

ANESTHETIC IMPLICATIONS FOR SURGICAL CORRECTION OF SCOLIOSIS

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Patients undergoing surgical correction of scoliosis present many challenges to anesthesiologists because of the pathophysiologic derangements caused by the disease and the demanding nature of the anesthetic care that is required. A thorough understanding of the pathophysiology of the disease, intraoperative concerns specific to the procedure, and the efficacy of various anesthetic management techniques is required by anesthesiologists to optimally care for patients undergoing surgical correction of scoliosis.

This literature review focuses on key considerations for anesthesiologists, including common comorbidities in patients with scoliosis, the need for induced hypotension, large surgical blood loss, the need for transfusion of blood and blood products, possible autologous blood donation and acute normovolemic hemodilution, patient positioning, possible intraoperative wake-up testing to assess motor function, spinal cord monitoring, and hypothermia.

Key words: Anesthesia, scoliosis, spinal fusion.

Scoliosis is a complicated spinal deformity involving lateral curvature of the spine, vertebral body rotation, and angulation of the ribs leading to thoracic rib cage deformity.^{1,2} The most common form is adolescent idiopathic scoliosis (AIS), with 1% to 3% of children between the ages of 10 and 16 years affected.³ Anesthesia providers must understand the potential physiologic derangements that accompany scoliosis. The anesthetic plan must allow for safe induction and positioning of patients, appropriate management of fluids and blood loss, and careful intraoperative and postoperative assessment of neurologic function. Appropriate psychological preparation of patients undergoing such procedures must also be considered.

This review explains the pathophysiology of scoliosis, delineates indications for surgery, and highlights specific anesthetic concerns related to surgical correction of spinal curvature.

History and review of literature

In the fifth century BC, Hippocrates described scoliosis and believed it was the product of poor posture.⁴ Galen (AD 131-201) is thought to have first used the term *scoliosis* to describe spinal curvature.⁴ Both of these early physicians treated scoliosis through axial distraction with the use of extension devices.⁴ Galen added chest binders to aid in control of spinal curvature.⁴ Later, Paré (1510-1590) developed iron corsets to correct poor posture.⁴ Jules Guerin (1839) was credited with the first surgical treatment for scoliosis. He performed percutaneous myotomies of the vertebral musculature, although he was later banned from

practice as a result of his work. In the 1880s, Sayre attempted to correct spinal curvature with the use of plaster of Paris casts applied as patients stood in a vertical suspension device.⁴ The discovery of x-rays in 1895 aided in the visualization of spinal deformity, although, according to Moen and Nachemson,⁴ the hypothesis that poor posture was the cause of scoliosis held throughout the 19th century. Treatment options continued to include bracing, as well as traction beds and exercises. None of these treatments were effective in correcting the deformity.⁴

In 1902, Lange performed spinal fusions on patients with tuberculous kyphosis using steel rods and wire anchored to the spinous processes to correct the deformity.⁴ Hibbs performed his first spinal fusion for scoliosis in 1914. His technique required preoperative traction and 6 to 12 months of postoperative cast immobilization.⁴

A significant step forward in the treatment of scoliosis occurred in 1955 when Harrington developed distraction rods for the treatment of scoliosis in patients with poliomyelitis.^{4,5} This form of spinal fusion was the first to provide a "reliable means of obtaining and maintaining maximal deformity correction," although postoperative immobilization continued to be required.⁴ In the late 1970s, Luque, building on Harrington's work, developed a fixation technique involving sublaminar wires attached to Harrington or Luque rods.^{4,5} This method of spinal fusion was more stable and provided adequate fixation without the need for postoperative external immobilization.⁴ Today, spinal fusion for correction of scoliosis is achieved using the aforementioned techniques with

Cotrel-Dubousset or Luque rods, a combination of the two, or other newly developed systems.^{6,7}

Types of scoliosis

As noted in the Table,⁸ there are various types of scoliosis. The most common type of scoliosis is AIS, which is the focus of this literature review. Treatment for AIS includes posterior spinal fusion and, less commonly, anterior spinal fusion.

