Chapter

29 Anaesthesia for Orthopaedic and Scoliosis Surgery in Children

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Introduction

Anaesthetic requirements for children undergoing orthopaedic surgery can be very varied, ranging from simple to complex. The scope of surgery includes management of acute trauma, disorders of musculoskeletal development and highly specialised operations for congenital, neuromuscular and acquired musculoskeletal conditions. Complexity can be related to the invasiveness of the procedure or an underlying associated medical condition when even minor surgery can be hazardous due to anatomical, physiological or biochemical abnormalities.

This chapter will discuss the general principles of anaesthesia for elective orthopaedic and spinal surgery, common procedures and underlying medical conditions. Anaesthesia for hand surgery is discussed in Chapter 28. Emergency surgery is most commonly associated with trauma, which is discussed in Chapter 39. Regional anaesthesia is increasingly utilised to provide perioperative analgesia, which is described in detail in Chapter 15.

Preoperative Assessment and Preparation for Elective Surgery

Many patients presenting for orthopaedic surgery have coexisting conditions which influence the focus of examination and investigation.

Examples of coexisting conditions include:

- Cerebral palsy (gait correction, hip surgery, scoliosis surgery)
- Muscular dystrophy (scoliosis surgery)
- Osteogenesis imperfecta (fractures, scoliosis surgery)
- Arthrogryposis (joint contractures, scoliosis surgery)
- Neurofibromatosis (scoliosis surgery, pseudoarthrosis of the tibia)
- VATER/VACTERL association (scoliosis surgery, hand surgery)

Multidisciplinary review is essential preoperatively to assess, investigate and optimise and for health professionals, patients and carers to discuss risk. Orthopaedic patients often require repeat surgery and prolonged hospital admissions. Care should be individualised, and negative experiences minimised. Attention should be paid to the presence of muscle spasm and use of anti-spasmodics. Postoperative muscle spasm may be severe in an immobilised limb and should be anticipated and well managed. Patients with coexisting cardiac disease are particularly high risk, and all members of the multidisciplinary team must be involved in their preoperative assessment.

Cardiorespiratory Disease

Children with syndromes associated with cardiac disease require detailed review including electrocardiogram (ECG), echocardiogram and cardiology assessment. Diseases of the skeleton leading to thoracic cage deformities, scoliosis and restrictive lung disease can progress to pulmonary hypertension and cor pulmonale, and these children also require specialised review. The risks and benefits of surgery in such patients should be explored carefully using a multidisciplinary approach, with postoperative ventilation and critical care planned if required. Discussions regarding significant risks such as long-term ventilation, the need for tracheostomy and potential mortality must take place during the assessment process, prior to planned surgery.

Obstructive Sleep Apnoea

Obstructive sleep apnoea (OSA) is common in children with hypotonic neuromuscular diseases,

obesity and associated craniofacial abnormalities. Sleep studies should be considered in patients with symptoms of OSA to evaluate the need for respiratory support and plan the level of postoperative care. These patients are likely to have increased sensitivity to sedative premedication and opioid analgesia.

Airway Assessment

Assessment of the airway must take into account the potential for difficult mask ventilation and/or difficult tracheal intubation and/or cervical instability. For example, conditions such as achondroplasia and osteogenesis imperfecta may lead to craniocervical instability, placing the spinal cord at risk during tracheal intubation.

Preoperative Blood Tests

Preoperative blood tests will be guided by the history, examination and planned surgery. Blood transfusion is rarely required for peripheral orthopaedic surgery, as tourniquets are used routinely and many of these children will not require any preoperative blood tests.

Major pelvic and femoral operations, including pelvic osteotomy and total hip replacement, require full blood count, urea and electrolytes and blood group and antibody screen as a minimum. Coagulation testing should be undertaken for major tumour surgery such as hemipelvectomy, sacrectomy and femoral replacement as well as for spinal surgery. Abnormalities of the coagulation screen should lead to individual clotting factor assays.

Iron deficiency is common. Treatment of preexisting anaemia will reduce the risk of transfusion. Correction of nutritional deficiencies is straightforward, but occasionally erythropoietin is indicated in chronic disease. Vitamin D deficiency is common and frequently associated with orthopaedic conditions. Vitamin D and parathyroid hormone (PTH) levels should be measured and severe deficiencies treated.

Many children take anticonvulsants, which need to be continued in the perioperative period. Children taking these should have liver function tests monitored.

Venous Thromboembolism

Deep venous thrombosis (DVT) is uncommon in children, but all patients should have a DVT risk assessment. Risk factors include central venous catheter insertion, cancer, known thrombophilia (antiphospholipid syndrome, factor V Leiden, protein C, S or antithrombin III deficiency), obesity, significant medical comorbidities, oral contraceptive pill use, previous DVT, prolonged immobility, lower-limb fractures and pelvic, hip or spinal surgery and age. DVT prophylaxis is not normally required in prepubertal children unless there are specific risk factors, even after major surgery. Post-pubertal children are at higher risk and require good hydration, early mobilisation and mechanical compression methods to be used. Pharmacological prophylaxis with low molecular weight heparin (LMWH) should be considered and discussed with the surgeon in patients with multiple risk factors.

