Anaesthesia for spinal surgery in adults

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The spectrum of spinal surgery in adult life is considerable. Anaesthesia for major spinal surgery, such as spinal stabilization following trauma or neoplastic disease, or for correction of scoliosis, presents a number of challenges. The type of patients who would have been declined surgery 20 yr ago for medical reasons, are now being offered extensive procedures. They commonly have preoperative co-morbid conditions such as serious cardiovascular and respiratory impairment. Airway management may be difficult. Surgery imposes further stresses of significant blood loss, prolonged anaesthesia, and problematical postoperative pain management. The perioperative management of these patients is discussed. The advent of techniques to monitor spinal cord function has reduced postoperative neurological morbidity in these patients. The anaesthetist has an important role in facilitating these methods of monitoring.

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The scope of spinal surgery is considerable. Both adult and paediatric patients present for surgery, which may be elective or urgent. They mainly present with one of five pathologies: trauma, for example an unstable vertebral fracture; infection, for example vertebral abscess; malignancy (metastatic or primary disease with spinal instability, pain, and neurological compromise); congenital/idiopathic, for example scoliosis; or degenerative disease. In excess of 25 000 spinal operations were performed in the UK in 2001–2.112 Surgery may be required at any site in the spine from cervical to lumbosacral. Procedures range from minimally invasive microdiscectomy, to prolonged operations involving multiple spinal levels and significant blood loss. An osteotomy is a decompressive procedure, which releases compressive forces at a localized site. Stabilization of the spine involves instrumentation above and below the unstable spinal level. Distractive forces may also be applied to the spine, for example in surgery for scoliosis, with instrumentation placed over multiple spinal levels. Insertion of such devices may be through a posterior, anterior, or a combined approach involving repositioning of the patient part way through the procedure and major blood loss.

The challenge to the anaesthetist is to provide optimal surgical conditions whilst ensuring adequate oxygenation to the brain and spinal cord, and facilitating the use of intraoperative spinal cord monitoring techniques if appropriate.

Pathological conditions requiring spinal surgery in adult practice

Scoliosis

Scoliosis involves a lateral and rotational deformity of the spine, which occurs in up to 4% of the population.98 Most cases are idiopathic (70%) and occur with a male:female ratio of 1:4 (Table 1). Surgery is usually considered when the Cobb angle exceeds 50° in the thoracic, or 40° in the lumbar spine (Fig. 1A and B). Surgery aims to halt progression of the condition and to at least partially correct the deformity, preventing further respiratory and cardiovascular deterioration. Left untreated, idiopathic scoliosis rapidly progresses and is often fatal by the fourth or fifth decade of life, as a result of pulmonary hypertension, right ventricular failure, or respiratory failure.95

Muscle disorders

Muscular dystrophy and cerebral palsy are important causes of scoliosis. Of the muscular dystrophies, Duchenne...
It is usual for these patients to have acute-on-chronic pain problems. They are often receiving regular opioids, non-steroidal anti-inflammatory drugs, and simple analgesics. Patients may therefore have an increased requirement for intraoperative and postoperative analgesia as a result of pharmacodynamic-related opioid tolerance, and pharmaco-kinetic factors such as liver enzyme induction.

### Spinal trauma

Patients with traumatic injury frequently present for surgical spinal stabilization during the period of spinal shock, which begins almost immediately after the insult and may last for up to 3 weeks. Some degree of spinal cord dysfunction may also be present in patients with malignant disease presenting for spinal stabilization. The clinical effects depend on the level of injury to the spinal cord. A physiological sympathectomy occurs below the level of the spinal cord lesion, possibly causing hypotension secondary to arteriolar and venular vasodilatation. Injuries at or above T6 are particularly associated with hypotension, as the sympathetic outflow to splanchnic vascular beds is lost. Bradycardia also occurs if the lesion is higher than the cardiac sympathetic outflow (T2–T6), the parasympathetic cranial outflow being preserved. A complete cervical cord injury produces a total sympathectomy and therefore hypotension will be more marked.

Above the level of the lesion, sympathetic outflow is preserved. Vasoconstriction in upper body vascular beds and tachycardia may be observed in response to the hypotension resulting from reduced systemic vascular resistance (SVR) in the lower part of the body. Hypotension associated with spinal cord injury responds poorly to i.v. fluid loading, which may cause pulmonary oedema. Vasopressors are the treatment of choice. Other causes of hypotension should be excluded such as blood loss associated with other injuries. Hypoxia or manipulation of the larynx or trachea may cause profound bradycardia in these patients. Positive pressure ventilation (IPPV) causes marked arterial hypotension as the SVR cannot be raised to offset the changes in intrathoracic pressure caused by IPPV.

Mid to low cervical spine injuries (C4–C8) spare the diaphragm but the intercostal and abdominal muscles may be paralysed (Fig. 1C–E). This leads to an inadequate cough, paradoxical rib movement on spontaneous ventilation, a decrease in vital capacity by up to 50% of predicted values (as a result of a reduction in inspiratory capacity to 70% and expiratory reserve volume to 20% of predicted), a decrease in functional residual capacity to 85% of predicted, and a loss of active expiration. There is also an increased risk of venous thromboembolism in patients with spinal trauma, together with delayed gastric emptying, and impairment of thermoregulation. Administration of succinylcholine may cause hyperkalaemia from 48 h after the injury.

### Carcinomatosis

Patients with primary or secondary malignant disease of the vertebral column and spinal cord are increasingly being considered for surgery, the aims of which are primarily to relieve pain but also to excise the lesion, prevent further neurological deterioration, and stabilize the vertebral column. These patients have commonly lost a large amount of weight and have reduced physiological reserve.

Respiratory complications of malignancy are common in such patients, and include infection, pleural effusion, and pulmonary toxicity from alkylating agents (cyclophosphamide, chlorambucil, busulfan) or antimetabolites (methotrexate, azathioprine). Myocardial injury may also occur secondary to the use of chemotherapy (busulfan, cyclophosphamide, mitomycin). Metabolic derangements such as hypercalcaemia, and inappropriate secretion of antidiuretic hormone may develop. The latter is associated with small cell lung tumours, carcinoma of the prostate, pancreas and bladder, and central nervous system neoplasms.
characterized by extreme autonomic responses such as hypertension and tachycardia after stimulation of nerves below the level of the spinal cord lesion (for example, rectal, urological, peritoneal stimulation). Injuries higher than T7 have an 85% chance of producing serious cardiovascular derangement.

Preoperative assessment

When assessing patients before spinal surgery, particular care should be given to the respiratory, cardiovascular, and neurological systems; all may be affected by the pathology for which the spinal surgery is proposed.