Adolescent idiopathic scoliosis

Adolescent idiopathic scoliosis, or late-onset idiopathic scoliosis, is the most common structural deformity of the spine. It occurs near the onset of puberty in people without known congenital or neurologic abnormalities. This disease is manifested by lateral curvature and vertebral rotation of greater than 10°.^{3,9-11} There is a 1% to 3% incidence in adolescents (age 10-16 years), and females are affected more often than males with a ratio

of 3.6 to 1.^{3,10,11} The majority of these curves require no intervention.¹¹

Serial monitoring through clinical assessment and radiography is used to assess the progression of spinal curvature.¹⁰ Spinal bracing may be attempted to slow the curve progression and prevent the need for surgery, although low compliance among adolescents in wearing such devices has been reported.^{10,12}

The 4 main curve patterns in AIS include thoracic, lumbar, thoracolumbar, and double-major curves.³ Most treatment decisions for patients with AIS are made according to the likelihood of curve progression based on curve magnitude (Cobb angle), sexual maturity, and age.³ Disease progression in children and adolescents is more likely if a diagnosis of scoliosis is made at a younger age and before menarche in girls.³

Cobb angle and curve progression

In 1948, John Cobb developed the Cobb method for

Table. Classification of structural scoliosis⁸

Idiopathic (genetic) scoliosis (approximately 70% of all cases of scoliosis; classified by age of onset)
Congenital scoliosis (probably not genetic)
Vertebral
Open, with posterior spinal defect
With neurologic deficit (eg, myelomeningocele)
Without neurologic deficit (eg, spina bifida occulta)
Closed, no posterior element defect
With neurologic deficit (eg, diastematomyelia with spina bifida)
Without neurologic deficit (eg, hemivertebra, unilateral unsegmented bar)
Extravertebral (eg, congenital rib fusions)
Neuromuscular scoliosis
Neuropathic forms
Lower motor neuron disease (eg, poliomyelitis)
Upper motor neuron disease (eg, cerebral palsy)
Other (eg, syringomyelia)
Myopathic forms
Progressive (eg, muscular dystrophy)
Static (eg, amyotonia congenital)
Others (eg, Friedreich ataxia, unilateral amelia)
Neurofibromatosis (von Recklinghausen disease)
Mesenchymal disorders
Congenital (eg, Marfan syndrome, Morquio disease, amyoplasia congenital, various types of dwarfism)
Acquired (eg, rheumatoid arthritis, Still disease)
Others (eg, Scheuermann disease, osteogenesis imperfecta)
Trauma
Vertebral (eg, fracture, irradiation, surgery)
Extravertebral (eg, burn, thoracic surgery)

measuring the magnitude of spinal curvature.⁴ To perform this calculation, standing posteroanterior radiographs of the spine are obtained. With the aid of the radiographs, the surgeon can identify the most tilted vertebrae above and below the apex of the curve. The Cobb angle is derived from the angle between intersecting lines drawn perpendicular to the top of the uppermost affected vertebra and the bottom of the lowermost affected vertebra.⁹ This technique is still used today.

The degree of spinal curvature at skeletal maturity aids in predicting the magnitude of curve progression for the lifetime of the patient. Studies by Weinstein et al³ show that patients with AIS who have Cobb angles in the thoracic spine measuring less than 30° at skeletal maturity will have minimal disease progression in adulthood. Cobb angles measuring more than 30° in the thoracic spine are likely to progress an average of 19° during a life span, whereas thoracic curvatures measuring greater than 50° progress approximately 1° to 2° per year.³ Surgery is generally indicated to correct curvatures that measure between 40° and 50°. ^{9,11} Weinstein³ wrote, “double-curve patterns of the thoracic and lumbar spine are more likely to progress than single curve patterns, and larger curves have greater risk of progression.”