Pre-anaesthesia Checks

Wrong site surgery is a 'never event' and is a significant risk in orthopaedic surgery. There must be a special focus on pre-induction checks during the sign-in phase of anaesthesia, particularly when checking the consent for surgery and surgical site marking. Ionising radiation is commonly used during orthopaedic surgery, so the possibility of pregnancy must be excluded in female patients after menarche or over the age of 12 years.

Anaesthesia Techniques

Inhalational Induction

Medical factors favouring inhalation induction include management of a difficult airway or difficult venous access. In certain circumstances, the use of volatile agents is contraindicated. This can be absolute, as for malignant hyperthermia susceptibility (MHS), or relative where there is insufficient clinical evidence to guarantee safety, as in the case of the muscular dystrophies (see the section 'Muscular Dystrophy'). MHS is a specific autosomal dominant inherited disorder, and there are only a few rare diseases linked to MHS. These are:

- Core myopathies (particularly central core disease)
- King–Denborough syndrome
- Brody disease

Children with these conditions should all receive a 'trigger-free' anaesthetic. No other diseases have a proven association with MHS.

Neuromuscular Blocking Agents

Neuromuscular abnormalities are common in patients presenting for orthopaedic surgery. Suxamethonium should be avoided and can never be considered safe in this group of patients due to the risk of hyperkalaemia and cardiac arrest. If neuromuscular blockade is required, a judicious dose of a non-depolarising agent should be used (taking into account the severity of the neuromuscular condition).

Continued neuromuscular blockade after intubation is contraindicated if motor nerve function needs to be monitored. For example, during limb lengthening surgery, percutaneously applied wires and struts may cause nerve damage. This risk is minimised if a motor response can be detected if a nerve is inadvertently irritated. It is essential to monitor motor evoked potentials (MEPs) during scoliosis surgery.

Maintenance of Anaesthesia

Anaesthesia can be maintained using volatile agents or total intravenous anaesthesia (TIVA) using propofol and remifentanil. The aim is to provide safe operating conditions, facilitate spinal monitoring where indicated, provide good analgesia, achieve rapid recovery and minimise complications such as postoperative nausea and vomiting (PONV).

Antibiotics

Antimicrobial prophylaxis is indicated if metalwork is to be implanted, with the choice of agent directed by local policy. Antibiotics should be administered prior to skin incision and as soon as possible after induction so that tissue concentrations can be maximised – this is most important when a tourniquet is used.

Analgesia

Multimodal analgesia is central to optimal pain management. Local anaesthetic blocks should be used whenever possible, use of opioids kept to a minimum and deep anaesthesia avoided in vulnerable patients. Intraoperative ketamine and clonidine reduce opioid requirements. Clonidine may be added to local anaesthetics to enhance single-shot caudal blocks when indicated. Regular paracetamol and non-steroidal anti-inflammatory drugs (NSAIDs) should be given postoperatively unless there are contraindications. Oral opioids are usually adequate for soft tissue surgery, but IV opioids are often required postoperatively for bone-disrupting surgery, ideally by means of a nurse-controlled or patient-controlled analgesia (NCA or PCA) device.

Local anaesthetic infiltration can be used for simple procedures, however patients undergoing more complex surgery would benefit from single shot or continuous peripheral nerve blocks. The use of high-frequency ultrasound and appropriately sized probes can provide high-resolution images of neurovascular structures, tissue planes and needle position. The following regional techniques are effective:

Shoulder surgery:	Interscalene block
Upper-limb surgery:	Supraclavicular, infraclavicular and axillary brachial plexus blocks
Lower-limb surgery:	Caudal
	Epidural
	Femoral nerve block: anterior thigh and medial aspect of the knee
	Popliteal and saphenous nerve block: lower leg
	Ankle block: foot surgery

It is essential to monitor for nerve injury and compartment syndrome postoperatively if continuous epidural infusions are used. If removing the catheter at the end of surgery, consider elective top-up of the block prior to catheter removal.

Bladder catheterisation should be considered if an epidural is used, for prolonged surgery and in the presence of lower-limb plaster casts. Catheterisation will prevent acute postoperative urinary retention but also simplify patient care and prevent soiling of plaster casts.

Use of Non-steroidal Anti-inflammatory Drugs (NSAIDs) in Orthopaedic Surgery

Animal and human studies suggest that fracture healing and ossification is reduced by NSAIDs, probably owing to their effects on cyclo-oxygenase-2 and mesenchymal cell differentiation, but this is controversial and not all studies are consistent. There is no evidence from studies in children that NSAIDs have a detrimental effect upon bone

healing, and the analgesic benefit of short-term NSAIDs frequently outweighs any theoretical risk. If bone healing is a major concern, NSAIDs should be limited to the first 48 hours postoperatively.

