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Anaesthesia for spinal surgery in children

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Spinal surgery is performed in children of all age groups. Some of these children will have significant, other medical problems. For most, surgery will be performed in the prone position. Blood loss may be high for some types of surgery, and patients will benefit from use of a blood-sparing technique. Many patients will require spinal cord monitoring to assess cord function and to prevent neurological deficit.

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Children may need spinal surgery for a variety of underlying pathology, including congenital defects, primary or metastatic tumours, haematomas, abscesses, trauma, arteriovenous malformations (AVMs), herniated discs, and consequences of other primary pathology. The most common diseases that require surgery on the spinal cord are neural tube defects and their associations, namely tethered cord, diastematomyelia, and syringomyelia.

Tumours in children presenting for spinal surgery are a less common occurrence while vascular disease of the spine (e.g. AVMs) is rare. Disc disease is also rare in children, but may be encountered in adolescents.

Far more commonly, surgery on the bony spine is undertaken in children for the correction of scoliosis, which may be idiopathic or secondary. Surgery may also be performed for the treatment of spinal cord injuries in children. Children with cerebral palsy (CP) may present for implantation of intrathecal baclofen pumps to control muscle spasm.

The aim of all spinal surgery is to correct or limit neurological deficit. Anaesthesia for spinal surgery in children must address surgical requirements for positioning and monitoring in addition to taking into consideration the associated medical problems, age-related pathophysiology, the potential for blood loss, and the potential for vascular compromise of the spinal cord. The paediatric anaesthetist is presented with a spectrum of underlying pathology in children over a wide range of age and size. A percentage of children who require spinal surgery will have other underlying medical problems.

Neural tube defects (Myelodysplasia)

Myelodysplasia is an abnormality in fusion of the embryologic neural groove during the first month of gestation. The incidence is 1 per 1000 live births.[40] Failure of neural tube closure results in a sac-like herniation of the meninges (meningocele) or a herniation of neural elements (myelomeningocele).[24] Myelomeningoceles most commonly occur in the lumbosacral area, but can occur at any level. High thoracic defects will result in a severe neurological deficit.

Spina bifida

Spina bifida refers to a failure of the fusion of the vertebral arches.[20 24] In 5–10% of patients, it occurs as *spina bifida occulta*, in which the skin and soft tissues cover the defect, usually at L5. A surface abnormality, which may be either a skin dimple or a hairy patch, is usually present. The defect in the vertebral arches communicates with the meningocele or myelomeningocele in *spina bifida aperta*.[20]

Myelodysplasia exposes the nervous tissue and places the patient at risk for infection and death. Early closure of the defect reduces the risk of infection and thus limits progressive neural damage and decreased motor function. Repair of myelomeningocele is a surgical emergency, and neonates should be operated on in the first 24 h of life for closure of the defect.[11]

Tethered cord

Tethered cord results when a thick rope-like filum terminale persists and anchors the conus at or below the L2 level. Neurological signs may develop because of abnormal tension on the spinal cord, especially during flexion and extension movements.[30 54] Surgical transection of the thick filum terminale tends to halt the progression of neurological signs. Orthopaedic and urological symptoms may result in

children with uncorrected meningoceles as a result of tethering of the spinal cord by sacral nerve roots.[35 39]

Diastematomyelia

Diastematomyelia refers to the division of the spinal cord into two halves by a projection of a fibrocartilaginous or bony septum originating from the posterior vertebral body and extending posteriorly. It represents a disorder of neural tube fusion with persistence of mesodermal tissue from the primitive neurenteric canal. The majority of cases involve the lumbar vertebrae and tend to be associated with abnormalities of the vertebral bodies, including fusion defects, hemivertebra, hypoplasia, kyphoscoliosis, spina bifida, and myelomeningocele.[18] Neurological signs result from flexion and extension movements of the cord. Diastematomyelia may coexist with a tethered cord. The condition is likely to be picked up in the preschool age.

The treatment of symptomatic patients is the excision of the bony spur or septum and lysis of the adherent structures.