Flexible thoracic curves that do not involve significant lumbar curvatures can be corrected with posterior spinal fusion with instrumentation.¹³ The anterior approach is required for fusions of stiff thoracic curves to gain spinal mobility and improve posterior correction.¹³ Thoracolumbar curves are more challenging because they involve manipulation and instrumentation of multiple vertebral levels. This increases surgical time, blood loss, and the risk of neurologic complications. If the lumbar spine is flexible and adequately balanced, fusion of the thoracic curve may be all that is needed; otherwise, extensive fusion may be required.¹³

Prevalence of back pain and mortality is the same in patients with untreated AIS and the general population.^{3,9} In a prospective natural history study by Weinstein et al,¹¹ it was found that untreated adults with lumbar idiopathic scoliosis alone are productive and function at a high level at 50-year follow-up. Untreated late-onset idiopathic scoliosis causes little impairment other than back pain and cosmetic concerns.¹¹

Coexisting diseases

- *Respiratory system.* Thoracic curvatures in AIS reduce the mechanical efficiency of the chest wall, leading to restrictive lung disease.¹⁴⁻¹⁶ Patients with Cobb angles of greater than 50° at skeletal maturity

have a higher likelihood of developing deficits in pulmonary function.¹¹ When thoracic curves reach 70° to 100°, restricted ventilation may lead to alveolar hypoventilation, arteriovenous shunting, and, possibly, cor pulmonale.¹⁶ In a study of idiopathic scoliosis, Lin et al¹⁶ found that pulmonary function was most closely related to Cobb angle, number of vertebra involved in the scoliotic curve, location of the uppermost vertebra, and patient age.

As lateral curvatures progress, the vertebral bodies and spinous processes rotate toward the concave part of the curve. The rotation of the vertebrae cause the ribs on the convex side to angle posteriorly, forming a rib hump and a narrow thoracic cage.¹ As the thoracic curvature increases, vital capacity, forced expiratory volume in 1 second (FEV₁) and PaO₂ decrease.³ Decreased inspiratory capacity with normal expiratory flow results in diminished FEV₁ and forced vital capacity, yet the FEV₁/forced vital capacity ratio remain normal.¹⁶ A preoperative vital capacity of less than 35% is considered a relative contraindication for surgery.¹⁷ Mehta and Gibson⁵ noted that, as a clinical correlate, “the presence of an adequate cough is a good clinical indicator of a satisfactory forced expiratory volume.”

Pulmonary function must be optimized preoperatively. Symptoms of upper and/or lower respiratory infection should prompt a thorough examination. Anesthetists and surgeons may want to consider postponing the surgery for 4 to 6 weeks to allow full recovery from the respiratory infection.¹⁸

- *Cardiac system.* Patients with high-degree spinal curvature and pulmonary hypertension are at risk for cor pulmonale. This may develop as loss of pulmonary capillaries and subsequent arterial hypoxemia occurs.¹⁴ Hypoxic pulmonary vasoconstriction takes place in the face of reduced PaO₂.¹⁹ If this vasoconstriction is sustained, there is hypertrophy of vascular smooth muscle in the lung, and pulmonary vascular resistance is irreversibly increased.¹⁹ This increased resistance is transmitted back to the right ventricle, resulting in right ventricular hypertrophy and eventual cardiomyopathy.¹⁹ In patients with known or suspected cardiac compromise, consultation with a cardiologist during the perioperative period, as well as invasive cardiac monitoring during surgery, may be warranted.^{5,17}

Preparation of patients for surgery

- *Physical preparation.* Patients undergoing scoliosis surgery require extensive preoperative preparation. Spirometry is performed to determine the extent of restrictive lung disease if it is present, and a chest radi-

ograph is necessary to assess lung fields and cardiac silhouette.²⁰ A 12-lead electrocardiogram should be obtained to document cardiac ischemia and axis deviation. An echocardiogram may be considered to determine cardiac function and rule out structural abnormalities.²⁰

