

Adam C. Adler and Howard Teng

A 12-year-old female with a history of spastic quadriplegia from a perinatal hypoxic event is scheduled to undergo surgical repair of her scoliosis. She has a history of epilepsy well controlled on levetiracetam. She requires bi-level positive airway pressure (BiPAP) 10/5 cm H₂O at night. She takes glycopyrrolate to help control excessive secretions. Her parents are concerned about postoperative pain control and ask what other medications may be used for her.

PREOPERATIVE CONSIDERATIONS

What Is Neuromuscular Scoliosis (NMS)?

Neuromuscular scoliosis is a spinal deformity associated with neuromuscular disorders such as cerebral palsy, muscular dystrophies, or paralysis. The spine deformity is caused by an imbalance of truncal muscles. It often presents at an early age and can become severe as the patient grows, often involving the entire thoracolumbar spine.

How Does NMS Differ from Idiopathic Scoliosis (IS)?

Idiopathic scoliosis has no definite known cause and is classified by age group:

- Infantile scoliosis <3 years
- Juvenile scoliosis 3–10 years
- Adolescent scoliosis >10 years – most common

Drs. Adler and Teng have contributed equally to this chapter to constitute first authorship.

Unlike NMS, idiopathic scoliosis does not continue to progress with skeletal maturity and is typically associated with mild comorbidities if at all.

What Types of Comorbidities Might a Patient with Any Scoliosis Have?

For patients with IS, the main complication is disfigurement of the torso. Some patients may also present with mild pain, although severe pain is uncommon and warrants further evaluation.

Of greater concern is the cardiopulmonary complications that can arise from scoliosis. While NMS patients are more likely to present with severe curvatures, patients with IS greater than 50 degrees may also develop cardiopulmonary difficulties. Restrictive lung disease occurs due to a decrease in vital capacity. Pulmonary hypertension due to severe restrictive lung disease and chronic hypoxia may develop in patients with extreme curvature.

Patients with NMS often have other conditions such as sleep apnea, impaired swallow and gag reflexes, impaired respiratory musculature, gastroesophageal reflux, and limited mobility. All these comorbidities may increase the risk of aspiration or infectious pneumonia.

What Is the Cobb Angle?

The Cobb angle is a measure of the curvature of the spine (Table 47.1). It is the angle formed by the perpendicular lines between the upper surface of the top vertebra and the lower surface of the bottom vertebra (Figure 47.1). An angle of greater than 10 degrees is considered abnormal and surgical intervention usually is only warranted for angles greater than 40 degrees. The correlation between the Cobb angle and patient condition is shown in Table 47.1.

INTRAOPERATIVE CONSIDERATIONS

Review the Main Surgical Stages of Scoliosis Correction Surgery and Related Anesthetic Implications

After induction of anesthesia, neuromonitoring electrodes are placed and baseline levels are obtained: the anesthetic should be stable at this point, i.e., Total intravenous anaesthesia (TIVA) started and not rapidly changing. A bite block *must* always be in place prior to neuromonitoring to protect the tongue and

Table 47.1 Cobb angle measurements and associated effect on cardiopulmonary status

Cobb angle	Effect on cardiopulmonary status
<10	Normal
>25	Increased pulmonary arterial pressures seen on echocardiogram
>65	Restrictive lung disease
>100	Symptomatic lung disease

should be secured to avoid dislodgement. The tongue should be in the middle of the mouth free of any pressure from other lines (e.g., oral glucose tolerance (OGT)/temperature probe). Motor testing should be performed under vision to assure the tongue is not trapped by the teeth.

The patient is positioned prone and padded. All pressure points should be checked and padded appropriately. Auscultation for bilateral breath sounds should occur prior to incision. Antibiotics should be administered; however, care must be taken to avoid greater than one hour from administration to incision as the preparation is often lengthy.

Surgical exposure is associated with significant blood loss and stimulation. Surgeons will often request controlled hypotension and occasionally a single dose of neuromuscular blockage to prevent large muscle twitch with electrocautery. A short-acting neuromuscular blocker should be used and communicated with the neuromonitoring technician.

The spinous processes are removed and the pedicles exposed, also associated with progressive blood loss.

Pedicle screws are inserted bilaterally at each level to be corrected. Evoked potentials should be checked with each screw placement to ensure stability.