Syringomyelia

Syringomyelia is defined as a cystic cavity within the spinal cord, which may communicate with the cerebrospinal fluid pathways or remain localized and non-communicating. The central canal of the spinal cord is normally obliterated after birth by the cellular proliferation of the spinal cord, and the ventricular system terminates at the obex in the caudal floor of the fourth ventricle. The disturbed embryology of the caudal cerebellum in the spina bifida–Arnold-Chiari malformation complex frequently alters the spinal cord and causes the central canal to remain enlarged and patent, causing symptomatic hydrosyringomyelia.[37]

Table 1 Development of the CNS

It is the first system to begin and last to complete development. The processes by which the CNS develops follow three steps:
Neurulation
Canalization
Retrogressive differentiation

Neurulation is the process by which the neural tube initially folds—it constitutes the first 7 stages, which occur between 16 and 28 days of life and results in the formation of brain and spinal cord through L2–L4.

Canalization is the process of neural tube formation that occurs caudal to the neural tube formed by neurulation. It consists of stages 13–20, which occur between 30 and 52 days, and results in the formation of sacral and coccygeal segments.
Cells proliferate in the neural tube wall in this region. This 'secondary' phase of caudal neural tube development and the development of associated vertebrae produce an excess number of segments.

Retrogressive differentiation consists of a degenerative process in which the excess segments formed by canalization are remodelled. It eventually brings the conus medullaris to its adult level opposite L1–L2.
This happens after stage 18 and takes place between day 46 and birth resulting in the formation of the filum terminale and the cauda equina.

Knowledge of the development of the central nervous system (CNS) aids understanding of the above conditions and is summarized in Table 1.

Chiari malformations

These are a collection of anatomic abnormalities that include displacement of the cerebellar vermis through the foramen magnum, elongation of the brainstem and fourth ventricle, and non-communicating hydrocephalus. Most children with meningomyelocele have an associated Arnold-Chiari malformation (Chiari II) and ultimately develop hydrocephalus, usually within the first month of life. This will necessitate a drainage procedure to be performed—either a ventriculo-peritoneal shunt or a ventriculostomy.[51 53]

Primary spinal cord tumours

These constitute a fifth of all CNS tumours in children. They are either intramedullary or extramedullary, which, in turn, can be either intradural or epidural.[19 41]

The most common intramedullary tumours are low-grade astrocytomas and ependymomas.[6 23] Extramedullary *intradural* tumours are usually benign and arise from neural crest tissue. They include neurofibromas, ganglioneuromas, and meningiomas.[25] Extramedullary epidural tumours are usually metastatic lesions arising from primary neuroblastomas, sarcomas, and lymphomas.[8]

With modern surgical techniques, many tumours can be safely and totally resected. Surgical removal of benign extramedullary tumours is associated with a good prognosis.

Acute spinal cord injuries

In children, acute spinal cord injuries can result from indirect trauma because of hyperflexion, hyperextension, or vertical compression accidents;[29] fracture dislocation of the vertebral column or epidural bleeding may also compromise spinal cord integrity because of the mass effect.[16]

Common causes of spinal cord injury include traumatic breech deliveries, physical abuse (shaken baby), automobile and diving accidents, falls from playground equipment, and congenital defects such as underlying vertebral abnormalities in Down's syndrome.[33]

Surgery for spinal cord injuries is only undertaken after a full secondary survey and imaging.[5] Approximately half of children with spinal injuries show no abnormality on spine X-ray.[9 48] Fracture dislocations are treated with traction and immobilization. Vertebral fusion is indicated for unstable injuries. Laminectomy and inspection of the cord are reserved for patients with progression of neurological

signs in whom computed tomography or magnetic resonance imaging images suggest an epidural or intraspinal haemorrhage.

Scoliosis

Scoliosis is a fixed, structural, lateral curvature of the spine with associated rotation of the vertebrae. The severity of the curve is evaluated on standing spinal radiographs using the Cobb angle. Scoliosis can be congenital or acquired. Congenital scoliosis, which may present at any age, is as a result of either failure of vertebral segmentation (called a *bar*) or failure of formation (called a *hemivertebra*). Congenital scoliosis is often part of a generalized condition, such as Goldenhar syndrome or spina bifida, and may be associated with abnormalities in the renal, cardiac, respiratory, or neurological systems.[4] The indication for surgery is documented progression at any age. Most acquired scoliosis is idiopathic. Infantile onset idiopathic scoliosis (scoliosis before the age of 8 yr) carries the most serious prognosis and if left unchecked is likely to result in cardiopulmonary failure in middle age.[55]

Vascular disease of the spine[13 34]

This is rare but may cause spinal compression, vascular steal, and spinal cord ischaemic damage. The maintenance of spinal cord perfusion pressure (SCPP) and avoidance of cord compression are crucial considerations.

