Chapter 65. Anesthesia for Orthopedic Surgery

Joshua Dooley; Gavin Martin

Key Points

1. Orthopedic surgery is associated with high incidences of deep venous thrombosis and pulmonary embolism.
2. The need for anticoagulation results in anesthesia issues specifically related to the potential for neuroaxial hematomas.
3. Unique complications in orthopedic surgery are related to tourniquet use and fat embolism.
4. Regional anesthesia is associated with lower morbidity and mortality than is general anesthesia.
5. Prone spinal surgery cases have unique complications related to patient positioning, such as nerve injuries, ventilation problems, and blindness.

Anesthesia for Orthopedic Surgery: Introduction

Orthopedic anesthesia presents many challenges to anesthesiologists. Patients range in age from infant to centenarian. This patient population shows the full spectrum of comorbidities. Many of the procedures are associated with significant postoperative pain. Surgery on isolated extremities can be performed using a variety of regional anesthetic techniques for both anesthesia and postoperative analgesia. However, providing adequate analgesia using central neuraxial techniques can be challenging, especially when deep venous thrombosis (DVT) prophylaxis with low-molecular-weight heparin (LMWH) is needed. This challenge has led to the development of many peripheral nerve block techniques and advances in the equipment used for these techniques, including continuous nerve catheters and ultrasonography for identification of nerve plexuses. Recent literature has shown a benefit of regional anesthesia over general anesthesia with respect to mortality, morbidity, postoperative analgesia, and functional recovery. The use of ultrasonography to place nerve blocks may offer a significant advantage over peripheral nerve stimulation. A meta-analysis looking at the advantage of ultrasonography over nerve stimulation technique showed improved efficacy in respect to onset and quality of block.[1] It also appears that the minimum amount of local anesthetic required to successfully perform the nerve block may be greatly reduced by using ultrasonography instead of the traditional nerve stimulation technique.[2] This may be of great benefit in reducing the incidence of local anesthetic toxicity. This chapter considers the factors pertinent to anesthesia for orthopedic surgery and reviews the appropriate management.

Specific Problems in Orthopedic Patients

Rheumatoid Arthritis

Because of the nature of the disease, patients with rheumatoid arthritis present for many orthopedic procedures, ranging from joint replacement surgery to cervical spine surgery. These patients can be very challenging to treat for a variety of reasons. Deformities of the extremities are common, which may make arterial and intravenous (IV) access and positioning of the patient more difficult. Great care must be taken when positioning patients, with adequate padding needed to prevent pressure necrosis of the patient's skin. Positioning the patient while he or she is awake often is useful. Of major concern in any patient with rheumatoid arthritis is the possibility of cervical spine instability.[3] Cervical spine involvement occurs in more than half of patients with rheumatoid arthritis, with atlantoaxial dislocation the most common abnormality. Pain and evidence of spinal cord injury are the main symptoms and signs of cervical spine involvement. However, the presence of symptoms may not correlate with the severity of radiologic abnormalities. Computed tomography and magnetic resonance imaging provide detailed images of the bone and spinal cord and should be considered in at-risk patients before anesthesia is provided. Flexion and extension cervical radiographic views may be required to exclude instability and are often done as first-line imaging of the cervical spine. Cervical spine instability may be overlooked in some patients based on clinical examination alone. Temporomandibular involvement may further restrict the anesthesiologist's ability to gain adequate access to the airway.[2] Both atlantoaxial instability and temporomandibular involvement may necessitate an awake fiberoptic intubation. The development of fiberoptic laryngoscopes has altered the management of rheumatoid patients when general anesthesia with intubation is considered necessary. These fiberoptic laryngoscopes allow the physician to proceed with induction in the usual fashion and use the optics of the device to navigate difficult airways (**Fig. 65-1**). However, patients with confirmed subluxation in the cervical segment should be intubated under appropriate sedation that allows for the assessment of neurologic symptoms in case of spinal cord trauma. Another airway problem is related to the potential for cricoarytenoid arthritis, which makes passage of an endotracheal tube extremely difficult.[4] Passing of an endotracheal tube in itself may cause dislocation of the laryngeal cartilages. Hoarseness and inspiratory stridor may indicate the presence of cricoarytenoid arthritis.

Figure 65-1.

Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

View of the vocal cords on a digital screen from a video laryngoscope.

As a systemic disease, rheumatoid arthritis may result in a variety of organ dysfunctions (**Table 65-1**). Pulmonary, cardiac, renal, and hematologic changes are important to anesthesiologists. All of these systems must be thoroughly assessed before any surgical procedure. Patients with rheumatoid arthritis are commonly managed with a variety of drugs, including steroids and nonsteroidal anti-inflammatory drugs (NSAIDs). Thus, patients may require preoperative steroid supplementation to prevent acute adrenocortical insufficiency and cardiovascular collapse during anesthesia. However, use of NSAIDs is controversial because of implications with regard to their effects on gastric mucosa, renal toxicity, platelet dysfunction, and cardiovascular effects. Use of cyclooxygenase-2 (COX-2) inhibitors, such as celecoxib, may allow reduction in the prevalence of hemorrhage in the gastrointestinal tract as well as renal dysfunction. Recent studies have shown an increase in death from cardiovascular events in patients taking these drugs long term. The Food and Drug Administration (FDA) subsequently issued a warning that COX-2 inhibitors potentially increase the risk of heart attack and stroke.[5] The risk however, appears to be similar to that of other NSAIDs. It appears that all NSAIDs increase the risk of cardiovascular events. Methotrexate, also used in the management of rheumatoid arthritis, is responsible for hematologic and pulmonary side effects, including pancytopenia and irreversible pulmonary fibrosis. Etanercept, a tumor necrosis factor inhibitor used in the management of patients with aggressive rheumatoid arthritis, has also been suggested to be the cause of acute lung injury and polyneuropathy because of demyelinization of nerve fibers.

