controlled hypotension can be achieved using various medications.[226–232] According to the 2019 practice advisory update from the ASA Task Force on Perioperative Visual Loss, the North American Neuro-Ophthalmology Society, and the SNACC, deliberate hypotension should only be used on a case-by-case basis.[214]

Recommendation:
(1) Information related to baseline blood pressure, the presence of neurological deficits, and preexisting end-organ injury may influence intraoperative mean arterial blood pressure targets which must be individualized to the patient (Class I, Level of Evidence C-EO).

Positioning Associated Risks

Articles reviewed (6): 3 practice advisory/systematic reviews, 3 retrospective cohort studies.

Complications may occur during complex spine surgery in supine, prone, and lateral positions. Reported complications

include brachial plexus injuries,[233] cardiovascular collapse,[234] ophthalmologic injury/perioperative vision loss/acute angle-closure glaucoma,[214,235] peripheral nerve injury,[235] myocutaneous injury,[236,237] chest pressure sores,[234] oropharyngeal swelling, macroglossia,[234] and dislodgement of the endotracheal tube and accidental extubation.[234,235] Careful positioning,[214] padding of peripheral nerves, use of barrier protection, avoidance of direct pressure on the eyes (to reduce risk of central retinal artery occlusion),[214] and periodic position checks are essential to prevent position-associated complications. Suggested positioning for patients at high risk for perioperative vision loss include ensuring that the head is level with or higher than the heart and maintained in a neutral forward position (ie, without significant neck flexion, extension, lateral flexion, or rotation).[214]

Recommendations:

(1) Informed consent must be obtained from the patient/legal next of kin regarding the risks associated with positioning (Class I, Level of Evidence C-EO).
(2) Every effort must be made to prevent position-related complications (Class I, Level of Evidence C-EO).
(3) Whenever possible, periodic position checks must be performed in patients undergoing major complex spine surgery (Class I, Level of Evidence C-EO).

Surgical Site Infections

Articles reviewed (1): 1 clinical practice guideline.

A clinical practice guideline was developed jointly by the American Society of Health-System Pharmacists, the Infectious Diseases Society of America, the Surgical Infection Society, and the Society for Healthcare Epidemiology of America to provide evidence-based recommendations for antimicrobial prophylaxis during surgery.[238] Despite appropriate antibiotic use, it is difficult to achieve a surgical site infection rate of 0%, implying that surgical site infections are multifactorial and likely to represent a composite outcome measure. Risk factors for surgical site infection include prolonged preoperative hospitalization, diabetes, elevated serum glucose ($\geq$125 mg/dL preoperatively or $\geq$200 mg/dL postoperatively), smoking, alcohol abuse, previous surgical site infection, and obesity. Specific procedure-related risk factors include surgery duration >2 to 5 hours, blood loss >1 L, staged procedures, multilevel fusions, screw/plate placement, and combined anterior-posterior fusion.

General considerations regarding surgical site reduction include: (a) intravenous antibiotic prophylaxis; (b) screening for methicillin-resistant *Staphylococcus aureus*; (c) optimal timing of administration for different antimicrobial agents (eg, vancomycin infusion should be started as early as 120 min before the surgical incision); (d) individualizing drug choice, initial dose, and redosing depending upon renal clearance; (e) continuous quality improvement with adherence to institutional antibiograms, and; (f) glycemic control, as well as the strategies outlined earlier to reduce intraoperative blood loss.

Recommendations:

(1) Intravenous antibiotics should be administered within 60 minutes before surgical incision, followed by appropriate redosing during surgery (Class I, Level of Evidence A).
(2) The recommended antibiotic regimen is cefazolin (2 or 3 g for those >120 kg) or an equivalent first-generation cephalosporin. If there is evidence that gram-negative organisms are the cause of surgical site infection, consider combining clindamycin or vancomycin with another agent, for example, cefazolin for those not beta-lactam allergic or aztreonam/gentamicin/single-dose fluoroquinolone for those beta-lactam allergic (Class I, Level of Evidence A).

Glycemic Control

Articles reviewed (1): 1 systematic review.

According to the Society for Ambulatory Anesthesia and the Endocrine Society, intraoperative blood glucose levels should be maintained between 100 and 180 mg/dL.[239] Intravenous insulin is recommended for glycemic control during major complex surgery in patients with anticipated hemodynamic changes, significant fluid shifts, expected changes in temperature, the requirement for inotropes, or lengthy operative times (>4 h).[239]

Recommendation:

(1) Serial intraoperative and postoperative glucose monitoring using an intravenous insulin algorithm may be useful to maintain blood glucose <180 mg/dL in diabetic patients (Class I, Level of Evidence C-EO).

Venous Thromboembolism Prophylaxis

Articles reviewed (3): 3 retrospective cohort studies.