Airway assessment

The potential for difficulty in airway management should always be considered, particularly in those patients presenting for surgery of the upper thoracic or cervical spine. A careful assessment should be made for previous difficulty in intubation, restriction of neck movement, and the stability or otherwise of the cervical spine. Stability is defined as the ability of the spine, under physiological loads, to resist displacement, which causes neurological injury. It is essential to discuss preoperatively the stability of the spine with the surgeon. The cervical spine may be assessed clinically (presence of pain or neurological deficits), and
radiographically (lateral or flexion/extension plain films, computer aided tomography, and magnetic resonance imaging). The stability of the cervical spine is dependent on ligamental and vertebral elements. Damage to these elements may not be detectable by plain x-rays alone. The adult cervical spine below C2 is unstable or on the brink of instability when one of the following conditions are met: (i) all the anterior or all the posterior elements are destroyed; (ii) there is >3.5 mm horizontal displacement of one vertebra in relation to an adjacent one on a lateral x-ray; or (iii) there is more than 11° of rotation of one vertebra to an adjacent one. Above the level of C2, examples of unstable injuries include: disruption of the transverse ligament of the atlas (a distance of greater than 3 mm in adults between the posterior corpus of the anterior arch of C1 and the anterior border of the odontoid process, when measured on a lateral plain x-ray film, is diagnostic); and a Jefferson burst fracture of the atlas following axial loading, which causes atlantoaxial instability. Disruption of the tectorial and alar ligaments and some occipital condylar fractures also cause atlanto-occipital instability.

Some inherited disorders such as DMD may lead to glossal hypertrophy, and previous radiotherapy to tumours of the head and neck can cause difficulty in direct laryngoscopy. A decision must be made, whether to intubate the patient awake or asleep.

Respiratory system

Patients presenting for spinal surgery frequently have impaired respiratory function. Those who have sustained cervical or high thoracic trauma or who have multiple injuries may be artificially ventilated preoperatively. Others have recurrent chest infections.

Preoperatively, respiratory function should be assessed by a thorough history, focusing on functional impairment, physical examination, and appropriate investigations (Table 2). Scoliosis causes a restrictive pulmonary deficit, with reduced vital capacity and reduced total lung capacity (TLC). The residual volume is unchanged. The severity of functional impairment is related to the angle of the scoliosis, the number of vertebrae involved, a cephalad location of the curve, and a loss of the normal thoracic kyphosis. The extent of functional impairment cannot, therefore, be directly inferred from the angle of scoliosis alone. The most common blood-gas abnormality is a reduced arterial oxygen tension with a normal arterial carbon dioxide tension, as a result of the mismatch between ventilation and perfusion in hypoventilated lung units. Respiratory function should be optimized by treating any reversible cause of pulmonary dysfunction, including infection, with physiotherapy and nebulized bronchodilators as indicated.

There is controversy over whether surgery for idiopathic scoliosis improves or worsens pulmonary function. However, the type of surgery proposed may have a significant influence upon postoperative pulmonary function, and may explain the contradictory findings in studies of non-homogenous groups of patients. Surgery involving the thorax (anterior approach, combined approach, or rib resection) was associated with an initial decline in forced vital capacity (FVC, 19% of baseline values), forced expiratory volume in 1 s (FEV₁, 13%), and TLC (11%) at 3 months. This was followed by subsequent improvement to preoperative baseline values at 2 yr postoperatively. Surgery involving an exclusively posterior approach, however, was associated with an improvement in pulmonary function tests by 3 months (although not reaching statistical significance); and an improvement that was statistically significant at 2-yr follow-up: FVC (14% increase from baseline), FEV₁ (14%), TLC (5%).

Older studies have reported that if preoperative vital capacity is less than 30–35% of predicted, postoperative ventilation is likely to be required. A history of dependence on continuous nasal positive airways pressure at night is also a sign of severe functional impairment and of reduced physiological reserve. These findings should prompt serious consideration as to whether surgery repre-

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<td>Urea, electrolytes</td>
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CT scan
Pulmonary function tests (bronchodilator reversibility)
Pulmonary diffusion capacity
Dobutamine-stress echocardiograph
Dipyridamole/thallium scintigraphy
Liver function tests
sents an appropriate balance between its potential benefits and the high risk of long-term postoperative ventilation in such patients.

**Cardiovascular system**
Cardiac compromise may be a direct result of the underlying pathology, for example in patients with muscular dystrophies. Cardiac dysfunction may also occur secondary to scoliosis, which causes distortion of the mediastinum, and cor pulmonale secondary to chronic hypoxaemia and pulmonary hypertension. Assessment of functional cardiovascular impairment is difficult in patients who are wheelchair-bound. Minimum investigations should include an electrocardiograph, and echocardiography to assess left ventricular function and pulmonary arterial pressures (Table 2). Dobutamine stress echocardiography may be used to assess cardiac function in patients with a limited exercise tolerance.

**Thromboembolic prophylaxis**
Patients undergoing spinal surgery may be at increased risk of thromboembolic disease as a result of prolonged surgery, prone positioning, malignancy, and extended periods of postoperative recumbency. The use of compression stockings and/or pneumatic boots is recommended. Many surgeons prefer not to administer anticoagulants because their use may be associated with haemorrhagic complications, including increased blood loss and epidural haematoma.

**Neurological system**
A full neurological assessment of the patient should be made preoperatively. This should be documented for three reasons. First, in patients undergoing cervical spine surgery, the anaesthetist has a responsibility to avoid further neurological deterioration during manoeuvres such as tracheal intubation and patient positioning. Secondly, muscular dystrophies may involve the bulbar muscles, increasing the risk of postoperative aspiration. Thirdly, the level of injury and the time elapsed since the insult are predictors of the physiological derangements of the cardiovascular and respiratory systems which occur perioperatively. If surgery is contemplated within 3 weeks of the injury, spinal shock may still be present. After this time, autonomic dysreflexia may occur.

**Anaesthesia technique**
The type of monitoring chosen to assess spinal cord integrity has a bearing on the anaesthetic technique used.

**Premedication**
The use of bronchodilating agents may be of value in optimizing respiratory function preoperatively. In patients with a high spinal cord lesion, or those in whom fibre-optic intubation is to be undertaken, administration of anti-cholinergic agents such as atropine or glycopyrrolate (200–400 µg by i.v. or i.m. injection) should be considered. Many patients will have factors which increase the risk of regurgitation and aspiration of gastric contents, such as recent opioid administration, high spinal cord injury, or recent traumatic injury. In these circumstances, it may be prudent to premedicate patients with a histamine-2 receptor antagonist such as ranitidine, or a proton pump inhibitor such as omeprazole, and with sodium citrate. Some patients may have nasogastric tubes in situ, which decrease the competence of the upper oesophageal sphincter.

**Induction**
Choice of induction technique, i.v. or inhalation, is guided primarily by the patient’s condition and by consideration of the ease with which the trachea may be intubated. Preoxygenation is advisable in all patients. Unless there are concerns over the stability of the cervical spine or airway maintenance (see below), i.v. induction is suitable for all but the sickest patients.