Table 65-1 Extra-articular Manifestations of Rheumatoid Arthritis

Cardiovascular	Pericardial inflammation and effusions, myocarditis, vasculitis, valvular fibrosis
Pulmonary	Pleural effusions, pulmonary fibrosis, pulmonary granulomata, fibrotic nodules (Caplan syndrome)
Hematopoietic	Normocytic normochromic anemia, Felty syndrome (enlarged spleen, leucopenia, and recurrent infections), platelet dysfunction (NSAID therapy)
Renal	Amyloidosis
Endocrine	Adrenal insufficiency (glucocorticoid therapy)

NSAID, nonsteroidal anti-inflammatory drug.

Blood Loss

Orthopedic surgery can be associated with significant blood loss, particularly trauma surgery, multilevel back surgery, redo arthroplasty surgery, and surgery in which tourniquet use is precluded. Spinal and joint replacement surgeries offer a unique problem because of the large surface of cancellous bone that is exposed during surgery. Bleeding from cancellous bone is not easily controlled using standard techniques such as vessel ligation and cautery.

Despite improvement in the screening process for allogenic blood donations, there still exists the potential for transmission of infectious diseases and transfusion reactions. Bierbaum et al[6] investigated the need for blood transfusion in 9482 patients who had undergone total hip or total knee replacement surgery. Fifty-five percent of patients undergoing hip surgery and 39% of the knee replacement patients required some form of blood transfusion. Of these patients, 66% received autologous blood, and 34% received allogenic blood. Patients who receive a blood product transfusion are more likely to have infections and thus an increased hospital stay. Techniques regularly used in orthopedic surgery to reduce the need for allogenic blood transfusion include hypotensive anesthesia, preoperative hemoglobin optimization using iron and erythropoietin, preoperative autologous blood donation, acute normovolemic hemodilution, and intraoperative and postoperative red blood cell salvage techniques.[7-9] Hypotensive anesthesia has been shown to significantly reduce blood loss during surgery. A study by Sharrock et al[10] showed that intraoperative blood loss in 250 consecutive hip replacement patients was approximately 250 mL if the surgery was performed with hypotensive anesthesia. The lower arterial and central venous pressures and—importantly—lower peripheral venous blood pressure in the surgical wound may explain this difference. This study showed that hypotensive anesthesia produced by regional anesthesia is superior to general hypotensive anesthesia.[10] Of concern with any hypotensive technique is the potential for increasing ischemic cardiovascular and neurologic events, which was not seen in the study by Sharrock et al.[10] However, this technique should be used with caution in elderly adults and in patients with a significant cardiovascular history. The use of hypotensive techniques in the prone position should be cautioned because of the potential complication of postoperative blindness. The subject is discussed at a later stage in this chapter.

Preoperative autologous blood donation has been widely used in orthopedic patients but has many drawbacks, including iatrogenic anemia, high cost, clerical errors resulting in transfusion reactions, and wastage of blood products. Its main benefit is the potential to reduce the transmission of infectious diseases and the avoidance of immune-mediated transfusion reactions such as acute lung injury. A benefit of intraoperative normovolemic hemodilution over autologous blood donation is that the blood is taken off and replaced with crystalloid or colloid just before incision, and the blood remains with the patient at all times. This process reduces the potential for clerical errors that lead to transfusion reactions and substantially reduces cost. Downsides to this technique are that it is labor intensive and that excessive hemodilution may result in coagulation disturbances. Recombinant human erythropoietin used either in conjunction with autologous blood donation or normovolemic hemodilution or alone has the potential to ensure higher preoperative hematocrits and reduce the need for allogenic blood transfusion.[11] Use of procoagulants, such as tranexamic acid (proteinase inhibitor) and aminocaproic acid, is not routine but may reduce intraoperative blood loss.[12,13] These medications block proteolytic enzymes such as plasmin, the enzyme responsible for fibrinolysis. The concern with use of any procoagulant, especially in joint replacement surgery, is the possibility of an increased incidence of DVT, although studies have not shown this side effect.[14]