Anaesthetic technique

Preoperative considerations

When assessing a child for spinal surgery, it is important to adopt a holistic approach. Many children have congenital problems and may present for multiple procedures. Associated medical conditions, details of previous medical and surgical procedures, previous anaesthetic records, and details of ongoing treatments must be sought. Particular attention should be paid to the condition of the respiratory, and cardiovascular systems, and the CNS. Impairment of function of these systems can be an association or a consequence of the condition requiring spinal surgery.

As spinal surgery is a major procedure in a child with underlying medical problems, preoperative investigations should be ordered. A list of useful investigations is included in Table 2. Myelodysplastic lesions of the CNS are generally not associated with an increased incidence of associated anomalies of other organ systems. Specifically, the incidence of congenital heart disease is not increased in patients with CNS lesions; so, routine preoperative screening need not include a cardiology evaluation.[11]

Vertebral defects may be associated with other congenital anomalies. The VACTERL syndrome—vertebral defects, anorectal malformations, cardiovascular anomalies, tracheoesophageal fistula, renal (genitourinary), and limb malformations, is seen in 13% of children with tracheo-oesophageal fistula.[31]

Meningoceles and myeloceles are usually repaired within the first day of life to minimize bacterial contamination of the exposed spinal cord and subsequent sepsis, which is the most common cause of death in this population during the newborn period.[11] The anaesthetic concerns relate to the size and maturity of the patient, and are summarized in Table 3. Repair of the myelomeningocele is usually the first of numerous surgeries that the child will

Table 2 Anaesthetic considerations for spinal surgery in children

Pre-operative considerations
- Evaluation of all organs systems to pick up other congenital defects.
- Evaluation of the nervous system and documentation of neurological deficit.
- Evaluation for anatomical abnormalities leading to 'airway challenge'.
- Specific age-related anaesthetic considerations (e.g. neonates).
- Awareness of associated pathology (e.g. Arnold-Chiari malformation, CP).
- Evaluation of respiratory and cardiovascular status.
- Previous anaesthetic records.
- Awareness of potential for latex allergy.
- Psychological status.
- Premedication as appropriate.

Pre-operative investigations
- Full blood count.
- Urea and electrolytes.
- Clotting profile.
- Liver function tests.
- Chest X-ray.
- Baseline arterial blood gas analysis.
- Spirometry as appropriate, when possible.
- Cervical spine imaging as appropriate.
- ECG and echocardiogram as appropriate.

Induction of anaesthesia
- Consider fibreoptic-aided intubation if anticipating a difficult airway or for unstable spinal injuries. Consider intubation in lateral position to protect the neuroplaque.
- Secure adequate venous access.
- Routine monitoring—include invasive BP monitoring where appropriate.

Maintenance of anaesthesia
- Airway maintenance and securing the tube well.
- Prone position and ensuring safety in the prone position.
- Use of appropriate agents for anaesthetic maintenance.
- Facilitation of spinal cord monitoring.
- Maintenance of SCPP.
- Prevention of hypothermia.
- Maintenance of volume status.
- Awareness of potential for blood loss—blood/products organized.
- Blood conservation techniques where appropriate.
- Antibiotic prophylaxis after discussion with surgical team.

Monitoring
- Oximetry, capnography, and gas monitoring.
- ECG, BP (usually invasive), and core temperature.
- Monitoring of neuromuscular block.

Postoperative considerations
- High dependency/intensive care nursing where appropriate.
- Postoperative analgesia.

Table 3 Anaesthetic concerns in neonates

Peculiarities of the neonatal respiratory control and mechanics
- Hypercarbia stimulates respiration to a lesser extent than in adults.
- Hypoxia leads to sustained respiratory depression.
- Tendency to periodic breathing and increased risk of postoperative apnoea up to 60 weeks after conceptual age.
- Neonates are at increased risk of atelectasis.
- Diaphragm is susceptible to fatigue.
- Increased risk of airway obstruction and thoracoabdominal asynchrony under anaesthesia.