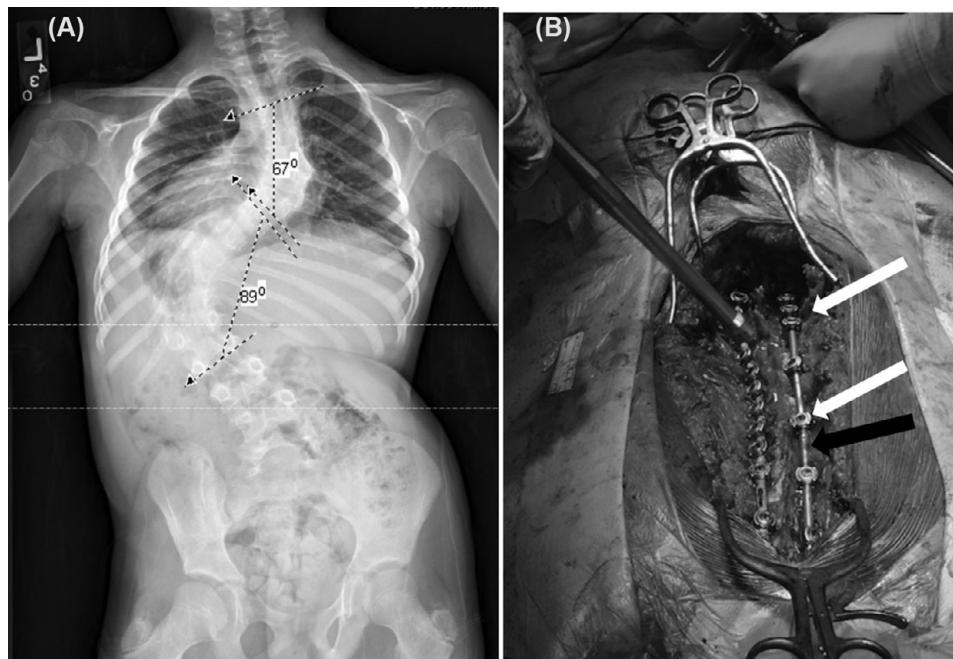


Figure 47.1 (A) Preoperative X-ray demonstrating the calculation of the Cobb angle. (B) Intraoperative image showing placement of pedicle screws (white arrows) and correction rods (black arrow) prior to curvature correction.

Vertical rods are then inserted, secured, and the curvature correction performed. Neuromonitoring should be carefully assessed for loss or reduction of signals.

Autologous and reconstituted bone matrix are packed into areas between surgical hardware and native bone to promote strong bond formation. TIVA should be adjusted planning for emergence.

Surgical closure: takes 30–60 minutes; termination of TIVA should be considered to avoid emergence delays. Long-acting liposomal bupivacaine (Exparel) may be used at the incision site to reduce postoperative pain.

What Are Anesthetic Considerations for Scoliosis Surgery with Respect to Blood Loss?

Blood loss, neuromonitoring, and positioning are the major concerns for the anesthetic management. Studies have noted that patients with adolescent idiopathic scoliosis may lose 750–1,000 mL of blood, while NMS patients experience substantially greater blood loss. Patients with Duchenne muscular dystrophy may have 2,000 to 4,000 mL of blood loss.

Large bore intravenous access and invasive monitoring are necessary, but may be more difficult in NMS patients due to severe contractures and frequent blood draws or line placements. Techniques such as hemodilution, intraoperative blood salvaging, and preoperative autologous donation can help to conserve the amount of homologous blood given.

Antifibrinolytic agents like tranexamic acid can be used to help reduce blood loss. At Texas Children's Hospital, tranexamic acid is given as a bolus at 50 mg/kg prior to incision in addition to a continuous infusion of 5 mg/kg/h.

Aminocaproic acid is another antifibrinolytic agent that may be used. Typically dosed as a bolus of 100 mg/kg followed by infusion of 1 mg/kg/h.

What Monitors/Vascular Access Should Be Considered?

Standard ASA monitors and urinary catheter should be used for all patients. Arterial line placement is generally standard for monitoring blood pressure

throughout the procedure as well as measurement of hemoglobin and hematocrit.

Central lines are generally placed in patients with NMS as they are at high risk of requiring vasoactive medications. For patients with IS, central line placement is not routine.

Some institutions employ a bispectral index (BIS) monitor to identify change in trends. When neuro-monitoring is performed depth of anesthesia based on EEG suppression can be discussed with the neuro-monitoring staff routinely throughout the case.

Temperature should be monitored continuously with a forced air warmer placed prior to surgical draping as these patients often become hypothermic during these cases.

What Accounts for the Higher Blood Loss during Surgery with NMS Patients Compared to IS Patients?

- Usually more levels requiring instrumentation
- Requirement of pelvic alignment in addition
- Poor nutritional status
- Impaired connective tissue function
- Concomitant seizure disorders with use of antiepileptics can decrease platelet levels and factor 8 levels

Is Controlled Hypotension Safe for Spinal Surgeries?