Cerebral Palsy and Pediatric Orthopedic Surgery

Cerebral palsy (CP) is a nonprogressive neurologic disorder that results from a variety of insults that may occur perinatally and during the first 2 years of life. The incidence of CP is estimated at 2.4 per 1000 live births.[15] Most cases of CP are of unknown etiology. Known causes of CP include antenatal infections, thyroid disease, asphyxia, meningitis, and trauma. Premature infants have a greater incidence of CP because of periventricular hemorrhages. A variety of classification systems for CP are available, with the Swedish classification the most commonly used.[16] Spastic CP constitutes 70% of cases followed by dyskinetic CP (10%), ataxic CP (10%), and mixed CP (10%). Children with CP commonly present for orthopedic procedures, such as tenotomies and osteotomies, to improve their gait and posture. Another common orthopedic procedure is surgery for scoliosis correction. A number of anesthetic considerations must be considered when anesthetizing children with CP. These pediatric patients have a high incidence of chronic respiratory infections because of repeated aspiration and a restrictive lung pattern caused by the presence of a scoliotic spine. The high incidence of aspiration is related to gastroesophageal reflux and the presence of bulbar palsies, which limit the child's ability to cough and clear oropharyngeal secretions. In fact, the second most common cause for surgery after orthopedic procedures is Nissen fundoplication for gastroesophageal reflux. These children should be seen preoperatively with special assessment of their respiratory function. They may require antibiotics, bronchodilators, and physiotherapy to optimize their conditions before they undergo surgery. Approximately 30% of children with CP also have epilepsy, most commonly the spastic hemiplegia variety. Anticonvulsant medication should be continued up to the time of surgery and restarted as soon as possible after surgery. Latex allergy resulting from the number of procedures these children undergo is common and should be sought in all children with CP. A latex-free environment for all CP cases should be practiced. Benzodiazepines and baclofen all have been used in CP children to reduce muscle tone. Baclofen acts as an inhibitor of γ-aminobutyric acid, an inhibitory neurotransmitter, and has been shown to reduce pain and the development of contractures associated with increased muscle spasms.[17] Baclofen can be given orally, but an intrathecal pump is the preferred route of administration. Because abrupt withdrawal of baclofen can result in seizures and hallucinations, it should be continued in the perioperative period.[17] Baclofen has been implicated in delayed arousal, bradycardia, and hypotension during general anesthesia.[18] Premedication with sedatives should be considered, but care is necessary, especially in hypotonic children, because a sedative may easily compromise the child's airway. Antacids and prokinetics should be used because of the high incidence of gastroesophageal reflux. Antisialagogues, such as glycopyrrolate, also should be considered to reduce the oropharyngeal secretions. The presence of gastroesophageal reflux may necessitate a rapid-sequence induction, but the muscle relaxant of choice is controversial. Studies have shown an increased number of extrajunctional acetylcholine receptors at the neuromuscular junction in children with CP, making hyperkalemia a potential problem when succinylcholine is used for muscle relaxation.[19,20] In addition, use of succinylcholine in children is controversial because of the potential for anaphylactic reactions. Nondepolarizing agents show less potency in children with CP, so larger doses of nondepolarizing agents may be needed to maintain a neuromuscular block during surgery.[21] The mean alveolar concentrations of the inhalational agents are lower in children with CP compared with normal children.[22] Intraoperative hypothermia caused by hypothalamic dysfunction is often a problem, and extra care is needed to maintain normothermia. Postoperative pain management can be an issue because of the child's inability to communicate adequately. Regional anesthetic techniques, such as caudals, epidurals, and peripheral nerve blocks, are very useful in these situations. Because of the young age of pediatric patients, these regional techniques often must be administered while the children are under general anesthesia. However, evidence indicates that this can be performed safely.[23] Epidural combinations of local anesthetics, opioids, and clonidine may be useful for postoperative pain management but require adequate postoperative management to detect oversedation and respiratory depression.

Antibiotic Prophylaxis

Surgical site infections remain a serious complication in surgery. A recent advisory statement from Medicare National Surgical Infection Prevention Project states that infusion of the first antimicrobial dose should begin within 60 minutes before surgical incision.[24] When a fluoroquinolone or vancomycin is indicated, infusion of the first antimicrobial dose should begin within 120 minutes before the incision because these drugs have significantly longer half-lives.[24] Adhering to this advisory statement is imperative not only to decrease the risk of surgical site infections but also to attain full reimbursement.

Major Orthopedic Procedures

Anesthesia for Extremity Surgery

A general anesthetic can be used as the anesthetic of choice for all orthopedic procedures. However, a regional anesthetic technique can be used to provide both anesthesia and postoperative analgesia for a variety of orthopedic procedures, including arthroscopic, fracture, and joint replacement surgery. For lower limb surgery, central neuroaxial techniques can be used in addition to peripheral nerve blocks.