Positioning

Pre-existing neurological deficits, contractures, deformities and fractures should be carefully documented. Meticulous positioning is essential to avoid intraoperative damage. Each joint should be carefully padded to provide support to prevent pressure sores and accidental dislocation in children with contractures. The prone position is discussed further in the section 'Scoliosis Surgery'.

Tourniquets

Pneumatic tourniquets are placed whenever indicated. Inflation pressures are determined by systolic blood pressure. Lower-limb inflation pressures should be set at approximately 150 mmHg above systolic and upper-limb 100 mmHg above systolic pressure. Adequate skin padding under the tourniquet is essential, and the site must be protected from any ingress of irritant fluids such as skin cleaning fluid. Inflation times should be limited to 75 minutes and simultaneous bilateral inflation avoided. Inflation times above 90 minutes lead to a progressive rise in core temperature. Tourniquets must be used with caution in children with sickle cell disease, with careful exsanguination of the limb prior to inflation.

Specific Orthopaedic Conditions

Developmental Dysplasia of the Hip

Congenital or developmental dysplasia of the hip (DDH) occurs in approximately four in 1,000 live births, with females more often affected than males. Prolonged displacement of the femoral head from the acetabulum can lead to permanent dislocation, dysplasia and eventual osteoarthritis if left undetected. Treatment should begin in the neonatal period and aims to reduce the dislocation and optimise the position of the femoral head in the acetabulum, thus promoting healthy growth. This can be achieved non-invasively by traction or closed reduction with application of a hip frog plaster (hip spica). Invasive procedures are needed in difficult cases; this may involve adductor tendon releases (to improve mobility and relocation of the femoral head), open reduction of the joint, femoral rotational osteotomy to improve femoral head engagement and acetabular procedures to improve the coverage of the femoral head.

Anaesthetic Management

Major hip surgery may result in significant blood loss. Often the exact nature of the surgical intervention is not known until after further examination and arthrogram under anaesthesia. Insertion of a regional block can be delayed until the surgical procedure to be performed is confirmed. Single-shot caudal or lumbar epidural are effective intraoperatively for all invasive procedures, although opioids are often required to cover skin incisions over the iliac crest by the end of extensive procedures. Opioid NCA/PCA will be required postoperatively. Postoperative immobilisation is often achieved using a hip spica – this limits the use of a lumbar epidural catheter, as there is minimal access to the lumbar spine. The legs need to be raised to reduce swelling postoperatively and a postoperative haemoglobin level checked. Capillary refill and distal pulses should be examined regularly to detect circulatory compromise.

Application of Hip Spica

A hip spica is an extensive hip plaster cast that is the cornerstone of treatment to maintain hip position in smaller children. The patient must be suspended on a casting table during application. Control of the airway may be difficult in this position, and even if undertaken as a sole procedure, intubation should be considered. Moving the patient onto the spica table is stimulating and may reveal a lighter plane of anaesthesia than expected, particularly if the spica is applied at the end of a long procedure and the surgical site is covered by a regional block; take care to maintain an appropriate depth of anaesthesia at the end of surgery. Application of a hip spica can take 40 minutes, and it can be challenging to keep the child warm. Double nappies are used to avoid soiling of the cast and should be in place before the child wakes up. Urinary catheterisation simplifies immediate postoperative care after extensive surgery.

Congenital Talipes Equinovarus

Congenital talipes equinovarus (CTEV), or clubfoot, is a common congenital deformity occurring in approximately one in 1,000 live births. Most

cases are idiopathic but can be associated with neuromuscular abnormalities. Early treatment is by soft tissue manipulation and serial casting. Percutaneous Achilles tendon lengthening or soft tissue release may be required to aid correction, and in later stages osteotomy may be needed. Rarely, the correction is achieved by application of an external frame and gradual correction.

Anaesthetic Management

Occasionally the patient will need to be positioned prone. A caudal epidural block is standard practice, and if an osteotomy is performed, regional techniques, including popliteal and saphenous nerve blocks, can be used. Parenteral opioids will be required postoperatively. Any procedure involving the stretching of muscles combined with postoperative casting will be associated with postoperative muscle spasm. Severe intermittent cramping pain that is unresponsive to opioids may become apparent as the caudal recedes. Spasm responds to oral diazepam, and this should be prescribed preoperatively rather than pursuing increasing doses of opioids.

Limb Lengthening

Simple limb length imbalance can be corrected via epiphysiodesis (fusion of the growth plate) or require complex operations for limb lengthening via the Ilizarov method. The latter procedure involves complex osteotomies, distraction and fixation with an external fixation frame, which can be gradually extended. There is a high risk of compartment syndrome, particularly with tibial lengthening, and therefore regional anaesthetic techniques are usually avoided to facilitate postoperative neurovascular monitoring. However, these are painful procedures which require multimodal analgesia, usually with postoperative PCA/NCA opioids.