Controlled hypotension is a common technique to prevent blood loss in various surgeries. It is best accomplished using medications that are easily titratable such as nitroprusside, esmolol, nicardipine, or remifentanil. The use of volatile anesthetics for the purposes of controlled hypotension is limited due to neuromonitoring concerns.

Controlled hypotension is usually safe in an otherwise healthy patient. A mean arterial pressure of 55–60 mmHg is often the lowest target blood pressure. Historically, extremes of hypotension were performed and are no longer recommended. Some patients, especially those with NMS, may be at risk for end-organ ischemia due to their comorbidities, necessitating caution with controlled hypotension. The risks of decreased perfusion and ischemia

necessitate that normocarbia, normovolemia, and adequate hemoglobin are maintained to ensure sufficient oxygen-carrying capacity in the patient.

What Medications Are Used to Provide Controlled Hypotension Spinal Surgeries?

- Nicardipine: 0.5–5.5 mg/kg/h (total should be less than 15 mg/h)
- Esmolol: 50–150 mcg/kg/min
- Labetolol: 0.1–1 mg/kg/dose (bolus dosing)

How Will Anesthetics Affect Neurophysiologic Monitoring?

Volatile anesthetics and nitrous oxide all attenuate somatosensory evoked potential (SSEP) waveforms and thus should be maintained at a low minimum alveolar concentration (MAC) if used at all. Opioids, benzodiazepines, propofol, and dexmedetomidine all have minimal effects on SSEPs and MEPs. Ketamine can be used to augment SSEP and motor-evoked potential (MEP) amplitudes, and thus can be useful for NMS patients who have weaker waveforms at baseline. If using ketamine, it is important to maintain a steady state to ensure that changes in neuro-monitoring, if present, are not related to changes in medication administration.

Wake-up tests also may be used to check for spinal cord integrity by asking the patient to move his or her hands and feet when awake. Because of the possibility of conducting a wake-up test, short-acting anesthetics such as remifentanil and desflurane are beneficial.

What Immediate Interventions Should Occur If Signal Loss Is Observed?

- Switch to 100% oxygen.
- Notify surgeon.
- If possible, reverse last surgical intervention (i.e., last pedicle screw placed).
- Increase mean arterial pressure (MAP) >80 with vasoactive medication.
- Ensure normothermia and normocarbia.
- Maintain hematocrit >30.
- Consider steroid bolus and infusion: methylprednisolone 30 mg/kg then 5.4 mg/kg/h.

- Consider wake-up test to assess function in developmentally appropriate patients.
- Consider stat MRI.

What Are the Common Anesthetics Used to Maintain Anesthesia During Spine Surgery?

Most scoliosis surgeries are done with neuromonitoring of the spinal cord tracts. Providers tend to employ total intravenous anesthesia using a combination of the following:

Hypnotic/Sedatives

- Propofol: 100–250 mcg/kg/min
- Dexmedetomidine: 0.1–1 mcg/kg/h
- Midazolam: 0.02–0.1 mg/kg/h

Analgesics

- Sufentanil: 0.2–2 mcg/kg/h
- Fentanyl: 0.5–2 mcg/kg/h
- Methadone: 0.05–0.2 mg/kg bolus at start of case
- Remifentanil: 0.2–1 mcg/kg/min
- Ketamine: 5–20 mcg/kg/min

Depth of anesthesia should be discussed with the neuromonitoring provider to allow for adjustments to the anesthetic based on the level of EEG suppression.

Some institutions allow for use of low concentrations of inhaled agents (sevoflurane or nitrous oxide).

Long-acting local anesthetic is also commonly employed (Exparel) to reduce postoperative incisional pain.

How Does Prone Positioning Affect Cardiopulmonary Status?

Prone positioning can significantly increase intraabdominal pressure. As a result, ventilation may be impaired due to reduced chest compliance. The increased intraabdominal pressure may cause compression of the inferior vena cava (IVC), and thus lead to hypotension and decreased cardiac output. Compression of the IVC can also lead to engorgement of the paravertebral and epidural veins, causing increased bleeding in the surgical field. Consequently,