A comprehensive laboratory evaluation should also be ordered preoperatively. A complete blood cell count and clotting profile should be done, as should a type and crossmatch.²¹ Autologous blood donation may be used for patients with idiopathic scoliosis.²⁰ Regardless of whether autologous or allogeneic transfusion is planned, blood should be available in the operating room before the surgical procedure is started. Anesthetists should also be prepared to administer fresh frozen plasma and platelets to correct consumption of clotting factors that results from massive blood loss and transfusion.

- *Psychological preparation.* Due to the magnitude of most surgical procedures for correction of scoliosis, anesthetists must realize that the patient and the family will likely have many questions and fears related to the surgery and anesthesia. Thorough preoperative teaching is important to provide information that may allay their anxiety. It is crucial for anesthetists to assess the developmental level of each patient and to establish rapport.

Parental presence may be helpful during the immediate preoperative period and in the operating room during induction. A parent who will be present during induction of anesthesia should be told what to expect as the child goes to sleep. There should also be adequate nursing staff to ensure one-on-one support of the parent during the induction period. Preoperative sedation with oral or intravenous midazolam may also benefit some patients. Depending on the psychological maturity of the patient, inhalation or intravenous induction may be undertaken.

If an intraoperative wake-up test is planned as part of the surgical procedure, it is imperative for anesthetists to explain the process and to reassure the patient that this is a controlled event. This will minimize the patient's anxiety and help ensure cooperation during the assessment. Patients should understand that they will be awakened briefly during the surgery and asked to respond to commands to move their feet and hands. They should be assured that they will neither feel pain nor remember being awake during surgery.

Monitoring

At least 2 peripheral intravenous lines are needed during scoliosis correction procedures to accommodate fluid and blood administration and the delivery of

vasoactive medications. Anesthetists may also want to consider placement of a central venous or pulmonary artery catheter if impaired cardiac function or pulmonary hypertension is present. The electroencephalography personnel will place electrodes to monitor somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs).

Invasive arterial blood pressure monitoring is required whenever the use of vasoactive drugs or induced hypotension is contemplated or when major blood loss is anticipated.²² The arterial line also offers ease of access for serial monitoring of arterial blood gases, hematocrit values, and hemoglobin and serum lactate levels.²¹ Monitoring of coagulation is also useful during this procedure.²³ An indwelling urinary catheter should be placed to allow monitoring of urine output and to assist anesthetists in determining fluid replacement requirements.

Positioning for surgery

Positioning for scoliosis surgery should be carried out with the goals of protecting the patient from neurologic damage and optimizing chest ventilation and venous return. If an anterior approach is required, the patient may be placed in the lateral position. The more common posterior approach requires the patient to be placed prone on the operating table. Therefore, induction and intubation should occur in the supine position on the transport cart.

Positioning devices must be in place before turning the patient to the prone position. These devices include the operating table, such as the Jackson table, and frame that supports the chest and pelvis, such as the Wilson frame, to be used for the procedure. Specialized headrests such as preformed foam headrests, pillows for the lower legs and feet, arm boards, and padding for bony prominences are also required.²⁴

Once prone, the patient's position must be optimized to ensure free excursion of the chest and abdomen. This is required to promote adequate ventilation and to avoid compression of the inferior vena cava and femoral veins. Adequate peripheral vascular return avoids engorgement of the epidural plexus, which may increase bleeding at the operative site.²⁵

Blood loss and fluid management during scoliosis surgery

Patients undergoing corrective surgery for scoliosis may lose significant amounts of blood. Typical blood loss for these procedures may exceed 50% of a patient's blood volume and is directly related to the number of vertebrae fused, surgical time, whether bone graft is taken from the hip, increased intra-

abdominal pressure, and anesthetic factors such as increased arterial or venous pressure, and intermittent positive-pressure ventilation.²⁶ Consumption of clotting factors may occur during the procedure if severe blood loss occurs.²³