Cerebral Palsy

Cerebral palsy results from central nervous damage caused either antenatally or in the immediate perinatal period. It is characterised by motor dysfunction, which can be classified into spastic (most common), dyskinetic, ataxic or mixed. The clinical picture is highly variable. Some patients may have normal intellect masked by communication difficulties; during the preoperative visit, it is essential to enquire about levels of comprehension and not to make assumptions that will alienate the child. The Gross Motor Function Classification System (GCMFS) is used to categorise the child's motor function and ranges from level 1, where children can walk and perform gross motor skills, to level 5, where children require a wheelchair for all movement and are limited in maintaining antigravity head and trunk posture.

The area of the brain affected will dictate any associated problems. Epilepsy occurs in about 40%, and intellectual or cognitive problems are common. Swallowing and feeding problems are frequent and can result in malnutrition and recurrent chest infection. These patients are at risk of developing chronic respiratory insufficiency. Gastro-oesophageal reflux is common, and many have anti-reflux procedures, often with a gastrostomy. Enthusiastic feeding can rapidly develop into obesity with little appreciation of the underlying lack of muscle mass. Difficult venous access is common. Scoliosis is common and can further impact upon respiratory function. Many children have had ventriculo-peritoneal shunts inserted for the treatment of hydrocephalus, and damage to these systems must be avoided. Latex allergy occurs with greater frequency in this group of patients.

Orthopaedic surgery is aimed at improving function, mobility and reducing pain. The simplest procedure is injection of botulinum toxin into the spastic muscles combined with postoperative physiotherapy and splinting. This is usually performed as a day-case procedure, even for the most high-risk patients. Hip surgery can be performed to reduce painful dislocation or enhance function by rotational femoral osteotomy to realign the limb. Fixed flexion deformities require extensive soft tissue releases and casting to maintain the correction.

Anaesthetic Management

Gastro-oesophageal reflux and respiratory impairment are common, so in all but minor procedures the child should be intubated and ventilation controlled. In the absence of a gastrostomy, the placement of a nasogastric tube simplifies the postoperative administration of anticonvulsant therapy. Difficult venous access increases the need for central access; care must be taken to avoid damage to ventriculo-peritoneal drainage systems. Temperature regulation is often disordered, and in severe cases the basal metabolic rate so low that

severe hypothermia may occur rapidly. Pain assessment is difficult in the postoperative period owing to general irritability and poor communication. Muscle spasm must be managed aggressively, and the early use of oral diazepam is encouraged. Opioids must be used when indicated, although atypical responses are common. There is a fine balance between the safe provision of analgesia and respiratory compromise, and postoperative respiratory infections are common and can be life threatening. High-dependency care is frequently required to manage postoperative analgesic and respiratory requirements safely.

Muscular Dystrophy

The dystrophinopathies include Duchenne muscular dystrophy and the less common Becker muscular dystrophies. Progressive muscle weakness leads to respiratory failure and cardiomyopathy that can progress to circulatory failure. Recent advances that have extended survival and reduced morbidity include non-invasive ventilatory support, steroids and a variety of cardiovascular drugs. Scoliosis is common and the decision to proceed to surgery must be balanced against the risks of surgery in this group of patients.

TIVA should be used in muscular dystrophy patients and exposure to volatile agents avoided. Volatile agents and suxamethonium are associated with anaesthesia-induced rhabdomyolysis (AIR), hyperkalaemia and cardiac arrest, although this is rare. This metabolic derangement is distinct from malignant hyperthermia (MH) and can first appear on emergence from anaesthesia with the onset of spontaneous movement.

Blood loss during surgery is increased due to impaired contraction of arteriolar smooth muscle. Poor cardiac function and respiratory reserve require expert management.

Osteogenesis Imperfecta

Osteogenesis imperfecta (OI) is a group of rare autosomal-dominant inherited connective tissue disorders with four major variants which result in increased bone fragility. Bones are osteoporotic and easily fractured, and joints are hypermobile and frequently dislocated. Surgery is usually indicated for the treatment of fractures and scoliosis. Airway management, positioning and blood pressure measurement can result in fractures. The risk of fractures from tourniquets is high. Suxamethonium should be avoided because of unpredictable effects of fasciculations, but OI is not associated with MH. Some OI patients have a bleeding diathesis due to defective platelet aggregation, and bleeding is increased from exposed abnormal bone matrix, which can be severe and difficult to control.