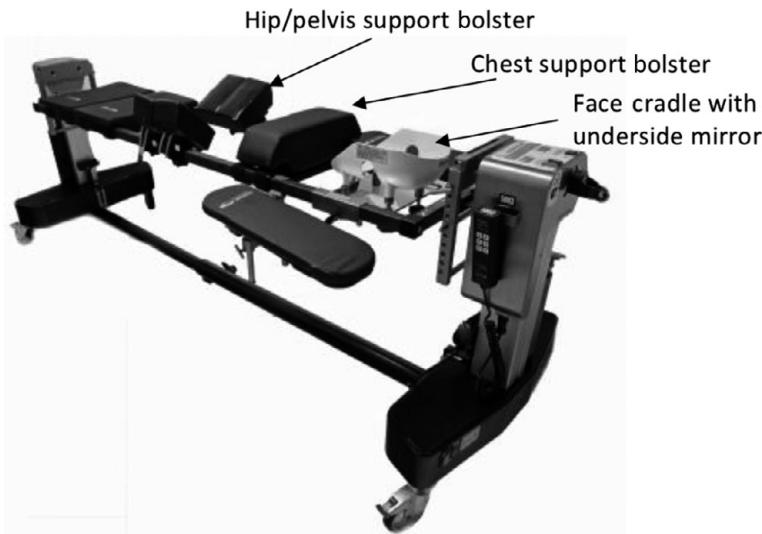


Figure 47.2 Standard spine table with key positioning features outlined

care should be taken to minimize abdominal compression by using special frames and tables (i.e., Jackson Spine table) (Figure 47.2).

What Other Considerations Are Required for Patients in the Prone Position?

Patients undergoing scoliosis surgery in the prone position are at higher risk for eye injuries. Vision loss is most frequently due to ischemic optic neuropathy. Other eye injuries include corneal abrasions, optic vein engorgements and retinal ischemia and cortical blindness. The external pressure on the face from placing the patient's head in a mask, foam pillow, or other similar devices is one of several factors that may contribute to vision loss. If the anesthetist is not careful to relieve any pressure from the eyes, ischemia may occur. Additionally, hypotension and anemia may further decrease perfusion pressure to the eyes.

As with positioning for any surgery, care must be taken to avoid pressure on peripheral nerves such as the ulnar nerve. Other areas at increased risk of external pressure injury from prone positioning include the male genitalia, breasts, feet, and the anterior superior iliac spine. A plan to close or cover the patient's incision and turn him/her supine must also be established ahead of time in case CPR is needed as the prone position affords a higher incidence of venous air embolism.

What Pharmacologic Adjuncts Can Be Used Intraoperatively?

- Ketorolac: 0.5 mg/kg up to 30 mg if hemostasis is adequate: should be discussed with the surgeon prior to administration
- Acetaminophen: 12.5–15 mg/kg IV up to 1000 mg per dose
- Diazepam: 0.1 mg/kg IV

POSTOPERATIVE CONSIDERATIONS

What Are Common Immediate Postoperative Considerations?

While rare for patients with IS, patients with NMS may require postoperative intubation. The decision to remain intubated is dependent on: preoperative respiratory status, ease of surgical procedure, degree of correction, blood loss, fluid administration, and ongoing need for transfusion or vasopressors. Scoliosis surgery itself causes a decrease in pulmonary function of up to 60 percent of baseline values during the first postoperative week and can last up to six months afterwards.

Pain can be severe after surgery and is best treated with a multimodal approach. IV opioids are often the primary analgesic and a basal infusion may be

needed. Nonsteroidal antiinflammatory drugs like ketorolac are also helpful and often started on postoperative day one. However, due to concerns for impaired bone healing, the use of NSAIDs is often center-dependent. Other analgesics that may be helpful include acetaminophen, ketamine, and antiepileptics (gabapentin). Some centers use epidural catheters for the management of postoperative pain. In this method, one or two catheters are inserted by the surgeon prior to wound closure. Intraoperative methadone is frequently given, especially to patients with IS, due to its long duration of action.

Bleeding and hypotension can continue to be postoperative concerns as well. Consequently, serial labs, fluid resuscitation, and occasionally vasopressors may be needed.

Muscle spasms are a major source of morbidity and pain postoperatively, especially in patients with NMS that are unable to ambulate. Muscle relaxants (e.g., diazepam) should be considered, as early as in PACU. Untreated muscle spasms,

especially in children with NMS, are often confused with incision pain and are less well managed by opioids.

What Are Common Postoperative Considerations in the Days Following Scoliosis Surgery?

Patients with IS should be considered for enhanced early recovery pathway.

Attention to aggressive pulmonary toilet, especially for nonambulatory patients, is crucial to avoid pulmonary morbidity:

Early ambulation and physical therapy.

Removal of indwelling lines as early as tolerated.

Advance diet as tolerated.

Encourage use of non-opioid analgesics as well as bowel regimen.

Compression boots for DVT prophylaxis.

Suggested Reading

- DePasse JM, Palumbo MA, Haque M, et al. Complications associated with prone positioning in elective spinal surgery. *World J Orthop.* 2015;6: 351–9. PMID: 25893178.
- Gornitzky AL, Flynn JM, Muhly WT, et al. A rapid recovery pathway for adolescent idiopathic scoliosis that

improves pain control and reduces time to inpatient recovery after posterior spinal fusion. *Spine Deform.* 2016 Jul;4(4):288–95. PMID: 27927519.

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