The use of succinylcholine in patients with muscular dystrophies has long been known to cause cardiac arrest secondary to hyperkalaemia, and should be avoided. In patients with denervation as a result of spinal cord lesions, the increased number of perijunctional nicotinic acetylcholine receptors on skeletal muscle can cause hyperkalaemia after administration of succinylcholine. The time between denervation and the risk of a potentially fatal hyperkalaemic response is not known in humans. In animal studies, the peak increase in serum K⁺ was 14 days after injury, with a half-peak increase at 8.4 days. Changes in potassium levels began 4 days after injury. It is probably safe to use succinylcholine in the first 48 h after injury to the spinal cord. Thereafter, hyperkalaemia may occur for an indeterminate period, but most authors agree it is safe to use it again 9 months after the injury. The use of bolus doses of i.v. induction agents reduces the amplitude of evoked potential responses, and in particular, cortical responses, but these effects do not prevent useful intraoperative recording of cortical somatosensory potentials and transcranial electrical motor evoked potentials (MEP). Inhalation agents reduce the amplitude of evoked potential responses to a greater degree than do i.v. induction agents, but no studies have compared an inhalation induction technique with an i.v. technique in this respect.

**Intubation**
A decision must be made at preoperative assessment whether to intubate the patient awake or asleep, and whether fibre-optic laryngoscopy will be required. The patient must be counselled fully about the decision at this time (Fig. 2).
Awake or asleep?
Indications for awake intubation include the risk of delayed gastric emptying, the need to assess neurology after intubation is complete (in cases such as an unstable cervical spine), or the presence of a neck stabilization device (such as halo traction), which prevents adequate airway maintenance in an unconscious patient. Otherwise, i.v. induction of anaesthesia followed by a non-depolarizing neuromuscular blocking drug is the technique of choice.

Direct or fibre-optic laryngoscopy?
There is controversy as to whether direct laryngoscopy is a major factor contributing to cord injury in patients with cervical spine instability. Other factors such as hypotension and patient positioning may be equally important. Direct laryngoscopy with manual in-line stabilization or a hard collar, is an accepted means of intubation for many patients provided this can be achieved without any neck movement. Fixed flexion deformities, which involve the upper thoracic and cervical spine may make direct laryngoscopy impossible. These patients require the use of fibre-optic laryngoscopy to facilitate tracheal intubation. The intubating laryngeal mask airway may be a useful alternative, with or without fibre-optic guidance, for anaesthetists familiar with its use.

Awake fibre-optic intubation will be required in patients wearing stabilization devices such as halo vests, which make conventional airway access impossible, and in those where difficulty is anticipated because of anatomical reasons, for example micrognathia, limited mouth opening. In patients with an unstable cervical spine, instillation of local anaesthesia into the airway to facilitate awake intubation may cause vigorous coughing. In such cases, it is preferable to use nebulized lidocaine rather than a cricothyroid injection or administration of local anaesthetic through the fibre-optic scope.

Anterior approaches to the thoracic spine may necessitate the use of a double-lumen endobronchial tube. Alternatively, the surgeon and anaesthetist may agree that a single lumen tracheal tube will suffice, allowing more limited intraoperative lung retraction.

Maintenance
A stable anaesthetic depth is required in order that changes to somatosensory or MEPs can be interpreted reliably. A technique involving nitrous oxide 60% and isoflurane less than 0.5 MAC is compatible with somatosensory evoked potential (SSEP) monitoring, but in nitrous oxide 60%, end-tidal isoflurane concentrations greater than 0.87% make MEP monitoring uninterpretable. An i.v. technique using propofol is therefore recommended. Neurophysiologists monitoring evoked potentials should be made aware of any sudden decrease in arterial pressure, or the need to...
administer a bolus of opioid or change the anaesthetic depth. Sudden cardiovascular instability during anaesthesia may result from spinal cord and brain stem reflexes, from mediastinal distortion as a result of surgical manipulation, or more commonly from blood loss.

**Induced hypotension**

Hypotensive anaesthesia may be used to improve the surgical field and to reduce blood loss during major spinal surgery. A number of hypotensive agents have been studied during surgery to correct scoliosis. They include ganglion blocking agents, volatile agents, calcium channel antagonists, sodium nitroprusside, nitroglycerin, and, in children, the dopamine-1 receptor agonist, fenoldopam. Mean arterial pressure (MAP) is typically maintained at 60 mm Hg. There is little evidence that any particular agent is superior, but the avoidance of tachycardia is an essential part of a good anaesthetic technique.

Caudal epidural anaesthesia has also been shown to reduce surgical bleeding by 50% in patients undergoing lumbar spinal surgery. This was thought to be as a result of a reduction in sympathetic tone causing a measurable decrease in lumbar vertebral intravascular pressure. This technique, however, is not as controllable as continuous i.v. titration of a short-acting hypotensive agent, nor suitable for operations involving the thoracic and cervical spine. It may also hinder early postoperative neurological assessment.

**Muscle relaxation**

When myogenic motor evoked responses are to be recorded, neuromuscular block must be carefully monitored and a constant depth of block maintained. It is advisable to administer a non-depolarizing neuromuscular blocking agent such as atracurium using a continuous i.v. infusion device during major spinal surgery.

**Intraoperative monitoring and positioning of the patient**

**Cardiovascular monitoring**

Prolonged anaesthesia in unusual positions, combined with significant blood loss, the haemodynamic effects of thoracic surgery, and where appropriate controlled hypotension, necessitates detailed monitoring of the cardiovascular system. Invasive arterial pressure monitoring is mandatory. In the prone position, central venous pressure (CVP) may be a misleading indicator of right and left ventricular end-diastolic volume. A study of 12 paediatric patients undergoing surgery for scoliosis in the prone position, compared CVP and transoesophageal echocardiography (TOE) in assessment of ventricular filling. Measurements were made before and after positioning. CVP rose from 8.7 (1.3) mm Hg (mean (SEM)) supine to 17.7 (2.5) mm Hg prone, but left ventricular end diastolic diameter measured by TOE, fell from 37.1 (2.9) to 33.2 (3.0) mm. In three patients in whom pulmonary artery occlusion pressure (PAOP) was also measured, there was an increase in PAOP on being turned from the supine (mean 12.7 mm Hg) to the prone position (mean 28.0 mm Hg), although there were insufficient data for statistical analysis. These results demonstrate that there is no correlation between the measurement of cardiac volume indicators by TOE and CVP or PAOP in such conditions. High CVP values may be misleading indicators of adequate cardiac filling in the prone position. The changes are probably a result of raised intrathoracic pressure causing reduced ventricular compliance and compression of the inferior vena cava. Dependent lower limbs cause a reduced venous return to the heart.