Arthrogryposis Multiplex Congenita

Arthrogryposis multiplex congenita (AMC) describes the condition of congenital non-progressive symmetrical joint contractures arising from a variety of causes of fetal immobility. Neurogenic causes are present in the vast majority and often associated with a reduction in muscle mass. The involvement of the temporomandibular joint may limit mouth opening and, if combined with micrognathia, may make intubation difficult. Vascular access can be extremely difficult owing to the abnormal and featureless appearance of the limbs. There is a common association with congenital heart disease. Surgery is often needed to correct lower-limb deformities to improve posture and joint mobility and for scoliosis. Intraoperative temperature monitoring is essential, since patients cool rapidly due to low muscle mass, but they may also develop a hypermetabolic state, distinct from malignant hyperthermia, which can require active cooling. There are reports of a similar hypermetabolic state in osteogenesis imperfecta.

Sarcoma

Sarcomas arise from connective tissue and comprise both soft tissue and bone tumours. Approximately 60 malignant bone tumours are diagnosed in children annually in England whilst soft tissue sarcomas account for approximately 6% of paediatric malignancies. Osteosarcoma and Ewing sarcoma mostly affect children and young adults. Benign bone tumours include osteochondromas, bone cysts (simple and aneurysmal), fibrous dysplasia, Langerhans cell histiocytosis and non-ossifying fibromas.

Osteosarcoma is the most frequent primary cancer of bone and accounts of over 10% of solid cancers in adolescents. It usually arises in the metaphysis of long bones, most commonly around the knee, and there is suggestion of an association with rapid bone growth and the pubertal growth spurt.

Ewing's sarcoma is a round cell tumour that most frequently involves the long bones, pelvis,

ribs and vertebral column. It is the second most common primary malignant bone tumour in children and adolescents. All forms are of high grade, and approximately 26% of patients with Ewing's sarcoma have metastatic disease at presentation. Multidisciplinary treatment involving preoperative neoadjuvant combination chemotherapy, surgery, postoperative adjuvant chemotherapy and radiotherapy is usually required.

Many of the chemotherapy treatment regimens for sarcoma are cardiotoxic and require baseline and surveillance echocardiography. Preoperative blood tests are essential to examine renal, liver and haematological side effects of chemotherapy. Neoadjuvant chemotherapy can result in patients presenting for major surgery with anaemia and neutropenia, and the timing of surgery needs to be considered to permit recovery and appropriate treatments, including the use of granulocyte colony stimulating factor and transfusion.

The range of surgeries for sarcoma is wide, including limb salvage operations, massive resections (e.g. hemipelvectomies or sacrectomies) and amputation. Such operations require multidisciplinary planning and preoperative preparation of the patient and parents for the effects of chemotherapy and surgery and the subsequent recovery and need for further chemotherapy. Limb amputation carries additional psychological challenges to the child and family and requires preoperative preparation with psychologists, nurse specialists and prosthetists.

Anaesthetic management of major resection surgery requires planning for major haemorrhage and postoperative pain management. Central venous access, invasive blood pressure monitoring and rapid infusion and warming systems should be utilised. Cell salvage is not routinely employed due to the theoretical risks of metastasis. Central neuraxial and regional anaesthesia is used as routine, with the use of postoperative parenteral analgesia. Patients are routinely managed in a high-dependency environment postoperatively.

Scoliosis Surgery

Scoliosis is an abnormal lateral curvature of the spine and can be classified into congenital, idiopathic (infantile, juvenile, adolescent) and acquired. Congenital scoliosis arises as a result of failure of fetal vertebral formation, segmentation or a combination of both. It is commonly associated with other abnormalities and often progresses rapidly at an early age. The major causes of acquired scoliosis are neuromuscular diseases, particularly cerebral palsy and the muscular dystrophies.

Surgical treatment is indicated when the degree of curvature or its rate of acceleration puts other organs at risk or when pain intervenes. The type of surgical intervention depends upon the reason for the scoliosis and the child's skeletal maturity. Before skeletal maturity, the aim is to allow growth whilst controlling the progression of the curve. In older children, when truncal growth has slowed down the aim is to correct the deformity and prevent any further progression with a definitive procedure. The most common procedures requiring anaesthesia are posterior spinal surgery, anterior spinal surgery, insertion of growing systems and application of plaster jackets.

The largest group requiring surgery comprises adolescents with idiopathic scoliosis. These patients are fit and healthy; pre-assessment should concentrate on imparting information and the detection of anaemia. This group of patients is ideal to include in enhanced recovery after surgery programmes. At the other end of the spectrum are patients with progressive end-stage neuromuscular disease, where multidisciplinary discussions are required to focus on the potential benefits and the risks of surgery.

All patients requiring scoliosis surgery should attend a pre-assessment clinic. Multidisciplinary involvement is mandatory. Pre-assessment allows for the detection and optimisation of any underlying disease and secondary morbidity. Risks of anaesthesia need to be discussed openly and can sometimes limit the surgical options. Postoperative care needs to be planned and the likelihood of elective postoperative ventilation evaluated.