Characteristics of neonatal circulation and myocardial function
- Limited functional reserve.
- Myocardium less able to generate force.
- Myocardium more dependent on extracellular calcium.
- Balance in favour of the parasympathetic system.

Immature hepatic function
- Require adjustment of drug dosing intervals and maintenance dosing.

Immature renal function
- Tolerate fluid restriction and fasting poorly.

Higher incidence of intraoperative complications
- Dislodgement of the tracheal tube.
- Tracheal tube obstruction.
- Bronchial intubation.
- Pneumothorax.
- Failure of anaesthetic equipment.
- Hypothermia.

require. Many genitourinary and orthopaedic procedures may be needed in the future, and the threat of developing latex allergy is real. The main latex exposure is in the surgeons' gloves, and ideally all gloves and equipment used in these children should be latex-free from the first exposure.[28]

A full preoperative assessment of neurological deficit, especially in the cases of spinal injuries and muscular dystrophies, helps the anaesthetist to pick up pre-existing neurological deficit and involvement of bulbar muscles.

A discussion with the child (where appropriate) and the parents enables the anaesthetist to explain the induction procedure, address the issues of risk and informed consent, allay anxiety and prescribe premedication if required.

Induction and maintenance of anaesthesia

A general anaesthetic technique involving intubation and mechanical ventilation is usual for all spinal surgery. Induction may be by inhalation or i.v. type. Patients are placed prone, and it is important to ensure that the tracheal tube and lines are well secured before and after turning the patient. The use of an armoured tracheal tube minimizes the risk of kinking. Protection of the eyes and pressure points must be ensured. For repair of meningoceles and myelomeningoceles, tracheal intubation may need to be performed with the child in the lateral decubitus position or supine using a padded ring in order to protect the neuroplaque.[11] Induction can be by inhalation or i.v. type unless a difficult intubation is anticipated.

Muscle relaxation is normally achieved with a non-depolarizing neuromuscular blocking agent. In neonates, the onset of action of atracurium is only slightly longer than that of suxamethonium. If a nerve stimulator is to be used to identify functioning nerve tissue, then suxamethonium is the relaxant of choice.

Venous access needs to be secured in all children. In cases where major blood loss may be a problem more than one large cannula will be needed. Blood loss may be excessive in children undergoing resection of spinal cord tumours or AVMs and in scoliosis surgery.

Fluid management will include replacement of third space loss and blood loss. Third space loss may be high in closure of large meningomyeloceles. Blood loss depends on the complexity and duration of the procedure. For myelodysplasias, it is usually not excessive unless the lesion is extensive, necessitating skin grafting.

Any standard technique can be used for maintenance of anaesthesia—inhalation or i.v. The focus of intraoperative management is minimizing spinal cord ischaemia and compression on the spinal cord. These are accomplished by maintenance of SCPP through control of blood pressure (BP) and minimizing venous congestion by careful positioning of the patient to prevent compression of the abdomen. We need to ensure spinal cord perfusion while producing a bloodless surgical field. Remifentanil is becoming increasingly popular for this purpose. Remifentanil is an ultra-short-acting opioid, which produces profound analgesia, has a rapid onset, excellent titrability, and a rapid offset. It can be used as a part of either an inhalation or an i.v. maintenance regime. Propofol and remifentanil can be used together for total i.v. anaesthesia in older children.[15]

Monitoring during spinal surgery should routinely include ECG, pulse oximetry, capnography and anaesthetic agent monitoring, temperature (core and peripheral), neuromuscular block, and BP (usually invasive). Central venous pressure monitoring should be undertaken in patients with associated cardiac disease and where major blood loss is anticipated. In addition to routine monitoring and vascular access, placement of an arterial line should be considered in long surgical cases, especially for tumour resection. It is wise to place a urinary catheter in such cases. Frequent evaluation of acid–base status, haemoglobin, haematocrit, and coagulation profile may be needed in some patients. Monitoring for air embolus will also need to be undertaken in some types of surgery, especially that for scoliosis.[17]

The state-of-the-art management for paediatric spinal cord injuries in the operating theatre mandates control of the airway while the patient is under spontaneous ventilation and, optimally, with continuous somatosensory evoked potential (SSEP) monitoring. Accurate monitoring during extension and positioning is of prime importance, because this phase may lead to catastrophic spinal movement and irreversible injuries. Spinal electrical monitoring should be part of the perioperative care of these patients

and should be used throughout the procedure until the patient is turned supine; the trachea is extubated, and the integrity of the spinal cord confirmed.