Upper Extremity Surgery

The variety of brachial plexus blocks available means that several options for block technique can be used for upper extremity procedures.[25] The most important factor in choosing a block is the anticipated location of the incision, although other variables can affect the decision. Patient factors, such as weight, degree of pulmonary dysfunction, and coagulation status, also play a role. Choice of local anesthetic depends on balancing the time of onset with the desired duration of block. For procedures on the shoulder, interscalene block using 30 to 40 mL of local anesthetic is the preferred technique. This dose should ensure block of the suprascapular nerve, which branches off from the plexus quite proximally. Superficial cervical plexus block also is important, although it usually is achieved as an effect of an interscalene block. To cover anterior incision sites, supplemental intercostobrachial nerve block is needed as well. The sensory distribution of this nerve is highly variable. To cover posterior incision sites, paravertebral blocks of the T1 and T2 nerve roots or skin infiltration by the surgeon are necessary. If paravertebral blocks are used, separate injection of the intercostobrachial nerve is unnecessary. Anesthesia from the midhumerus to the hand can be achieved with a supraclavicular, infraclavicular, or axillary block. Each of these techniques has unique advantages and drawbacks that may make that technique particularly useful in a given patient. Ultrasonography is playing an increasing role, particularly in more superficial upper extremity blocks (**Fig. 65-2**). Supplemental injection of the peripheral nerves more distally can be performed to salvage partially successful proximal blocks. Bier block can be used to perform short-duration forearm and hand surgery, but it does not provide postoperative analgesia. A description of the various peripheral nerve block techniques is given in Chapter 48.

Figure 65-2.

Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

Supraclavicular nerve block using ultrasound.

Shoulder Replacement Surgery

More than 80000 shoulder arthroplasty procedures are performed annually in the United States. Shoulder replacement surgery, similar to knee and hip replacement surgery, can result in significant postoperative pain. Both general anesthesia and interscalene nerve blocks can be used for anesthesia, either alone or combination. Increasingly more shoulder procedures are performed on an outpatient basis, which has necessitated the use of a variety of techniques to improve postoperative pain. Use of interscalene nerve blocks alone for anesthesia and analgesia offers patients a significant advantage in terms of pain scores, time to ambulation, time to discharge, and need for unexpected admission compared with general anesthesia.[26] Other techniques used for postoperative pain include intra-articular infusions of local anesthetics and suprascapular nerve blocks. The continuous delivery of intra-articular local anesthetic via means of an indwelling-catheter has recently been discredited because of the erosion of the articular cartilage by the local anesthetic infusion. Suprascapular nerve blocks have been shown to be superior compared with patient-controlled IV analgesia.[27] Potential benefits of suprascapular nerve block compared with interscalene nerve block are ease of performance, lower volumes of local anesthetics needed, and fewer complications such as phrenic nerve paralysis and intrathecal injection. The major drawback of suprascapular block compared with interscalene nerve block is that suprascapular nerve block must be combined with general anesthesia, thus necessitating airway manipulation and exposing the patient to the deleterious physiologic changes associated with general anesthesia. In some studies, intra-articular infusion of bupivacaine has shown no benefit compared with placebo.[28] Many shoulder surgeries are undertaken with the patient placed in a 45-degree semirecumbent position (beach chair position). This position presents problems related to potential difficulties with airway access if a regional anesthetic is the sole anesthetic technique. It is essential to test whether the interscalene block is adequate for the surgical procedure before the procedure is started because access to the airway during the case can be difficult. Another problem with this position is reduced venous return to the right side of the heart, resulting in reduced preload and potential hypotension, especially with use of general anesthesia. This condition may result in the need for increased fluid resuscitation. Lower extremity noninvasive blood pressure measurements should be used with caution, if at all, because these measurements do not provide accurate information for determining cerebral perfusion pressure for the patient in a beach chair position. To ensure cerebral perfusion is adequate, continuous processed electroencephalogram or cerebral oximetry should be monitored on some patients in the beach chair position.[29] These considerations include patients with previous neurologic ischemic events, carotid stenosis, arterial vascular disease, and significant cardiovascular risk.

Patients with significant cardiovascular problems should be positioned slowly, and the anesthesiologist should always be aware of the potential for venous air embolism, particularly with patients in the sitting position.

The problems of embolic phenomenon, as seen in hip or knee replacement surgery, are generally not seen in shoulder replacement surgery. In general, use of invasive lines, such as central lines and arterial lines, is not required for these cases, depending on the presence of comorbidities.