Preoperative Assessment

A thorough assessment is required, including a full history of previous procedures under general anaesthetic; in particular, any potential difficulties with airway management, potential for airway obstruction, cervical spine instability and risks of induction using volatile anaesthetic drugs should be assessed.

Respiratory function is the critical area of focus. Many children find it difficult to cooperate with formal assessment of respiratory function. Frequent chest infections, poor cough or

symptoms suggestive of sleep apnoea warrant further investigation, which may include blood gas analysis, respiratory function tests and, most usefully, sleep study analysis. Sleep studies monitor continuous SpO_2 and transcutaneous CO_2 and provide useful information as to the need for postoperative respiratory support. Respiratory investigations can also be used to monitor the progression of neuromuscular disease and guide preoperative intervention and the need for of noninvasive respiratory support. The increased use of home ventilation has increased the number of patients being offered surgery despite advanced respiratory disease.

Cardiomyopathy may be a feature of the muscle pathology leading to scoliosis, or a structural cardiac anomaly may be part of an associated syndrome. Severe chest wall deformity rarely leads to primary cardiac insufficiency. Severe pulmonary disease can lead to elevated pulmonary vascular resistance and right ventricular dysfunction. Previous cardiac surgery itself may predispose to scoliosis by disrupting chest wall growth secondary to damage to the ribs and sternum. The severity of cardiac disease can be masked in wheelchair-bound patients by lack of activity, and surgery can produce unique stresses that may result in acute decompensation. A recent ECG and echocardiogram are required. Children with progressive neuromuscular disease may require a cardiac MRI scan before surgery to give an objective measure of cardiac and myocyte function.

Nutrition needs to be optimised preoperatively and any feeding difficulties resolved. Supplementary enteral feeding may need to be started. Similarly, patients with a raised body mass index should be managed to reduce the risks of perioperative morbidity, including wound infections. Anaemia and vitamin D deficiency should be investigated and fully treated before embarking upon major surgery.

Epilepsy is common, and therapy should be continued over the perioperative period with a management plan for breakthrough seizure activity, including conversion to alternate intravenous therapies should there be a significant postoperative ileus delaying medication absorption. Patients often take steroids, cardiac medications and contraceptive therapies, and they may need specialist perioperative plans.

Spinal Cord Injury and Monitoring

Spinal cord damage is a prime concern during scoliosis surgery. Injury can be caused by direct mechanical trauma or vascular insufficiency. Mechanical trauma can be caused by malpositioning of instrumentation or due to compression or stretch of neural structures during spinal manipulation. Vascular insufficiency may result from disruption of the arterial blood supply during spinal manipulation or vascular spasm following an insult.

Monitoring of spinal cord function intraoperatively is essential. This is achieved using monitoring of somatosensory evoked potentials (SSEPs) and transcranial motor evoked potentials (MEPs) and occasionally by performing a 'wake up' test. Surface and needle electrodes are placed on the scalp, neck and limbs once the patient is asleep to elicit and record evoked potentials. SSEPs monitor the main sensory pathways, the dorsal columns, that make up the posterior third of the cord, which are supplied by two spinal arteries. MEPs monitor the main motor pathways, the corticospinal tracts, within the anterior cord, which, although making up two thirds of the spinal cord, are only supplied by a single spinal artery and as a result is more susceptible to ischaemia.

Additional modalities such as free-running or triggered electromyelography may be utilised to detect pedicle breaches or malpositioning of screws. Electroencephalography (EEG) may be recorded to observe ongoing cortical activity and gauge the depth of anaesthesia. A neuromonitoring specialist monitors these modalities continuously throughout the procedure.

Evoked potentials (SSEPs and MEPs) are suppressed by all types of anaesthetic agents to some extent, so optimisation of anaesthesia is required. MEPs are more severely suppressed by inhalational agents than TIVA, so for robust neuromonitoring, TIVA is recommended. Since MEPs monitor muscle activity, neuromuscular blockade should be avoided intraoperatively. As a consequence of transcranial stimulation, muscle contraction occurs, so a bite block is essential to prevent injury to the tongue and mouth, as well to protect the tracheal tube.

Baseline waveforms are obtained once the patient is positioned and must be deemed adequate for monitoring prior to the start of surgery. In some circumstances, pre-positioning baselines may be beneficial. Clear communication between anaesthetic, surgical and neuromonitoring staff is always vital so that significant neuromonitoring changes are identified promptly. This

allows appropriate interventions to be made in a timely fashion to reduce the risk of permanent neurological deficit.

Common events resulting in neuromonitoring changes are:

- Insertion of instrumentation, for example screws or cages
- Manipulation of the spine, such as rod insertion and curve correction
- Periods of cardiovascular instability

Neuromonitoring can also be of benefit in detecting peripheral nerve compromise due to patient positioning, such as compression of the brachial plexus or ulnar nerve at the elbow, which can often be resolved by simple repositioning of the affected limb.