Decisions about where the child should be cared for after operation depends on the pre-existing cardiac and respiratory function, duration of the procedure, intraoperative events, extent of blood loss, hypothermia, and analgesic requirements. Some children need postoperative ventilation and intensive care nursing.[4 55]

A general template for the anaesthetic considerations for spinal surgery in children is summarized in Table 2.

Important considerations in spinal surgery

The prone position

The majority of spinal surgery in children is done in the prone position. The prone position refers to a facedown patient with supports placed beneath the upper chest, shoulders, and iliac crests, allowing freedom of abdominal movement to facilitate ventilation and to reduce intra-abdominal pressure so as to reduce bleeding from the epidural plexus. The head is usually placed in a headrest in the neutral position or turned to one side while resting on the pillow. A padded foam or jelly pad may be used to protect the ear and eyes.

In younger patients, bolsters or jelly rolls may be used to provide support to the torso while lifting the abdomen free from the surface of the operating table and stabilizing the patient. For larger number patients and larger, specific surgical procedures, the Wilson, Relton-Hall (Imperial Surgical Co., Toronto, Canada), or the Andrew frames can be used. These usually consist of four adjustable posts designed to hold the patient while prone: two posts support the upper chest and the other two support the iliac crests. One must be aware of the complications that can occur in the prone position (Table 4). Meticulous attention to detail can prevent their occurrence.

Table 4 Complications of the prone position

Unintentional extubation
Eye complications
• Corneal abrasions
• Conjunctival and periorbital oedema of the dependent eye
• Retinal ischaemia
• Postoperative visual loss because of ischaemic optic neuropathy (ION)
Entangling of cables
Accidental dislodgement of access and monitoring lines
Abdominal compression leading to impaired ventilation, increased bleeding from epidural plexus, and decreased cardiac output
Improper head and neck positioning leading to venous and lymphatic obstruction
Macroglossia
Possibility of venous air embolus

Temperature maintenance

Premature infants and term neonates are particularly vulnerable to hypothermia, because they have little s.c. fat. Hypothermic neonates are more prone to apnoea, bradycardia, hypotension, and acidosis.[26] Children are more vulnerable to hypothermia because of their greater surface area to body mass ratio. Infants maintain normothermia by a combination of vasoconstriction and brown fat thermogenesis, but cannot increase their metabolic rate in response to mild intraoperative hypothermia. Over 1 yr of age, non-shivering thermogenesis is replaced by shivering. Hypothermia also prolongs recovery from neuromuscular block, impairs platelet function, and leads to a higher incidence of wound infections. Devices available to minimize intraoperative hypothermia include warming mattresses and hot air warming blankets such as the Bair hugger device and warmed fluids.[32]

Conservation of body heat is important for infants with a myelomeningocele, particularly because autonomic control below the level of the defect is abnormal. Operating theatre temperature should be 27°C and radiant heat lamps should be used during positioning and skin preparation. The neonate should be placed on a warm air mattress.

Spinal cord blood flow

Vascular anatomy

The spinal cord vascular anatomy comprises separate anterior and posterior circulations that arise from the vertebral arteries and are supplemented by intercostal and lumbar vessels from the descending aorta. A single anterior spinal artery supplies the ventral two-thirds of the spinal cord, which includes the corticospinal tracts and motor neurons. Paired posterior spinal arteries form a plexus-like arrangement on the surface of the cord and supply the dorsal one-third of spinal cord parenchyma, which transmits proprioception and light touch. There is essentially no collateral flow between the anterior and posterior circulations.[50]

The anterior spinal artery, which supplies motor neurons and tracts, is of uneven calibre and is not functionally continuous. The blood flow to the anterior spinal cord is supplemented by collateral flow through radicular arteries arising from the aorta. Only 6–8 of the 62 radicular vessels present during development persist into adult life. The large distance between these radicular arteries leaves watershed areas at the upper thoracic and lumbar levels, and thus making the spinal cord particularly vulnerable to ischaemia. The great radicular artery of Adamkiewicz arises from the aorta between the T8 and L3 nerve roots, and supplements the blood flow to the anterior portion of the distal thoracic spinal cord and lumbar enlargement.[3] It provides up to 50% of the entire spinal cord blood flow and

may be injured during aortic or spinal surgery or after spinal trauma.[45 52]

The venous outflow of the spinal cord is divided into two systems called the vertebral and venous plexuses. These internal and external plexuses communicate with each other and with the segmental systemic veins.