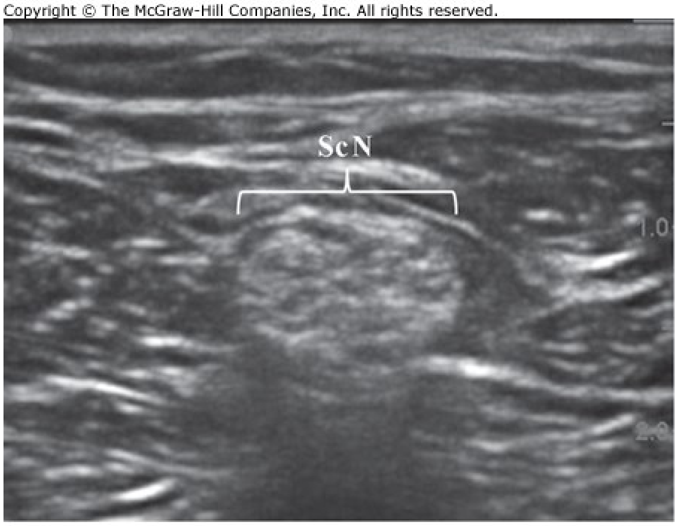
Lower Extremity Surgery

Many different regional anesthesia techniques are available for lower extremity orthopedic surgery.[30] Neuraxial techniques are appropriate for any lower extremity procedure in most patients, but aggressive use of postoperative anticoagulation for prevention of DVT and pulmonary embolism (PE) may limit the use of postoperative epidural analgesia. Peripheral nerve blocks with or without continuous catheter use offer an alternative to neuraxial techniques, which may be safer in the setting of perioperative anticoagulation with efficacy at least equal to that of epidural analgesia. For procedures on the hip and proximal femur, lumbar plexus block[30] in conjunction with a proximal sciatic nerve block[30,31] provides acceptable analgesia. A femoral nerve block can be used instead of a lumbar plexus block, although it is less likely to provide block of the obturator and lateral femoral cutaneous nerves.[32] Addition of paravertebral nerve blocks at the first and second lumbar levels may be needed to provide complete anesthesia. Alternatively, the procedure can be accomplished using a spinal anesthetic alone or a combination of spinal anesthesia with a lumbar plexus and sciatic blocks or catheters for postoperative analgesia. Epidural or combined spinal epidural anesthesia provides a simpler route of anesthesia and analgesia[33] and may be acceptable for postoperative use if the epidural is managed in accordance with the third consensus statement on neuraxial anesthesia and anticoagulation of the American Society of Regional Anesthesia and Pain Medicine (ASRA) (2010).[34] The main goal of these guidelines is to decrease the occurrence of neuraxial hematoma. In general, hip procedures are associated with less postoperative pain than are knee procedures, making prolonged regional analgesia less important. Anesthesia and analgesia for procedures involving the knee and distal femur can be accomplished with either neuraxial techniques or peripheral nerve blocks. Lumbar plexus block offers more complete anesthesia of the thigh than does femoral block but is deeper and may be more difficult in obese patients and those with a history of lumbar spine surgery.[32] Sciatic nerve block is crucial for coverage of the posterior cutaneous nerve of the thigh and for the knee joint itself.[35] Procedures involving the foot and ankle, as well as those involving the tibia and fibula, are primarily covered by a sciatic nerve block. This can be achieved by blockade of the sciatic nerve at the popliteal level. **Figure 65-3** shows an ultrasound scan of the popliteal nerve. Block of the saphenous nerve may be necessary, depending on the location of the incision and the need for tourniquet. The saphenous nerve can be blocked via either femoral nerve block or a distal dedicated saphenous nerve block. Blocking the saphenous nerve at the femoral nerve level results in weakness of the quadriceps femoris with an inability to extend knee. This may make mobilization more problematic compared with performing a dedicated saphenous block, which is purely sensory. Recently, ultrasound techniques have been described in which the saphenous nerve is blocked in the adductor canal just below the sartorius muscle[36] (**Fig. 65-4**). Ankle block without the use of epinephrine is adequate for procedures on the foot if no tourniquet use is expected.

Figure 65-3.