Posterior Spinal Surgery

Posterior spinal surgery is increasingly performed as the sole procedure to correct scoliosis due to technological advancements in the equipment used and improved neuromonitoring. Spinal fixation is usually achieved by attaching a pair of suitably curved rods to the bony spine. Previously this was achieved with a combination of pedicle screws in the lumbar region and laminar hooks or wires in the thoracic and cervical region. Currently most procedures use screws inserted into the pedicles throughout the spine to provide a more robust attachment. This enables the bony spine to be manipulated to a greater degree, achieving more correction and restoring trunk symmetry and balance. Ongoing advances include the use of image guidance and robotics.

Anaesthetic Management

The technique for induction of anaesthesia can be as preferred, but the needs of intraoperative spinal monitoring will dictate further management. TIVA is required for successful motor monitoring, and neuromuscular blockade can only be used to aid intubation. High-dose intraoperative opioids provide optimal conditions, and propofol/remifentanil-based TIVA is a common choice.

Analgesia

Pain relief intraoperatively is best provided by high-dose, short-acting opioids, usually fentanyl or a continuous infusion of remifentanil. Postoperatively, pain control requires a multimodal technique. Paracetamol should be given regularly along with regular NSAIDs if excessive bleeding has not occurred. Large doses of opioid will be required postoperatively via NCA/PCA initially with background infusions. Other strategies include the use of ketamine, clonidine, diazepam, regional techniques and intraoperative spinal opioid administration. Postoperatively, the patients usually have to lie supine for 12 hours to tamponade the wound and reduce bleeding.

The two major concerns for anaesthesia in posterior spinal surgery are high anticipated blood losses and surgery in the prone position.

Blood Loss

Blood losses can be life-threatening. Bleeding occurs from the traumatic detachment of muscle from the spine and from bone. For definitive spinal fixation to occur, the periosteum of the bony elements must be removed and the interarticular joints need to be disrupted. This, combined with bleeding from the pedicle marrow, provides a vast area over which bleeding can occur. Higher blood losses are expected with increased tissue disruption, longer lengths of surgery, fusion into the pelvis and the development of coagulopathy. In extreme cases, haemostasis is only achieved by judicious premature surgical closure of the wound. Blood should be immediately available for all but limited posterior procedures.

Venous access is dictated by anticipated blood loss. Two large-bore peripheral cannulae are desirable. A system for rapid infusion should be available, preferably with integrated warming. Central venous access is indicated when large losses are expected and peripheral access is limited, when coexisting disease adds complexity or when extended postoperative venous access is required. Intraoperative arterial access is desirable in all but the most limited cases, as blood pressure can change rapidly owing to fluid loses and occasionally as a result of spinal cord disruption. It is an essential guide to spinal perfusion pressures. Blood pressure should be controlled intraoperatively to reduce blood losses. Profound hypotension may compromise cord perfusion, and if spinal monitoring detects deterioration, this needs to be aggressively reversed. Urinary catheterisation is standard to assess fluid balance and will be required in the initial postoperative period.

Blood loss during surgery is reduced by maintaining normothermia and controlled hypotension,

avoiding hypertension and administering antifibrinolytics (e.g. tranexamic acid). Blood salvage should be routine, using an automated cell saver for suction blood, and to collect the blood rinsed out of swabs in physiological saline. In many cases, blood transfusion can be avoided, provided postoperative anaemia is acceptable. Massive blood transfusion leads to coagulopathy, which should be anticipated and actively treated to prevent escalation. Cord injury can occur during periods of hypotension, and cord monitoring should be used to assess adequacy of resuscitation.

Prone Positioning

The aim of safe prone positioning is to ensure that all tubes and lines remain secure, baseline physiological parameters are maintained and that the risk of nerve/tissue injury and blindness is kept to a minimum. Airway control in the prone position needs to be secure. Reinforced flexible tracheal tubes are ideal, and placement of a bite guard reduces possible damage to lips, tongue and tracheal tube. A nasogastric tube is necessary to decompress the stomach and can be retained into the postoperative period; a nasopharyngeal temperature probe is placed to assess core temperature. Positioning the patient prone requires time, coordination with the theatre team and familiarity with the equipment available to support the body. Vascular access must be secure, the abdomen must remain unrestricted, the head must be well supported in a neutral position without pressure on the orbits or nose and all peripheral pressure points must be padded. The arms must drape comfortably, without undue compression or extension that may lead to brachial plexus or peripheral nerve injury. The simplest way to assess posture is to replicate it on oneself to judge the degree of comfort and then modify as appropriate. Responsibility for positioning should be clear; logically, the anaesthetist should control positioning of the upper body as a minimum. A fenestrated warm-air body warmer enhances the ability to maintain normothermia, and clear drapes improve the ability to continuously assess the patient's position.