Various techniques are available to reduce blood loss. These include modifications in surgical technique, decreasing surgical time, positioning patients to prevent venous congestion, the use of neuromuscular blockers to relax the abdominal muscles, preoperative autologous blood donation, acute normovolemic hemodilution, induced hypotension, and infusion of shed blood through the use of a cell saver.²⁷

A study by Cole et al²⁸ suggested that administration of the platelet stabilizer and antifibrinolytic agent, aprotinin, significantly decreases blood loss and transfusion requirements in pediatric and adolescent scoliosis surgical patients, and a study by Karapurkar et al²⁹ yielded similar conclusions. In addition, ε-aminocaproic acid (Amicar) was found by Florentino-Pineda and colleagues³⁰ to be helpful in decreasing blood loss in patients undergoing posterior spinal fusion and instrumentation.

It is helpful to avoid excessive administration of fluids until after instrumentation is placed to decrease the amount of surgical blood loss resulting from hypervolemia. Once the instrumentation is complete, optimal fluid and blood administration can be achieved.

Autologous blood donation

The process of donating autologous blood begins in the preoperative period.^{21,31} Under the direction of blood bank personnel, patients may donate 2 to 4 U of their own blood, which is stored in a blood bank for use during surgery.^{21,31} Autologous blood donation lessens the risk of infection with human immunodeficiency virus and other blood-borne pathogens and the risk of transfusion reaction.²¹

Acute normovolemic hemodilution

Acute normovolemic hemodilution also may be used to reduce the need for allogeneic blood transfusion. Blood is removed from the patient in the operating room before the procedure and replaced with crystalloid or colloid.²¹

In a study by Fontana et al,²¹ blood was removed in the operating room and simultaneously replaced with an infusion of 5% albumin to maintain central venous pressure (range in study, 5-23 mm Hg) and pulmonary artery wedge pressure (range in study, 7-27 mm Hg). A target preoperative hemoglobin level of 7 g/dL was achieved while monitoring mixed venous

oxygen saturation.²¹ Fontana et al²¹ report that oxygen delivery is adequate when there is an absence of lactic acidosis, the mean arterial pressure is 60 mm Hg or more, the cardiac index is 2.2 L/min/m² or more, and the mixed venous oxygen saturation is 60% or more. Fontana and colleagues²¹ found that healthy children under general anesthesia and ventilated with 100% oxygen undergo hemodilution to the preceding hemoglobin level without signs of adverse hypoxia or impairment of overall cardiac performance.

Copley et al³² used acute normovolemic hemodilution in adolescents undergoing extensive spinal surgery and concluded this is a safe method to satisfy perioperative transfusion requirements. After induction and intubation, hemodilution was done by removing venous blood and replacing it with an infusion of crystalloid at a ratio of 3 mL of crystalloid to 1 mL of blood with a desired posthemodilution hematocrit value of 30%. The venous blood is then returned to the patient at the end of the surgical procedure.

Hypotensive technique

To reduce blood loss during the procedure, anesthesiologists may lower the patient's blood pressure through the use of vasoactive drugs. Surgical bleeding may stem from arterial, venous, or capillary sources; however, each can be minimized through the use of specific vasoactive drugs targeted to the particular type of blood loss that is occurring.²² Scoliosis procedures involve mainly venous bleeding for which vasodilators such as sodium nitroprusside and nitroglycerin may be used.