Blood flow regulation

Animal data suggest that the spinal cord blood flow is controlled by the same factors and the same general physiological principles as cerebral blood flow (CBF).[22 42] Spinal cord blood flow is lower than CBF, because absolute spinal cord metabolism is lower than that of the brain. Blood flow to the spinal gray matter is about half that to the cerebral cortex, and the flow to the white matter is about one-third of that to spinal gray matter.

SCPP equals mean arterial pressure minus extrinsic pressure on the spinal cord. Pressures exerted by local extrinsic mechanical compression, such as tumour, haematoma, spinal venous congestion, and increased intraspinal fluid pressure, can be important determinants of the SCPP. Spinal blood flow is maintained constant by vasodilatation or vasoconstriction of the cord's vasculature to accommodate for changes in mean arterial BP. Limits of spinal cord blood flow autoregulation are 45–180 mm Hg. Conditions that affect this autoregulatory mechanism include severe hypoxia, hypercapnia, and trauma.[22 42]

The spinal cord vasculature and cerebral vasculature react to changes in oxygen and carbon dioxide concentrations in a similar fashion. Epidural anaesthesia may affect the spinal fluid pressure.[21]

Spinal cord monitoring

Intraoperative monitoring of spinal cord function is considered a standard of care in spinal surgery.[43] Spinal cord monitoring usually forms a part of the surgical procedure for spinal injuries and for scoliosis correction. Methods of monitoring the integrity of the spinal cord function intraoperatively include

(1) The wake up test
(2) SSEP
(3) Motor evoked potentials (MEPs)
(4) Dermatomal responses

The wake up test

This was described 20 yr ago.[14] Before the use of electrical monitoring, it was a method of assessing spinal cord function during corrective procedures of the spine. The major advantage is that it assesses anterior spinal cord function (i.e. motor function). The hazards of this test include accidental extubation, air embolism on deep inspiration, and dislodgement of fixators. Its major limitation is that it assesses spinal cord function only at one specific time (i.e. during the wake up test) and not continuously during the procedure. False negatives are reported. Both inhalation and i.v. anaesthetic techniques are suitable for the 'wake up' test. A standard wake up test cannot be performed in infants and small children. Alternatives such as tetanic stimulation of the lower legs and observation of the clinical response can be tried in this age group.[38]

SSEP

This is a more widespread method of electrical monitoring of the spinal cord. SSEPs are a measurement of electrical potentials evoked by stimulation of the sensory system.[1] The response of constant current stimulation of the median, tibial, and, rarely, the sural nerve is recorded at the cortex using surface electrodes or a bipolar electrode placed epidurally by the surgeon. Baseline SSEPs are recorded in order to exclude neurological dysfunction and also to determine the feasibility of operative monitoring. Neurophysiology technicians monitor the latency and amplitude of the recordings continuously during anaesthesia and surgery. A >50% decrease in SSEP amplitude is deemed significant. Numerous anaesthetic agents interfere with the latency and amplitude of the SSEP. Surgical stimulation level and hypothermia also interfere with SSEP. Volatile agents, cold, hypoxia, hypercarbia, and spinal ischaemia suppress both SSEPs and MEPs.[7 12] Responses recorded from the cerebral cortex are more sensitive to the effects of anaesthetic agents than epidurally recorded responses. Neuromuscular block reduces muscle artifact on the recorded SSEPs. SSEP monitoring is a pathway-specific method; an injury not involving the sensory pathway will not be detected. Global cord monitoring may be possible with combined SSEPs and MEPs.[12]

Motor evoked potentials

MEPs may be either evoked EMGs or compound muscle action potentials (CMAPs).[27] They assess function of the motor cortex and the descending motor pathways. They may be obtained by stimulation of the motor areas of the brain or spinal cord through the intact skin, direct stimulation of the exposed neuronal tissue, or direct root stimulation (e.g. during the release of a tethered cord) recording a stimulus-related response either as a CMAP or as an efferent compound nerve action potential (CNAP). CNAPs allow the patient to have neuromuscular blocking agents.