**Respiratory monitoring**

Respiratory system monitoring should always include end-tidal carbon dioxide concentration and peak airway pressure. In major surgery, serial measurements of arterial oxygen tension are recommended. Patients with severe respiratory dysfunction as a result of scoliosis may have an increased alveolar-arterial oxygen gradient, which may be further increased during prolonged anaesthesia because of regional hypoventilation.

**Temperature monitoring**

Thermoregulation may already be impaired in patients who have spinal cord lesions before surgery. Prolonged anaesthesia causes significant heat loss. The use of temperature monitoring, warming of all i.v. fluids, and a warm air mattress device is recommended.

**Positioning**

Patient position for spinal surgery varies depending on the level of the spine to be operated upon and the nature of the proposed surgery. Patients may be repositioned intraoperatively. It is important that venous pressures at the surgical site are kept low to reduce bleeding (reverse Trendelenburg tilt and a free abdomen), and peripheral nerves, bony prominences, and the eyes are protected. It is also important to avoid displacement of unstable fractures during patient positioning. Intraoperative x-ray imaging is frequently required. The relevant spinal level must, therefore, be placed away from the central support of a radiolucent operating table.

**Lumbar surgery**

Anterior approaches require a laparotomy, and general surgical input may be required in difficult cases. Posterior surgery requires a prone patient with a free abdomen to keep epidural venous pressure low (the patient supported on a Wilson frame, for example, or a raised mattress with a hole for the abdomen). For disc surgery, patients are placed in
Thoracic surgery
Anterior approaches to the thoracic spine are via a thoracotomy with the patient supported in a lateral position. If a double lumen endobronchial tube is used to allow deflation of one lung for surgical access, a fibre-optic laryngoscope should always be used to check tube placement after the patient is finally positioned.88 Posterior approaches to the thoracic spine require a prone patient with an uncompressed abdomen.

Cervical surgery
Patients are usually positioned with their feet close to the anaesthetic machine. This allows surgical access to the head and neck. Extensions are needed to breathing circuits and i.v. lines, and it may be useful to place an i.v. cannula in the patient’s foot. Tracheal tubes must be carefully secured without impinging on the surgical field.

For anterior surgery, a reinforced tracheal tube will reduce the risk of airway obstruction as tracheal retraction occurs during surgery. The head is supported on a padded head ring, or the ‘horseshoe’ of a Mayfield neurosurgical operating table attachment. Traction may be required by tongs and weights placed into the outer bone plate of the skull for some or all of the procedure. Reverse Trendelenburg positioning minimizes venous bleeding and provides counter traction for the weight attached to the head. Venous pooling in the lower limbs and intraoperative retraction of the carotid artery make an arterial line advisable for most patients.

For posterior approaches to the cervical spine, the head of the prone patient can be supported on the gel-padded horseshoe of the Mayfield table attachment, or placed in a skull clamp. The orbits, the superior orbital nerve and the skin over the maxilla are at particular risk of ischaemic injury if positioning is incorrect. These problems are avoided by using a skull clamp. The height and degree of neck flexion may be adjusted intraoperatively, and pressure areas must be rechecked after such manoeuvres. Support for the tracheal tube and breathing circuitry is difficult; care must be taken if equipment has been taped to the operating table, that tubes are not dislodged as the head position is altered.

Venous air embolism is a risk for these patients because veins at the operative site are above the level of the heart.1 106 Unfortunately, methods to reduce blood loss such as reduced venous pressure increase the risk of this complication.

Blood conservation
Blood loss during single level procedures, especially for intervertebral disc-related disease, should not be excessive, but during more extensive spinal surgery, it can be considerable; typically losses are 10–30 ml kg⁻¹, a result of loss from deorticited bone and disruption of rich vascular networks.113 124 The degree of blood loss is associated with: the number of spinal levels fused; body weight;124 surgery for tumours;77 raised intra-abdominal pressure in the prone position;84 and the presence of DMD.76

Blood loss is associated with increased operative time, delayed wound healing, wound infections,120 and increased requirement for blood transfusion. The risks of allogeneic blood transfusion include: hypothermia, impairment of coagulation, hyperkalaemia, hypocalcaemia, transfusion reactions, acute lung injury, immunomodulation, and viral and bacterial infection. Allogeneic blood transfusion should therefore be reduced to a minimum. This can be accomplished by techniques to reduce blood loss and by autologous blood transfusion.

Reducing blood loss
Blood loss can be minimized by careful patient positioning, good surgical technique, controlled hypotensive anaesthesia, and by the use of agents such as antifibrinolytics. When patients are placed in the prone or knee-chest positions, care must be taken to minimize intra-abdominal pressure. It has been shown that positioning devices, such as the Relton-Hall frame, which allow the abdominal viscera to hang freely, reduce inferior vena caval (IVC) pressure by one-third compared with conventional pads.62 Raised IVC pressure is associated with lumbar venous engorgement and increased blood loss. One study has shown minor changes to patient positioning on the Wilson frame can reduce blood loss per vertebral level by approximately 50%.84

Hypotensive anaesthesia
Hypotensive anaesthesia has long been established as a safe and effective method for reducing blood loss by up to 58% during spinal surgery.66 111

Antifibrinolytic agents
Drugs such as the synthetic lysine analogues, tranexamic acid, and aminocaproic acid, and the protease inhibitor, aprotinin,23 74 113 have been used to reduce blood loss during spinal surgery. Only aprotinin, however, has been shown to cause a statistically significant reduction in intraoperative blood loss. Aprotinin is a polypeptide derived from bovine lung, which is an inhibitor of plasmin and kallikrein, forming a reversible complex with the serine binding site on the enzyme. It also preserves platelet function.34

Urban and colleagues113 compared the use of aprotinin, aminocaproic acid, or neither in 60 adult patients undergoing anterior-posterior thoracolumbar fusion under hypotensive anaesthesia using sodium nitroprusside and esmolol. Aprotinin (1 million KIU load over 30 min followed by 0.25 million KIU h⁻¹) and aminocaproic acid (5 g load over
Provision of autologous blood

Autologous blood can be made available to the patient by three methods: pre-deposit autologous transfusion, intraoperative acute normovolaemic haemodilution, and intraoperative red blood cell salvage.115

Pre-deposit autologous transfusion

The patient donates blood 3–5 weeks before surgery for use intraoperatively. This technique has been used widely in orthopaedic, general, and cardiothoracic surgery. It has been shown to reduce the requirement for allogeneic blood by up to 75% in lumbar fusion surgery.13 Disadvantages of this method include repeated visits for preoperative phlebotomy, wastage of unused blood, high cost, and possible risks of incompatibility because of clerical errors. Furthermore, difficulties arise in using the technique in children less than 30 kg and in adults with pre-existing anaemia or cardiovascular disease. Recombinant erythropoietin has been used before major surgery to raise preoperative haemoglobin levels in patients, such as Jehovah’s Witnesses, who object for ethical reasons to the use of blood products.102 It reduces allogeneic blood requirements in children undergoing scoliosis surgery,118 and it may also be used to facilitate autologous collection of blood, and intraoperative normovolaemic haemodilution.