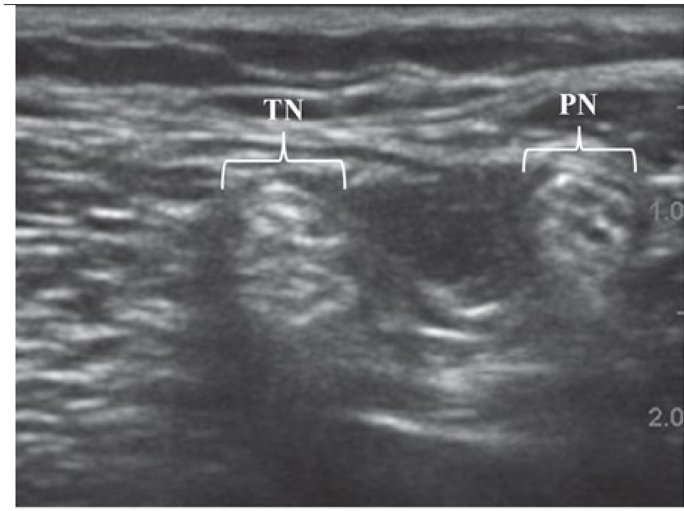
A

Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com



B

Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

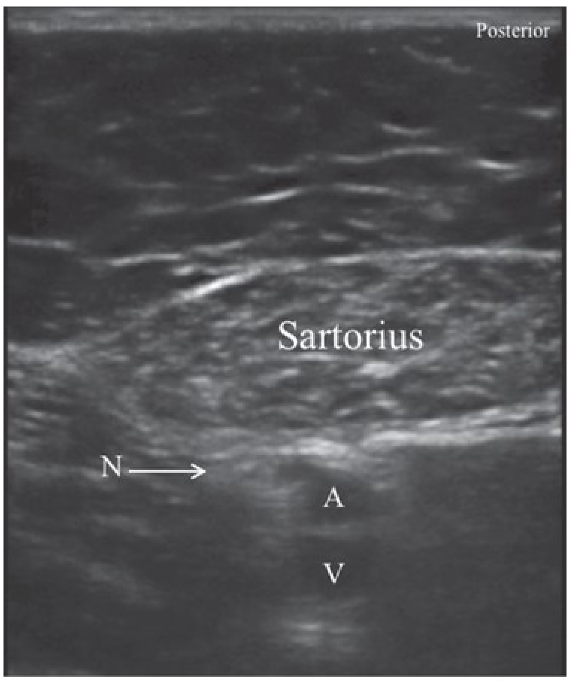


C

Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

A. Popliteal nerve block performed with ultrasound in a patient in the prone position. **B.** Ultrasound scan of the sciatic nerve 7 cm above the popliteal crease. Note that the nerve lies 1.0 cm below the skin (centimeter markings on right side of figure). ScN, sciatic nerve. **C.** Ultrasound scan in the popliteal fossa showing the division of the nerve into the medial tibial branch and lateral peroneal branch. PN, peroneal nerve; TN, tibial nerve.

Figure 65-4.



Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

Ultrasound image of saphenous nerve in the adductor canal illustrating the relationship with the sartorius muscle, femoral artery, and femoral vein. A, artery; N, nerve; V, vein.

The question as to whether general or regional anesthesia is superior with respect to outcome is controversial. A number of studies have shown no improvement in outcome with respect to mortality and morbidity.[37,38] However, other studies have shown that regional anesthesia and analgesia may reduce morbidity and mortality after surgery.[39-41] In a meta-analysis study, Rodgers et al[40] showed a 33% reduction in mortality. They also showed a significant decrease in the incidences of myocardial ischemic events, respiratory depression, rate of DVT formation, and blood loss. Wu et al[42] showed a death rate of 5.8 per 1000 (95% confidence interval [CI], 2.9-8.7) at 30 days postsurgery for cases using epidurals versus a death rate of 9.9 per 1000 (95% CI, 8.6-11.3) for cases using only general anesthesia. However, this benefit to patients must be considered in the context of the risk of epidural hematomas when neuroaxial anesthesia is given in the presence of anticoagulants such as LMWH. The risk, although small, has led to the publication of guidelines for use of regional anesthesia in patients receiving anticoagulants.[34] The 2010 guidelines depart from the 2003 guidelines by stating that LMWH should not be administered concomitantly with medications that affect hemostasis, such as antiplatelet drugs, standard heparin, or dextran. This has resulted in the reinvention and development of many peripheral nerve block techniques, including continuous peripheral nerve catheter techniques,[43] and use of ultrasonography to place these regional nerve blocks.[44,45]

Hip and Knee Joint Replacement Surgery

With the population of the United States aging and the prospect of "baby boomers" reaching retirement age in the next couple of decades, the number of patients requiring joint replacement will increase greatly. It is estimated that more than 1 million joint replacement procedures per year will be performed in the United States during the next decade. A variety of anesthetic techniques, consisting of general, spinal, epidural, combined spinal and epidural, and peripheral nerve blocks, are available to anesthesiologists. These techniques have been shown to be superior to routine patient-controlled analgesia and as efficacious as epidural anesthesia but with fewer side effects.[46-48] Some evidence suggests that regional techniques may result in earlier discharge and improved functional outcome.[47,49] Knee replacement surgery is especially associated with significant postoperative pain, and patients undergoing this surgery benefit greatly from some form of postoperative regional analgesia. Use of epidurals in the joint replacement setting has been severely restricted by the widespread use of LMWH. The introduction of a new synthetic antithrombin III pentasaccharide sequence, fondaparinux, that has a half-life of 17 hours may have huge implications for the performance of regional techniques.[50] Normal practice is to wait at least 2 half-lives after discontinuation of such drugs before placing a neuraxial block or manipulating epidural catheters. Unfortunately, this means that with fondaparinux, there will be no window of opportunity to perform the regional anesthesia techniques or remove an epidural catheter.

A variety of peripheral nerve blocks have been used for analgesia in knee replacement surgery. They include psoas compartment blocks (lumbar plexus), femoral nerve blocks, and sciatic nerve blocks. The psoas compartment approach may be superior to the femoral approach because it is associated with greater success in blocking the 3 main components of the lumbar plexus: femoral, obturator, and lateral femoral cutaneous nerves. Capdevila et al[51] showed a 95% probability of blockade of all 3 nerves if the psoas compartment approach is used versus 33% if the femoral approach is used. A study by Macalou et al[52] showed that addition of an obturator nerve block to a 3:1 femoral nerve block resulted in superior postoperative pain relief compared with a 3:1 femoral nerve block alone. The addition of a sciatic nerve block for postoperative pain management is controversial. Studies have shown a significant improvement in postoperative pain management if the sciatic nerve block is also used.[53,54] Other studies have shown no improvement in postoperative opioid requirements if a sciatic nerve block is used.[55]