Multiple pulse transcranial stimulation involves cortical stimulation with progressive energy aimed at detecting the threshold needed to achieve peripheral muscular signal. A modification of this threshold is a sensitive marker of spinal compromise.

Dermatomal responses

Pudendal nerve responses are a special case of dermatomal responses that are particularly useful, especially in patients with spina bifida.[10] The pudendal nerve carries sensory fibres from the penis, urethra, anus, and pelvic floor muscles, and supplies motor innervation to the bulbocavernosus and pelvic floor muscles, the external urethral sphincter, and the external anal sphincter. Cortical responses to the electrical stimulation of the dorsal nerve of the penis, the urethra, and the urinary bladder have all been described. Pudendal nerve responses are of similar morphology to the tibial nerve SEP and are best recorded from the same area of the scalp.

Cerebral palsy

CP is 'an umbrella term covering a group of non-progressive, but often changing, motor impairment syndromes secondary to lesions or anomalies of the brain arising in the early stages of its development'. The motor defect may be spasticity, ataxia, or dyskinesia. CP children may be treated with a variety of medications.

Baclofen is an agonist at the GABA-β receptor, acting in the spinal cord to inhibit the release of excitatory neurotransmitters and thereby reducing the muscle tone. It is the only medication currently used intrathecally with a demonstrable reduction in spasticity. Baclofen may be administered intrathecally via a programmable pump, which is implanted surgically.[2]

Children with CP can also present for spinal surgery with a secondary scoliosis. Their main medical problems may include difficult venous access, limb contractures making positioning a problem, epilepsy, gastro-oesophageal reflux, chronic upper airway obstruction, and difficulty in assessing pain management.[56] Evaluation of perioperative risk is very difficult especially in children with severe disability.

Blood conservation

Spinal surgical procedures have the potential for massive haemorrhage. Preoperative planning for spinal surgery should always include cross-matching of two or more units of blood. However, an increasing pressure on bloodstocks as a result of restrictions on potential donor suitability has resulted in measures to minimize homologous blood transfusion. These include preoperative supplementation with oral iron and possibly s.c. erythropoietin, predonation of blood, acute normovolaemic haemodilution, good surgical technique and haemostasis, correct positioning of the patient when prone, hypotensive anaesthesia (only with adequate cord monitoring), use of cell saver, aprotinin,[44 47] tranexamic acid,[46] intrathecal opiates, and monitored use of coagulation products. Acceptance of a lower postoperative haemoglobin level should reduce the need for postoperative transfusions.

Homologous blood transfusion is also associated with the risks of transmission of bacterial and viral infections, alloimmunization, immunomodulation, graft *vs* host disease, metabolic imbalance, and transfusion mismatch.[49] There is a growing medical and parental concern about these potential hazards.

Management of postoperative pain

Pain after spinal surgery usually requires use of an opioid-based technique. In younger children, this may be using a morphine infusion or a nurse-controlled analgesia. Children >7 yr of age may be able to use patient-controlled analgesia. Infiltration of the wound at the end of surgery with local anaesthetic will improve pain relief in the immediate postoperative period. Opioids should be supplemented with regular paracetamol and non-steroidal anti-inflammatory drugs if there are no contraindications to their use. For scoliosis surgery, this may be supplemented with the use of an epidural with the catheter inserted by the surgeon at the end of the procedure.[36]

Conclusion

Children may present for spinal surgery at any age from infancy to adolescence. The anaesthetist must consider age-related pathophysiology while planning the anaesthetic technique. Anaesthetic management requires a meticulous approach to safety, positioning, and spinal cord perfusion, with maintenance of normothermia and normovolaemia. Neurological deficit can be minimized by careful attention to preoperative assessment, good surgical technique, good haemodynamic control using cardiovascular monitoring, and continuous monitoring of spinal cord function.

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