Intraoperative normovolaemic haemodilution

This is performed immediately before surgery. Up to 1 litre of whole blood is removed, and stored in bags with anticoagulant according to the formula:31

\[
\text{Volume to be removed} = \frac{\text{EBV} \times (\text{initial Hct} - \text{target Hct})}{\text{mean Hct}}
\]

where EBV=estimated blood volume; Hct=haematocrit; mean Hct=arithmetic mean of initial Hct and the target Hct.

The removed blood is replaced by i.v. infusion of colloid or crystalloid to achieve normovolaemia with a reduced haematocrit. During surgery, less red cell mass is lost for a given volume of blood. The donated whole blood may be re-transfused once haemostasis is achieved, or a critical value of haemoglobin reached. The technique has been shown to reduce homologous blood requirements in spinal surgery.35 42

Intraoperative cell salvage

Blood lost during surgery is collected using commercially available equipment and is then anticoagulated, filtered for clots and debris, centrifuged, and resuspended in saline before re-infusion to the patient. Many litres of blood can be salvaged. It is the authors’ practice to use cell-salvaged blood where blood loss is anticipated to be greater than 15 ml kg⁻¹. Disadvantages are that re-infused red cells may contain residual anticoagulant, and also that coagulation factors and platelets are consumed at the wound site. Clotting factors may therefore need to be replaced using donor fresh frozen plasma. Only approximately half of the blood lost during surgery can be salvaged, and the technique is unsuitable if the operative field contains malignant cells or infection, as these may be disseminated through the body. The use of intraoperative cell salvage has been recommended by a consensus conference,3 concluding that despite the initial capital investment in equipment and disposables, ‘... it appears to be relatively inexpensive and may be cost saving…’. Nevertheless, a recent survey of UK surgeons found that logistical considerations were the main obstacles to using autologous blood transfusion, and that more surgeons were keen to use it than were actually doing so.109

Spinal cord monitoring

During surgery, when corrective forces are applied to the spine, while the spinal canal is surgically invaded, or when an osteotomy is to be undertaken, the spinal cord is at risk of injury. The incidence of motor deficit or paraplegia after surgery to correct scoliosis in the absence of spinal cord monitoring techniques has been quoted as between 3.7 and 6.9%.21 70 This figure may be reduced by intraoperative monitoring (IOM) to 0.5%.78 The American Academy of Neurology has published guidelines on IOM concluding ‘considerable evidence favours the use of monitoring as a safe and efficacious tool in clinical situations where there is a significant nervous system risk, provided its limitations are appreciated’.6 It is now considered mandatory to monitor spinal cord function for these types of procedures.

IOM ideally detects perturbations in spinal cord function early in order that the surgeon can take appropriate steps to correct them before irreversible damage occurs. The time, however, between a change in the electrophysiological recordings from the cord after over-distraction, and the onset of irreversible ischaemic damage is in the order of only 5–6 min in animal studies.80

A motor deficit is functionally more devastating to the patient than a sensory deficit. This is important to consider when evaluating the relative merits of each method of monitoring, some of which assess motor tracts, and some the sensory tracts of the cord (Fig. 3).
A knowledge of the methods of intraoperative spinal cord monitoring is important to the anaesthetist, as the anaesthetic technique can have profound effects on the ability to monitor spinal cord function accurately. There are four main methods of IOM: the ankle clonus test, the Stagnara wake-up test, SSEP, and MEP. These will be considered briefly, as there have been recent reviews on this subject.32 82

Ankle clonus test

Historically, this was the first test to be used. Clonus is repeated rhythmic movement elicited by the stretch reflex. The clonus test is usually performed during emergence, either at the end of surgery or during a wake-up test. All muscle paralysis must be antagonized. There is only a brief period between anaesthesia and wakefulness when it is possible to elicit clonus. The foot is sharply dorsiflexed at the ankle joint. Spinal cord injury is indicated by complete absence of repeated movements at the ankle joint.

In the neurologically intact, awake individual, higher cortical centres have a descending inhibitory influence on the reflex, and clonus is not observed after ankle stretch. In healthy individuals during anaesthesia, cortical centres are inhibited and there is a loss of descending inhibition via the spinal cord pathways on the ankle joint reflex. Clonus may, therefore, be elicited on ankle stretch, especially during emergence from anaesthesia. If the spinal cord is injured, however, the cord undergoes a period of spinal shock, and there is a loss of reflex activity accompanied by flaccid paralysis. During emergence from anaesthesia in these individuals, the ankle clonus reflex will not be present.

The test is easy to administer. Proponents of its use point to a high level of sensitivity (100%) and specificity (99.7%).40 However, the test can only be performed intermittently, and the absence of clonus could be a result of not only spinal cord damage, but also to an inadequate or too great a depth of anaesthesia. Furthermore, the presence of clonus does not exclude spinal cord damage; other parts of the spinal cord may be damaged leaving the ankle stretch reflex intact.

Stagnara wake-up test

This was first described in 1973.116 Preoperatively, the need for the test is explained; it will involve the patient making a specified motor response, usually in the lower limbs, to verbal command part way through the surgery. The test evaluates the gross functional integrity of the motor pathways (lower and upper motor neurons and muscles) involved in performance of this motor task (Fig. 3). The test does not assess the integrity of any part of the peripheral sensory system.

The surgeon must give the anaesthetist adequate warning of the need to perform a wake-up test as neuromuscular block must be antagonized and the plane of anaesthesia lightened. As the patient becomes more conscious, they are instructed first to perform an action involving muscle groups above the level of any potential cord damage, usually involving the upper limbs (for example, to grip the anaesthetist’s fingers). When a positive response is obtained, the patient is then instructed to move their legs,
and the response to this command noted. If the patient can move their legs, anaesthesia is deepened and surgery recommenced. If the patient is unable to move their legs, corrective measures are instituted immediately.

A wake-up test should be as easy and as rapid to institute as possible. This necessitates an anaesthetic technique that is reliable, but which may be quickly antagonized as many times as the surgeon requires. Wakening should also be smooth to minimize the risk of tracheal extubation. Furthermore, the patient should not experience any pain during the test and have no subsequent recall of intraoperative events.

A number of different anaesthetic techniques for the Stagnara wake-up test have been advocated, including volatile-based anaesthesia. A Danish group, in a randomized trial involving 40 patients, described the successful use of a midazolam-based anaesthetic, antagonized by flumazenil at the time of the wake-up test, compared with a propofol infusion technique. The midazolam/flumazenil group was found to have a shorter intraoperative wake-up time (mean 2.9 vs 16 min in the propofol group), shorter postoperative wake-up times (1.8 vs 13.9 min, respectively), and a better quality of intraoperative arousal. Five patients in the midazolam group, however, became re sedated in the recovery room and required further doses of flumazenil. Remifentanil is a potent μ-receptor agonist. Its ester linkage renders it susceptible to hydrolysis by tissue esterases, producing a half-life at its site of action of less than 10 min. It therefore has a pharmacokinetic profile suitable for use when a wake-up test must be performed. Preliminary reports using remifentanil suggest a delay between the surgeon’s request for a wake-up test and adequate conditions for neurological assessment of only 5 min.