Sodium nitroprusside decreases peripheral vascular resistance and blood pressure while increasing cardiac output and tissue perfusion in the presence of normovolemia or hypervolemia. However, when sodium nitroprusside is used in the face of hypovolemia, decreased venous return will produce decreased cardiac output and decreased arterial bleeding and, hence, will minimize blood loss.²² A reflex tachycardia may also occur, and β-blockers can be used to control heart rate and decrease cardiac output, reducing blood loss. In cases in which induced hypotension is used, ensuring adequate abdominal muscle relaxation optimizes venous return and avoids engorgement of the epidural plexus.^{20,24}

During induced hypotension, overadministration of fluid and blood to replace surgical losses should be avoided until after instrumentation is complete. Anesthesiologists must assess the urine output, laboratory values, heart rate, and blood pressure to determine appropriate fluid therapy.

Spinal cord blood supply

Knowledge of how blood is supplied to the spinal cord is a key to understanding the special risks involved in scoliosis surgery and the necessity for monitoring sensory and motor function throughout the procedure. Blood supply to the spinal cord is segmental. Three main arteries traverse the length of the cord, including 1 anterior spinal artery and 2 posterior spinal arteries. Each arises from the vertebral arteries.³³ Spinal arteries in the cervical and upper thoracic cord are also supplied by radicular branches of vertebral, ascending cervical, and superior intercostal arteries,³³ whereas arteries of the midthoracic cord are supplied by intercostal radicular arteries.³³ Spinal arteries found in the thoracolumbar cord are supplied by the artery of Adamkiewicz,³³ and those in the cauda equina are supplied by the lower lumbar, iliolumbar, and lateral sacral radicular arteries.³³

Gibson²⁰ reports that neurologic injury during scoliosis surgery can occur through the reduction of spinal cord blood flow by stretching or compression of vessels or interrupting blood flow to radicular arteries. Spinal cord ischemia is most common in the motor pathway that is supplied by the small, tortuous anterior spinal artery that, in some patients, can be easily interrupted.²⁰

Spinal cord monitoring

Given the risk of spinal cord ischemia during scoliosis surgery, methods for detection of spinal cord compromise have been developed. The oldest method of assessing spinal cord function is the intraoperative wake-up test, described by a renowned spine surgeon, Pierre Stagnara, in 1973 with the help of his anesthesiologist, Mme Vauzelle.^{34,35} Although somewhat controversial, the intraoperative wake-up test has remained the “gold standard” for assessment of motor function during spinal scoliosis surgery.³⁶⁻³⁸ The test involves awakening the patient after spinal distraction to discern whether motor function has been preserved. During the wake-up test, patients are awakened to the point that they can follow commands to move their feet and squeeze the anesthetist’s hands. The anesthesia is then deepened to allow completion of the surgery. However, this method of assessment has been criticized because it provides only a brief assessment of the patient’s motor function.³⁴ In addition, some patients may be unable to cooperate or follow commands. Others with neurologic disease may be paralyzed preoperatively, thereby negating the value of the wake-up test. Despite its widespread use, this technique has several limitations.³⁸ Intraoperative

assessment of voluntary motor function only provides a brief assessment of the patient’s condition, and it may fail to detect the onset of injury, ischemia, or nerve injury. There is also a risk of intraoperative recall.^{36,38} In addition, Pelosi et al³⁹ wrote that the Stagnara wake-up test “may be more accurate than SSEPs, but is no better than MEPs in predicting motor outcome,” that it “offers no information on sensory deficits which can be correctly anticipated by SSEPs in most instances,” and that it appears to “add no useful information to combined MEP and SEP monitoring.”

Contemporary methods for monitoring spinal cord function also exist. These include monitoring of SSEPs and MEPs. Electrophysiologic responses of the nervous system to sensory or motor stimulation are known as evoked potentials (EPs).⁴⁰ Intraoperative monitoring of EPs provides information about the functional integrity of neural pathways in anesthetized patients undergoing surgery.⁴⁰ Monitoring of EPs may be used in lieu of, or in addition to, the wake-up test.