The overall rate of venous thromboembolism after elective spine surgery is 0.5% to 1.1%.[240–242] Factors associated with postoperative venous thromboembolism include: (1) preoperative factors such as dependent functional status, paraplegia, quadriplegia, disseminated cancer, inpatient status, hypertension, history of transient ischemic attack, sepsis, and African American race; (2) intraoperative factors such as surgery duration >4 hours, emergency presentation, ASA III or greater, intraoperative blood loss >2000 mL, use of packed red blood cell transfusion, deep surgical site infection; and (3) postoperative factors including postoperative sepsis. The addition of low–molecular-weight heparin decreases the incidence of venous thromboembolism compared with mechanical prophylaxis alone (0% vs. 0.59%),[242] with no reported cases of epidural hematoma.[242]

Recommendation:

(1) To reduce the incidence of perioperative venous thromboembolic complications, nonchemical prophylaxis in the form of sequential compression devices may be applied before induction of general anesthesia and continued until chemical prophylaxis is promptly initiated in the postoperative period (Class I, Level of Evidence C-EO).

Postoperative Care Considerations

Articles reviewed (3): 3 retrospective cohort studies.

Postoperative Care Location

Various factors may affect the postoperative disposition of patients after complex spine surgery. Every attempt must be made to assess the risk-benefit of postoperative admission to an ICU versus admission to a general floor/ward. Institutional factors, such as resource availability, may influence these practices.

Factors that may influence postoperative admission to an ICU versus general ward/floor care include preoperative cardiopulmonary morbidities,[243] higher ASA physical status score,[243] long-segment fusion, prone position cases with blood loss in excess of 500 mL (829.3 ± 725.1 vs. 448.1 ± 385.2 mL),[243] airway edema, postoperative endotracheal intubation/mechanical ventilation status, length of surgery (256.5 ± 84.9 vs. 200.8 ± 80.5 min),[243] at risk for acute pain crisis, need to maintain higher mean arterial pressures, need for vasoactive agents, and frequent nursing neurological monitoring (every 1 to 2 h). The use of ERAS pathways may be associated with reduced ICU admissions, and reduced length of ICU stay after spine surgeries.[17,24]

Recommendations:

(1) Preoperative and intraoperative factors may be considered when planning patient admission to the ICU or floor/ward (Class IIb, Level of Evidence B-NR).
(2) To reduce the incidence of catheter-associated urinary tract infections, urinary catheters should be promptly removed in the postoperative period and patients monitored with serial postvoid residuals with clear guidelines for catheter reinsertion (Class I, Level of Evidence C-EO).
(3) Early enteral nutrition should be encouraged in patients after major complex spine surgery (Class I, Level of Evidence C-EO).

Continued Review of Institutional ERAS Pathways

An essential component of enhanced perioperative care in patients undergoing major complex spine surgery is continuous quality improvement. Mere implementation of a protocol is insufficient to improve outcomes.

Some studies have reported benefits of ERAS pathway implementation, including shorter postoperative length of stay,[16,19,20,23] reduced ICU length of stay,[16,17,24] improved postoperative pain control, reduced opioid use,[13,15] accelerated functional recovery with no increase in complications or need for reoperation/readmission,[20] fewer rescue antiemetics,[21] higher patient satisfaction scores,[16,20] and reduced costs.[16,17,23] However, other studies found no decrease in length of stay[18,21,22] and no reduction in 30-day readmission rates[17] or 30-day complication rates.[17–19] It is important to note that most studies published regarding spine ERAS pathways included patients undergoing either 1-level or 2-level surgery rather than complex spine surgeries including >2 levels.[244]

Recommendation:

(1) Institutions may form a multidisciplinary team of experts for the following reasons (Class I, Level of Evidence C-EO):
   (a) Identify performance measures.
   (b) Study the effects of local institutional ERAS pathway implementation.
   (c) Disseminate information related to trends in performance measures.
   (d) Audit compliance with existing ERAS pathways.
   (e) Identify opportunities for quality improvement.
   (f) Update protocol based on new evidence.

LIMITATIONS OF THIS LITERATURE REVIEW OF EVIDENCE REGARDING IMPLEMENTATION OF ERAS PATHWAYS AND FUTURE GOALS

The heterogeneity among institutions regarding various components relevant to anesthetic care of complex spine surgery patients is evident from the review of the published literature; see Table 1 for a summary of the evidence related to the perioperative care of complex spine surgery patients. Future multi-institutional research should focus on the adherence to anesthetic and nonanesthetic components of perioperative care pathways and their impact on shorter recovery times, reduction in anesthetic costs, ICU admissions, ICU/hospital length of stay, patient satisfaction, and overall cost reductions. Attempts should also be made to investigate the impact of prehabilitation medication reconciliation and comprehensive preoperative assessment in greater detail.

CONCLUSIONS

These clinical practice guidelines were developed to provide evidence-based recommendations for the perioperative management of patients undergoing major complex spine surgery. Many of the recommendations in these practice guidelines have moderate to low strength and lack a high level of supporting evidence. Anesthesiologists should consider unique institutional/patient-level characteristics when implementing these guidelines. Ongoing and future multi-institutional studies may allow for stronger recommendations with higher quality evidence. Anesthesiologists should incorporate new evidence into local practices as it becomes available.

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