Despite the use of such techniques, the test has a number of disadvantages. First, it requires the patient’s cooperation. Secondly, it poses risks to the patient of moving on or falling from the operating table and of tracheal extubation, often in the prone position. Thirdly, it requires not inconsiderable operator skill on the part of the anaesthetist. Fourthly, it is a valid measure of motor function at only the precise moment in time the test is instituted; it does not allow continuous IOM of motor pathways. The onset of a change in electrophysiological recordings and permanent neurological injury can occur more than 20 min after the last corrective force is applied to the spine. It is, therefore, conceivable that a wake-up test could be normal after the last corrective manoeuvre has been applied but before the onset of the resultant neurological deficit.

The place of the Stagnara wake-up test in spinal cord monitoring during spinal surgery should therefore be confined to situations in which electrophysiological monitoring techniques are not available, fail, or produce equivocal results.

**Somatosensory evoked potentials**

SSEPs are elicited by stimulating electrically a mixed peripheral nerve (usually the posterior tibial, peroneal, or sural nerves), and recording the response from electrodes at distant sites cephalad to the level at which surgery is performed (Fig. 4). Guidelines on stimulation and recording methods have been published. Typically, the stimulus is applied to the peripheral nerve on the left and the right limb alternately as a square wave for 0.1–0.3 ms, at a rate of 3–7 Hz. The intensity of the stimulus varies depending upon the electrodes and quality of skin contact, but is in the 25–40 mA range. Recording electrodes are placed in the cervical region over the spinous processes or over the somatosensory cortex on the scalp, or are sited during surgery in the epidural space. Baseline data are obtained after skin incision. This allows a stable plane of anaesthesia to be established during baseline recordings as anaesthetic agents affect SSEPs. During surgery, responses are recorded repeatedly. The functional integrity of the somatosensory pathways is determined by comparing the amplitude change and the latency change of the responses obtained during surgery to baseline values. A reduction in the amplitude of the response by 50% and an increase in the latency by 10% are considered by most workers as significant. The amplitude response is considered the primary criterion.

The pathways involved in the recorded responses include a peripheral nerve, the dorsomedial tracts of the spinal cord and, depending on the electrode placement, the cerebral cortex (Fig. 3). The physiological role of these tracts is to...
subserve sensations of proprioception and light touch. It must be emphasized that responses are not obtained from motor tracts, or from the anteriolateral sensory tracts of the spinal cord (subserving pain and temperature sensation). This has two important ramifications for the validity of SSEPs. First, because of the close proximity of the dorsomedial sensory tracts with the motor tracts in the cord, it is assumed that when using SSEPs, any damage to the motor tracts will be signalled by a change in SSEPs. This, however, cannot be guaranteed. Secondly, the blood supply of the corticospinal motor tracts differs from that of the dorsomedial tracts (Fig. 5). Hypoperfusion in the territory of the anterior spinal artery may cause ischaemia in the anteriolateral tracts, but not affect the dorsomedial tracts. It is, therefore, possible to have normal recordings from SSEPs throughout surgery, but to have a paraplegic patient postoperatively. Furthermore, in patients with pre-existing neurological disorders, reliable data can be recorded in only 75–85% of patients.

Effects of anaesthetic agents on SSEPs
Anaesthetic agents can have a significant impact upon SSEPs. Inhalation anaesthetic agents and nitrous oxide cause a dose-dependent reduction in SSEP amplitude and an increase in latency. Nitrous oxide 60% with isoflurane 0.5 MAC or enflurane 0.5 MAC is compatible with effective SSEP monitoring. A recent retrospective study of 442 cases found that 13/60 ‘false-positives’ (abnormal SSEPs with no neurological deficit postoperatively) were attributable to an increased concentration of inhalation agent.

I.V. anaesthetic agents also cause changes to SSEPs but to a lesser degree than inhalation agents. The cortical response appears to be most susceptible to anaesthetic agents; subcortical, spinal, and peripheral responses are less affected. A recent study of the use of propofol or midazolam as a continuous i.v. infusion combined with sufentanil was associated with maintenance of the amplitude of the cortical SSEP from baseline values to the end of surgery (propofol from 1.8 (0.6) to 2.2 (0.3) μV; midazolam from 1.7 (0.5) to 1.6 (0.5) μV). However, propofol and nitrous oxide used in combination caused a significant reduction in the amplitude of cortical SSEPs (from 2.0 (0.3) to 0.6 (0.1) μV). The latencies of the responses were not increased in any of the three groups of patients, but recovery was significantly delayed in the midazolam group. The authors recommended a propofol technique for surgery during which cortical SSEPs are to be recorded.

Opioids such as remifentanil and fentanyl administered via the i.v. route cause a small reduction in the amplitude and increase in the latencies of SSEPs. Intrathecal opioids have little effect on SSEPs. Neuromuscular blocking agents, as may be expected, cause no change in SSEPs.
Effect of controlled hypotension on SSEP

MAP during spinal surgery is usually maintained at lower than pre-induction values in order to minimize blood loss. Typically, controlled normovolaemic hypotension to a MAP of 60 mm Hg is used. MAP should not be allowed to decrease to less than 60 mm Hg as, at this point, SSEPs are lost and neurological ischaemic injury can occur. Maintaining MAP greater than 60 mm Hg is, however, no guarantee of safety. SSEPs demonstrate that the feline spinal cord is more vulnerable to destructive injury during pharmacologically induced hypotensive anaesthesia than during normotensive anaesthesia. Earlier animal work has shown that peripheral nerves, which do not have an autoregulated blood flow, are more sensitive to the effects of hypotension than the spinal cord. SSEPs may, therefore, be reduced by even moderate hypotension. Papastefanou, in a retrospective series of 442 cases, found 17/60 "false-positive" SSEP changes attributable to hypotension. Changes in SSEPs, whether a result of hypotension, or mechanical distractive forces, or a combination of both, must not be ignored.

Other factors

A decrease in core body temperature in animals causes a reduction in the amplitude of SSEPs by approximately 7% and an increase in latency of 3% for each 1°C reduction. There does, however, appear to be a protective effect of hypothermia on spinal cord function.

It is clear from a large multicentre study that the experience of monitoring teams in spinal surgery has a significant effect on outcome. Teams with experience of less than 100 cases had more than twice the postoperative neurological complication rate of teams with greater experience.