Somatosensory evoked potentials

Somatosensory EPs are the most widely used modality for monitoring the integrity of the spinal cord during scoliosis surgery. Anesthetists must remember, however, that SSEPs assess only the integrity of the ascending sensory tracts of the dorsal column.^{34,38-41} Monitoring SSEPs does not provide information about the spinal motor pathways that can be damaged during corrective surgery. This is because the motor pathways are located in the descending anterior and lateral corticospinal tracts, rather than the ascending tracts of the dorsal spinal column.^{34,38,39}

Somatosensory EPs represent reproducible electrical activity that reflects activation of cortical and subcortical structures following electrical stimulation of peripheral nerves.^{38,40} These electrical impulses are averaged via a computer to produce a waveform that represents time (in milliseconds) vs voltage (in microvolts).⁴⁰ The SSEP waveforms are measured in amplitude and latency. *Amplitude* signifies the evoked potential wave’s peak-to-peak voltage difference.⁴⁰ *Latency* represents the time from stimulus to peak of response.⁴⁰

During surgery, electrical impulses are delivered to the median nerve or posterior tibial nerves via surface electrodes. The impulses are then propagated centrally via the peripheral nerve to the dorsal column of the spinal cord where it ascends the dorsal column to the medulla. In the medulla, the impulse crosses the midline to the contralateral thalamus and then travels

to the primary somatosensory cortex. This electrical activity is recorded via scalp electrodes.^{38,40}

When spinal cord function is impaired intraoperatively, there is usually an increase in latency and a decrease in amplitude.³⁸ An increase in latency of more than 10% or a decrease in amplitude of more than 50% is considered significant. Such changes reflect loss of integrity of the neural pathway and a reason for intervention by the surgical team.^{38,40}

Motor evoked potentials

Motor EPs monitor the descending motor system located in the anterior and lateral corticospinal tracts and can be elicited by electrical or magnetic transcranial (tce-MEP) stimulation.³⁸ Motor EPs are based on findings from more than a century ago that excitable regions in the cortex cause segmental muscle contraction on electrical stimulation.³⁴

In 1996, Lang et al³⁴ analyzed MEPs using transcranial electrical cortical stimulation during spinal surgery under conditions of partial neuromuscular blockade. The researchers found that transient intraoperative loss of MEP amplitude never resulted in a postoperative motor deficit. However, complete loss of tce-MEP amplitude without recovery during the course of surgery always coincided with a postoperative motor deficit.³⁴ They concluded that reliability and ease of performance of this technique supports consideration of its use in cases in which intraoperative neurologic compromise is considered a significant risk.³⁴

When used together, SSEP and tce-MEP permit sequential assessment of the dorsal sensory and ventral motor columns, respectively.⁴¹ DiCindio and colleagues⁴¹ sought to determine the reliability and applicability of multimodality tce-MEP and SSEP monitoring for detection of spinal cord injury during surgical correction of scoliosis secondary to cerebral palsy or other neuromuscular disease. Their conclusion was that tce-MEP and posterior tibial nerve SSEPs can be monitored reliably in most patients with neuromuscular scoliosis, whereas patients with severe cerebral palsy present the greatest challenge to successful neurophysiologic monitoring.⁴¹

Pelosi et al³⁹ compared monitoring motor and sensory vs single-modality (motor or sensory) intraoperative spinal cord monitoring. The researchers found that combined SSEPs and multipulse transcranial electrical stimulation MEPs provide a “safe, reliable and sensitive method of monitoring spinal cord function in orthopedic surgery.”³⁹ They also reported that “the combined method was superior to single modality techniques, both for increasing the number of

patients in whom satisfactory monitoring of spinal cord function can be achieved and for improving the sensitivity and predictive value of monitoring.” The percentage of successful MEP recordings in the study by Pelosi et al³⁹ was larger with propofol than with isoflurane maintenance anesthesia.