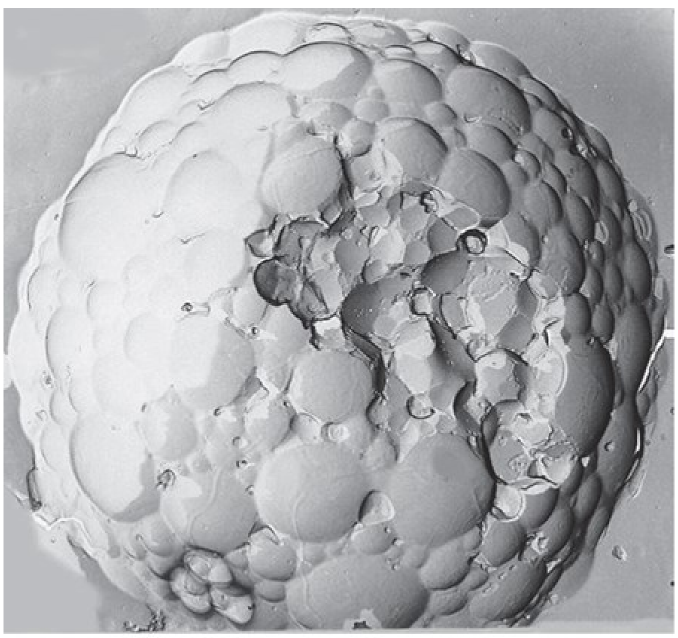
Whether the addition of peripheral nerve blocks to general anesthesia or spinal anesthesia offers any benefit to patients undergoing hip arthroplasty surgery is not as clear as in the case of knee replacement surgery. Biboulet et al[56] compared patient-controlled analgesia with morphine and a single injection of either a femoral or psoas compartment block. No difference in morphine consumption or pain scores was noted 4 hours after extubation. Other investigators have reported similar results using psoas compartment block for postoperative pain.[49] Thus, for hip replacement surgery, use of a spinal, epidural, or both may offer benefits to patients compared with general anesthesia in terms of mortality, morbidity, and pain control, but the addition of peripheral nerve blocks for postoperative pain appears to be of limited benefit. This may be in part because the pain after hip replacement surgery is of much shorter duration than in knee replacement surgery.[49,56]

The maximum duration of a single-shot nerve block depends on the local anesthetic used and the site of injection (lidocaine 2%, mepivacaine 1.5%, 4-6 h of analgesia vs ropivacaine 0.5%, bupivacaine 0.5%, 8-16 h of analgesia). Administration of additives, such as clonidine (50-150 mcg), may prolong the nerve block by another 2 or 3 hours. Use of continuous catheters in knee replacement surgery can extend the block indefinitely and can help patients avoid the severe pain experienced when the single-shot nerve block wears off. Evidence indicates that use of a stimulating nerve catheter improves the success rate of nerve catheters by avoiding subsequent failure of the catheter when the initial nerve block wears off (so-called "secondary block failure"). Salinas et al[43] showed a 100% success block rate when using a stimulating nerve catheter compared with an 85% success rate when using a nonstimulating nerve catheter. A recent semiquantitative systematic review including 11 randomized controlled studies has also shown improved analgesia with the use of stimulating catheters compared with nonstimulating catheters.[57]

Early mobilization and rehabilitation are important for the functional outcome of the patient. Use of a continuous catheter with local anesthetic causes motor weakness. Close collaboration among the anesthesia, orthopedic, and physiotherapy teams is needed to allow early mobilization with adequate analgesia. Lower concentrations of local anesthetic infusions produce less motor block but also may produce inferior analgesia. Starting patients on some form of oral analgesics before discontinuing the peripheral nerve catheters is essential to maintain adequate postoperative analgesia.

A new approach to postoperative pain management in patients undergoing lower limb joint replacement is the use of extended-release epidural morphine sulfate (DepoDur, SkyePharma, London, UK). This technology is based on liposomal products into which doses of 10 to 20 mg of morphine are incorporated (**Fig. 65-5**). This form allows the slow release of morphine into the epidural space over a 48-hour period without the need for an epidural catheter, thus avoiding anticoagulation issues. A study of hip replacement patients has shown a significant reduction in postoperative fentanyl requirements and pain scores.[58] The side effects are similar to those of other neuroaxial opioids. The most serious potential side effect is respiratory depression,[59] so patients must be monitored closely for 48 hours. Further developments of slow-release preparations of local anesthetics are awaited.

Figure 65-5.



Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

DepoFoam (SkyePharma, London, UK), an example of a liposomal delivery system used for epidural administration of 10 to 15 mg preservative-free morphine.

Invasive monitoring with arterial or central venous lines is generally not required except in patients with significant comorbidities or in patients undergoing revision of a previous joint replacement. Blood loss tends to be higher during revision joint replacement procedures. Methods used to reduce the requirement for blood transfusion are relevant to all patients undergoing joint replacement surgery (discussed earlier in this chapter in the section on blood loss).

Neck of Femur Fractures

Repairing neck of femur fractures is a common surgical procedure at trauma institutions. Management is generally surgical and involves either internal fixation with screws or plates or a hemiarthroplasty. Hip arthroplasty for management of femoral neck fractures is associated with a nearly 10-fold increase in the rate of perioperative mortality compared with elective hip arthroplasty. The 30-day mortality is 10%, and 20% to 30% of patients die within 1 year of surgery.[60,61] The reasons for this high mortality rate probably are the age of this population group (>70 years of age), the presence of comorbidities, and the high incidence of DVTs and PEs. Optimization of patient medical conditions before surgery is generally but not always recommended because delay in surgery caused by the need for management of comorbidities may increase the mortality rate by 2.5 times.[62] Thus, appropriate and timely medical care is important before anesthesia and surgery.