Effectiveness of SSEP monitoring

In a large retrospective multicentre study of over 51,000 procedures, SSEP monitoring was found to have a sensitivity of 92% and specificity of 98.9%. The false negative rate was 0.127% (normal SSEPs throughout the case but a neurological deficit postoperatively), or one in 787 procedures. The false positive rate was 1.51% (SSEP had changed, but no new neurological deficit postoperatively), or one in 67 procedures. Other studies have found a higher false positive rate (14.7%), and that SSEP monitoring has a lower specificity, 85.33%, but a sensitivity of 100%, probably explained by the smaller number of cases.

SSEP monitoring is currently the mainstay of spinal cord monitoring techniques. It is, overall, a reliable technique with a high sensitivity and specificity for early detection of intraoperative neurological compromise, and has a proven record over the last decade.

Motor-evoked potentials

As a result of the inherent problems using SSEPs as a monitoring tool during spinal surgery, and reports of postoperative paralysis despite apparently normal intraoperative SSEPs, efforts have been made to monitor motor tracts of the spinal cord (Fig. 3) as a more sensitive indicator of motor function.

MEP monitoring was first used clinically over 10 yr ago. Monitoring techniques are subdivided according to the site of stimulation (motor cortex, spinal cord); the method of stimulation (electrical potential, magnetic field); and the site of recording (spinal cord, peripheral mixed nerve, muscle). Each variation of the technique has advantages and disadvantages. The principle is the same; stimulation by whatever means cranial to the site of surgery causes prodromic stimulation of motor tracts in the spinal cord, and of peripheral nerve and muscle caudal to the site of surgery. Perturbation of motor pathway function by surgery leads to a reduction in amplitude and an increase in latency of the recorded responses.

The motor cortex can be stimulated by electrical, or magnetic means. Magnetic equipment is bulky and cumbersome but is not affected by the quality of electrode contact. Recorded responses are classified as myogenic or neurogenic. Myogenic responses result from the summed EMG activity in a muscle, such as tibialis anterior, in response to stimulation (Fig. 4). Neurogenic recordings arise from the summed electrical activity in a peripheral nerve or the spinal cord. The advantage of recording EMG responses is their large amplitude. The main disadvantage is their variable morphology. When recording EMG responses, the depth of muscle relaxation is of critical importance: if it is too deep, responses are unobtainable; if only residual block is present, there is a risk of injury to the patient, if violent movements occur in response to stimulation. Neuromuscular blocking agents should be administered by continuous infusion, and the depth of neuromuscular block monitored. The first twitch of the train-of-four response should be maintained at 10–20% of control. Neurogenic responses, however, can be recorded under complete neuromuscular block to avoid patient injury, and are more reliable in terms of amplitude, latency, and morphology.

Effects of anaesthetic agents on MEPs

Cortical evoked responses are more prone to the effects of anaesthetic agents than spinal-evoked responses. Propofol is a powerful suppressant of cortical evoked responses, causing a dose-dependent reduction in the amplitude of the response. A bolus dose of propofol 2 mg kg⁻¹ abolishes cortical MEPs. Volatile agents are also powerful suppressants of cortical evoked MEPs: MEPs are abolished or are too inconsistent to interpret at end-tidal isoflurane concentrations of 0.87 (0.08)% Midazolam and etomidate cause a significant but smaller reduction in the amplitude of the response. Opioids such as fentanyl have been variously reported as reducing the amplitude of the response, or causing no effect. Multiple pulse transcranial electrical...
stimulation techniques can improve the reliability of MEP recording further.

These findings have led to the need for significant modifications to the anaesthetic technique when cortical-evoked MEPs are measured. In the past, ketamine-based techniques have been used, but not without complications such as unpleasant hallucinations. An i.v. propofol infusion with fentanyl or remifentanil has been advocated and provides for adequate MEP recording in 97% of neurologically intact patients, when used with a multiple pulse stimulation technique.

**Effectiveness of MEP monitoring**

MEP monitoring is less reliable in patients with a pre-existing neurological deficit. Furthermore, early hopes of greater sensitivity of MEPs over other monitoring techniques may have been premature. There are recent reports of preserved neurogenic MEPs associated with postoperative motor deficit, which suggest the sensitivity of MEPs is less than 100%.

SSEP monitoring has become an accepted standard of care during spinal surgery. It is less affected by the technical difficulties associated with MEP monitoring. MEP monitoring is, however, becoming more widely used and the two methods should be regarded as complementary, with the use of a wake-up test reserved for situations where neurophysiological monitoring is not possible or responses are significantly perturbed during surgery.

**Postoperative care**

Patients undergoing spinal surgery frequently have significant co-morbidity. Surgery imposes the further stresses of significant blood loss, prolonged anaesthesia, and difficulties in acute postoperative pain management. Surgeons prefer patients to be conscious and able to respond to command immediately after anaesthesia, for early neurological assessment. It is also important that patients are able to expectorate, and to comply with physiotherapy as early as possible in the postoperative period.

**Indications for postoperative ventilation**

The decision to provide a period of postoperative artificial ventilation should have been made before surgery commences, and explained to the patient. The need for postoperative ventilation is suggested by patient and surgical factors. Patient factors include the presence of a pre-existing neuromuscular disorder, severe restrictive pulmonary dysfunction with a preoperative vital capacity of less than 35% of predicted, a congenital cardiac abnormality, right ventricular failure, and obesity. Surgical factors include a prolonged procedure, surgical invasion of the thoracic cavity, and blood loss greater than 30 ml kg⁻¹. Frequently, it is necessary only to provide artificial ventilation for a few hours in the postoperative care unit, until hypothermia and metabolic derangements have been corrected. Chest drains, if present, should be checked regularly to ensure patency; obstruction may lead to a pneumo- or haemothorax.

**Postoperative analgesia**

Pain management can be a considerable challenge. Patients undergoing spinal surgery, particularly through a thoracic approach, may have a large incision extending over several dermatomes. Many patients have pre-existing chronic pain conditions, may be cognitively impaired (some neuromuscular disorders), or be very young (children). A multimodal approach to analgesia is recommended, using a combination of simple primary analgesics, opioids, and regional anaesthesia techniques where appropriate. For initial postoperative analgesia, it is useful to restart, if possible, all the analgesics the patient was receiving preoperatively. Undoubtedly, the patient’s requirements will be increased postoperatively and additional therapy will be required.

**Parenteral opioids**

The use of parenteral opioids has been the mainstay of analgesia for all patients undergoing spinal surgery. Opioids can be administered via i.m., i.v. (continuous infusion and patient-controlled analgesia devices with or without background infusions), intrapleural, epidural, and intrathecal routes. Their use, via the i.v. route in particular, is associated with side-effects such as respiratory depression, nausea and vomiting, sedation, and gastrointestinal ileus. The latter may be especially disadvantageous after major spinal surgery, when some degree of paralytic ileus is common.