Effects of anesthetic agents on monitoring of somatosensory evoked potentials

Single anesthetic agents are known to affect the reliability of intraoperative SSEP monitoring. Therefore, anesthesiologists must become familiar with the effects of drugs used to anesthetize patients undergoing corrective surgery for scoliosis when SSEP monitoring is used. A literature review by Banoub et al⁴⁰ summarizes the pharmacologic influences of various anesthetic drugs on SSEPs. The article describes a dose-dependent effect of nitrous oxide and volatile agents on SSEPs. The authors suggested that end-tidal concentrations of 0.5 minimum alveolar concentration may be used when volatile agents are combined with nitrous oxide, whereas end-tidal concentrations up to 1.0 minimum alveolar concentration may be used in the absence of nitrous oxide. The literature review also stated that intravenous anesthetics have less of an effect on SSEPs than volatile agents. The use of continuous intravenous infusions of anesthetics and opioids, combined with low doses of volatile anesthetics, was suggested.

Monitoring of tce-MEPs and anesthetic agents

The primary problem that has slowed widespread application of intraoperative tce-MEP monitoring is anesthetic-induced depression of the motor system.^{38,42} A study by Ubags et al⁴² confirmed that isoflurane significantly depresses myogenic tce-MEPs, although the authors also demonstrated that application of multiple stimuli can partially overcome this depressive effect. However, the researchers also suggested that multipulse stimulation paradigms should be used and that the end-tidal concentration of isoflurane not exceed 1.0 minimum alveolar concentration. Complete neuromuscular blockade is not compatible with myogenic motor EP monitoring. However, a stable level of muscle relaxation as reflected by 1 or 2 twitches on a train of four elicited via a peripheral nerve stimulator should be maintained.³⁸

Hypothermia

Monitoring and maintenance of core temperature is vital. Sessler⁴³ wrote that *mild hypothermia*, defined as temperatures less than 36°C, may lead to various com-

plications. These include coagulopathy due to decreased platelet function, decreased resistance to surgical wound infection through direct impairment of immune function and decreased cutaneous blood flow, and decreased drug metabolism. In addition, hypothermia reduces conduction velocity in peripheral nerves and increases synaptic delay in awake and anesthetized patients.³⁸ The SSEP latency increases linearly with decreasing temperatures, whereas the amplitude of the cortical SSEP is unchanged with moderate hypothermia.³⁸ The patient's temperature should be maintained at 37°C through the use of forced-air warming devices, fluid warmers, and increased ambient temperature in the operating room.⁴³

Complications of scoliosis surgery

Paralysis is probably the most feared complication of scoliosis surgery.^{36,41} The incidence of paralysis following scoliosis surgery is 0.25% o 3.2%.⁴¹ Correction of more difficult scoliosis due to a neuromuscular disorder is more likely to result in a neurologic complication.⁴¹

Zhang et al⁴⁴ found that "...postoperative pulmonary complications increase with the deterioration of preoperative pulmonary function....Thus, preoperative pulmonary function could be useful to predict postoperative pulmonary complications."⁴⁴ Zhang and colleagues⁴⁴ further concluded that the surgical approach may impact the incidence of postoperative pulmonary complications because incidence of pneumothorax, hydrothorax, and atelectasis was 18 times higher when the transthoracic rather than the posterior approach was used.

Summary

Multiple studies have been done in an effort to determine the best anesthetic regimen to optimize operating conditions, facilitate spinal cord monitoring and intraoperative wake-up tests to assess motor function, and protect patients undergoing surgical correction of scoliosis from the dangers of allogeneic blood transfusions and hypothermia. Surgery for correction of spinal scoliosis presents many challenges to anesthesiologists. Anesthesia providers must develop an understanding of the patient's diagnosis and attendant comorbidities and then use the available research to formulate a safe anesthetic plan. That plan must address the multiple modalities that may be used to monitor spinal cord function and the physiologic derangements that may be induced by the anesthetic and surgical procedure. Once a plan of care has been developed, anesthesiologists must be prepared to implement and modify the plan accordingly.

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