Postoperative Care

All patients should be managed in a high-dependency unit (HDU) environment postoperatively. Elective admission to the paediatric intensive care unit (PICU) will depend on patient factors and the extent of surgery. The presence of severe behavioural issues, neuromuscular disease or cardiorespiratory disease will necessitate a period of elective ventilation so that stability can be established prior to extubation. Patients undergoing extensive combined anterior–posterior spinal surgery should electively be admitted to PICU for postoperative ventilation, even in the absence of underlying medical concerns. Occasional unplanned PICU admission may be necessary if massive blood loss has occurred.

Anterior Spinal Surgery

Anterior spinal surgery is usually performed to release the spine and enhance its flexibility to achieve a better degree of correction from the following definitive posterior fusion. The problems of anterior surgery are related to those of thoracotomy and therefore one-lung ventilation and postoperative pain relief. Surgery often involves a thoracoabdominal incision in the lateral position with disruption to the diaphragm. This type of surgery is inappropriate in patients with severe coexisting disease and significant respiratory impairment.

The conduct of anaesthesia is again influenced by spinal cord monitoring. A standard tracheal tube is adequate, as exposure of the spine is by lung retraction, and ventilation/perfusion mismatch rarely causes significant changes in oxygenation. Of greater concern is retraction resulting in compression of major blood vessels or mediastinal shift. For this reason, invasive arterial monitoring is essential. Blood loss is usually well controlled, and transfusion is rarely required. Central venous access is only required if peripheral access is difficult or if there is complicating coexisting disease.

Optimal pain relief in the postoperative period is essential to prevent lung collapse and infection. Coughing is inhibited by wound pain and irritation from the chest drain. Intraoperative infiltration of the intercostal nerves can be performed by the surgeon. Epidurals and other regional techniques can also be used. A multimodal approach to analgesia is used, with regular paracetamol, NSAIDs and opioid PCA/NCA that can be augmented with ketamine. Postoperative ventilation is rarely required, as patient selection implies that respiratory reserve is adequate, but patients should be nursed in an HDU environment.

Thoracoscopic Spinal Surgery

There is increasing interest in thoracoscopic spinal surgical procedures such as vertebral body

tethering (VBT). This involves anterior screws being inserted into the spine followed by a flexible plastic cord connected to these screws via a thoracoscopic approach. The cord is tensioned during the operation to provide an initial correction, whilst tethering limits growth on the outside of the curve to allow gradual correction of the scoliosis as the patient grows. This surgery necessitates one lung ventilation facilitated by a double-lumen tracheal tube or use of a bronchial blocker. Anaesthetic considerations are otherwise as for conventional anterior spinal surgery.

Growing Systems

Spinal fixation with a definitive fusion cannot take place whilst the spine is still growing. Growing systems provide dynamic stabilisation and correction of scoliosis in younger patients and permit further growth over time. With traditional growing rods, two rods are attached posteriorly with limited attachment to the spine. They overlap and their overall length can be increased by distraction over years. These remain in place until definitive posterior fixation is feasible. Blood loss is not a major issue since there is only limited exposure of the spine, but spinal cord monitoring is necessary, so it will influence the conduct of anaesthesia. The surgery for further distractions involves even less exposure, but again spinal monitoring will dictate anaesthetic technique.

Plaster Jacket Application

The use of plaster jackets offers a non-surgical management of scoliosis in young patients where significant growth is yet to occur. The programme requires repeated general anaesthetics as truncal growth is rapid in the early years. The child must be intubated and the tracheal tube fixed securely, as the application requires significant movement and precarious positioning with limited monitoring and access to the patient. The fixed thoracoabdominal jacket will impede ventilation, and an aperture must be cut as soon as possible to allow abdominal movement.

Wound Debridement for Wound Infection

Wound infection is a devastating and life-threatening complication after scoliosis surgery, owing to the amount of implanted material and underlying poor medical condition of many patients. Antimicrobial agents are continued routinely postoperatively until the wound becomes dry. Patients presenting for exploratory surgery with wound infection must be managed aggressively. Superficial infections may be connected to deep extensive lesions producing widespread tissue necrosis. Debridement can result in massive blood loss, and this must be anticipated. Long-term venous access is required to provide access for antimicrobial agents and often to supplement nutrition.

Key Points

- Children presenting for elective orthopaedic surgery may have associated medical conditions, and a careful history should be taken, particularly to identify associated neuromuscular disorders.
- Multimodal analgesia should be used, and regional anaesthetic techniques are of benefit.
- Procedures involving muscle stretch and casting may be associated with postoperative muscle spasm.
- All children undergoing scoliosis surgery should be assessed preoperatively in a multidisciplinary clinic. The perioperative major concerns are bleeding and spinal cord function.
- TIVA is the anaesthesia technique of choice to facilitate spinal cord monitoring in scoliosis surgery.

Further Reading

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