Patients with cancer may not be naïve to opioid drugs and such individuals must be assumed to have acquired a degree of opioid tolerance. For patients who have received long-term opioids preoperatively by other routes (e.g. enteral, transdermal), these should also be restarted as early as possible postoperatively, and gradually reduced over subsequent days or weeks.

**Non-steroidal anti-inflammatory drugs**

Simple analgesics alone afford inadequate analgesia even for relatively minor spinal surgery. Non-steroidal anti-inflammatory drugs (NSAIDs), both non-selective cyclo-oxygenase inhibitors, and selective cyclo-oxygenase 2 (COX 2) inhibitors, have however been used successfully after spinal surgery. But the use of a non-selective cyclo-oxygenase inhibitor NSAID cannot be recommended for intraoperative or early postoperative analgesia in such cases. Guidelines on the use of NSAIDs published by The Royal College of Anaesthetists do not specify their role for this purpose. The use of NSAIDs may increase bleeding time by 30–35%, cause gastritis, and be associated with acute renal failure, particularly in the presence of hypovolaemia and hypotension. The safety profile of selective COX 2 inhibitors in major spinal surgery is yet to be fully evaluated. If, however, patients have been taking NSAIDs to
help relieve their pain without complication preoperatively, it is useful to restart this medication in the immediate postoperative period for its opioid-sparing effects.

**Epidural analgesia**

The use of local anaesthetic agents, alone or in combination with opioids, by the epidural route after spinal surgery has been described, the epidural catheter being placed intraoperatively by the surgeon. Two recent studies compared epidural analgesia with parenteral morphine administered via patient controlled analgesia (PCA) devices after major spinal surgery. The retrospective study found time to full diet and hospital stay to be reduced in the epidural group, but the randomized study was unable to find any significant differences in pain scores, side-effects, or resumption of oral intake between the epidural and PCA groups.

Epidural anaesthesia with local anaesthetic agents can make neurological assessment difficult. Concerns over the rare but serious risks of epidural haematoma and infection associated with indwelling catheters have hindered its widespread use. The incidence of local superficial infection after routine epidural catheter placement has been quoted to be as high as 12%. However, the incidence of epidural abscess related to epidural catheter placement, although difficult to determine precisely, is rare. A recent review of the literature produced 42 case reports of epidural abscesses from 1974 to 1996, only 13 of which were sited for perioperative analgesia. The authors of this study identified in their own institution two catheter-related epidural abscesses in 13 000 epidural blocks (both of which were in obstetric patients). A higher incidence of epidural catheter-related abscesses may be anticipated for catheters inserted via a surgical wound.

The incidence of spinal haematoma in patients receiving spinal or epidural analgesia and low-molecular weight heparin is estimated to be between 1:1000 and 1:10 000. The clinical signs of epidural haematoma or abscess may be masked by postoperative pain, and pre-existing abnormal neurology. The infrequency of these complications further increases the risk of failing to detect them.

**Intrathecal analgesia**

The thecal sac is readily accessible during spinal surgical procedures, and intrathecal medication can be injected with technical ease before wound closure. Early reports of the use of intrathecal opioids for analgesia in children after spinal surgery, and other major surgeries, suggested that the use of morphine (20–30 μg kg⁻¹) was associated with excellent analgesia for up to 24 h, but was complicated by respiratory depression in 16% of patients. More recent studies suggest the optimum dose of morphine to be 2–5 μg kg⁻¹, which provides comparable analgesia for 24 h but with fewer side-effects such as respiratory depression, nausea, and pruritus. Doses of this order, in a large retrospective study of 5969 patients, produced respiratory depression in 3% of patients. There were no cases of neurological injury or spinal haematoma.

Significant pain can be expected for up to 4 days postoperatively after major spinal surgery. Intrathecal opioids alone, therefore, will probably be insufficient over this period. Parenteral opioids made available in the immediate postoperative period (as patient-controlled analgesia regimen, for example), in patients who have received intrathecal opioids, provide for a smooth transition from predominately intrathecal opioid-based analgesia to parenteral opioid-based analgesia. The use of such a regimen is advisable in the setting of a postoperative critical care facility; animal data suggest systemic and intrathecal opioids may act synergistically.

**Other techniques**

Intrapleural infusions of local anaesthetic and/or opioids may be considered after a thoracotomy. Intrapleural infusions of local anaesthetic agents have been reported to reduce systemic opioid requirements in such circumstances. A number of studies, however, have found intrapleural analgesia with local anaesthetic agents to offer inferior analgesia to epidural opioids, and there remains concern over the blood levels of local anaesthetic agents achieved, and the risk of local anaesthetic toxicity.

**Late complications**

A retrospective study of 1223 anterior thoracic and lumbar spinal procedures found a respiratory complication rate of 7% (adult respiratory distress syndrome, pneumonitis, atelectasis, infection), pulmonary embolism 0.8%, cerebral vascular accident 0.25%, and death 0.33% (four patients: one died of ARDS on day 31, one myocardial infarction on day 1, and two died of fatal pulmonary emboli on days 3 and 8).

Screening studies for thromboembolic complications after spinal surgery have quoted varied incidences between 0.395 and 15.5%. One partially randomized study found an incidence of 0.3% when Doppler ultrasonography was used postoperatively to detect venous thrombosis in patients treated with either mechanical (compression stockings and pneumatic boots), or pharmacological (warfarin) methods of prophylaxis. If, however, no methods of thrombophylaxis are used and venography is the screening method, incidences of venous thrombosis of 15.5% have been quoted. In one prospective study, symptomatic pulmonary emboli occurred in 2.2% of all spinal fusions, and these were more common after combined anterior/posterior approach procedures (6%), than posterior approach procedures alone (0.5%).

There has been a paucity of well-conducted randomized controlled trials comparing methods of thromboprophylaxis. Few would argue against the use of compression stockings and pneumatic boots, the use of which is relatively free of complications. However, the use of pharmacological...
methods of thromboprophylaxis (using heparin, for example) is contentious. Their use may be associated with haemorrhagic complications such as increased intraoperative and postoperative blood loss,93 and epidural haematoma. Further studies are required to adequately ascertain the most appropriate methods of prophylaxis against thromboembolism.

Treatment of thromboembolism produces the risk of major heparin-related complications (44%) such as epidural haematoma, gastrointestinal bleeding, and wound infection.10 Insertion of an IVC filter may be appropriate in these circumstances.

Conclusions

Spinal surgery presents a number of challenges to the anaesthetist. Patients are now undergoing major spinal surgery for conditions such as malignancy, scoliosis, and trauma, which would not have been contemplated 20 yr ago. Despite this, postoperative neurological morbidity has been reduced by advances in spinal cord monitoring techniques. The anaesthetist has an important role to play in facilitating the use of these new techniques. They must also manage the relief of postoperative pain in these patients, who have frequently been receiving several analgesics preoperatively.

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