Anesthesia involvement in the management of patients with neck of femur fractures can occur before the need for anesthesia for surgery and may involve the placement of a 3:1 femoral nerve block or fascia iliaca block in the emergency department for analgesia. Preoperative use of a femoral 3:1 block has been shown to be simple and to reduce the pain experienced, with few side effects.[63] The reduction in opioid doses required by patients can have substantial benefits. The question of whether general anesthesia or some form of regional anesthesia is best for these patients is controversial. The authors hold the opinion that regional anesthesia, including the use of spinal anesthesia, epidural anesthesia, combined spinal epidural anesthesia, or peripheral nerve blocks, is beneficial. Use of lumbar paravertebrals, lumbar plexus, and sciatic nerve block as the sole anesthetic technique for neck of femur fracture is a beneficial technique, especially in patients who, because of their comorbidities, cannot tolerate the drop in preload or afterload caused by spinal or epidural anesthesia.[31,64] An alternative method in this group of patients is the use of a continuous spinal catheter.[65] This method allows the anesthesiologist to titrate intrathecally the local anesthetic in small amounts while still obtaining the desired effect without the usual hemodynamic changes associated with a single large dose of intrathecal local anesthetic. Invasive line monitoring, such as arterial and central lines, may be needed, depending on the presence of comorbidities. The need for blood transfusion is uncommon, but adequate IV access and a blood cross-match should always be available. Keeping patients warm during the procedure is especially important in this elderly population. Finally, this group is at a much higher risk for development of DVT and subsequent PE. All patients must be adequately anticoagulated during the postoperative period to prevent this complication (see Deep Vein Thrombosis).

Spinal Surgery

Spinal surgery is frequently a challenge for anesthesiologists, involving a wide variety of procedures for treatment of different pathologies in the young to the very old patient population. It may involve surgery on the vertebrae of the spine in addition to the neural structures of the spinal cord.[66] Common pathologic reasons for surgery are listed in **Table 65-2**.

Table 65-2 Pathologic Reasons for Spine Surgery

Degenerative disease or arthritis
Congenital
Idiopathic
Trauma
Malignancy
Infection
Vascular abnormalities

The required position of patients frequently is prone. The prone position requires extra care and attention because it may be associated with an increased incidence of complications. Major spinal surgery can be associated with extensive blood loss. Although the majority of spinal surgery is elective, urgent surgery may be required after trauma or when spinal cord viability is a concern. Some patients undergoing spinal procedures require repeat surgery and may have high requirements for analgesics in the postoperative period.

Positioning

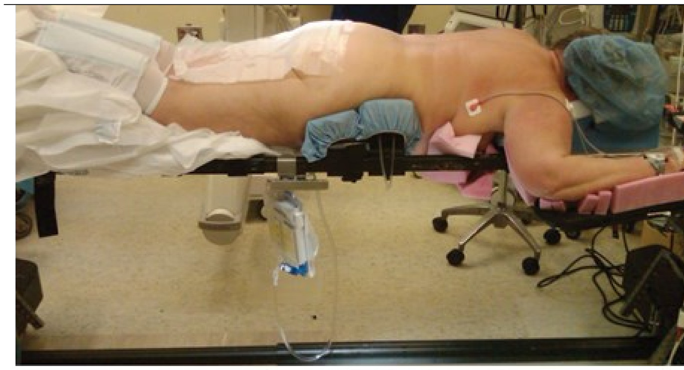
The majority of spinal surgery is performed with the patient in the prone position, although an anterior approach is sometimes used, particularly for cervical spine surgery. In addition, an anterior or lateral approach may be used for lumbar and thoracic spinal surgery. The ideal position allows easy access and maximal exposure to the site of surgery while allowing for a good operative field with minimal bleeding. Decompression of the stomach and bladder using an orogastric tube and a urinary catheter along with avoiding compression of the abdomen results in decreased pressure in the epidural veins and decreased blood loss. The site of surgery may be above the level of the heart, resulting in low venous pressure and decreased blood loss; however, it also is associated with a risk of venous air embolism. Hence, appropriate positioning of the patient is essential while being careful to avoid many of the potential complications. Although many different surgical tables and positions largely determined by surgeons' preference are available to improve exposure to the surgical site, many of the pertinent issues are common to all cases. First, extreme care must be taken when turning the patient, particularly patients at risk for spinal cord compromise. Particular attention should be paid to positioning of the head, neck, and arms.

Complications associated with malpositioning of the arms, including vascular and brachial plexus injury, have been reported (**Table 65-3**).[67] Such injuries are least likely to occur when the arms are placed by the patient's side. However, this position may invade the surgeon's space and restricts the anesthesiologist's access to arterial and venous access. Therefore, the patient is frequently positioned with the arms resting on padded arm boards and flexed at the elbow (**Fig. 65-6**). The elbow should not be flexed more than 100 degrees because such a position is associated with increased pressure within the cubital tunnel.[68] The abdomen, genitalia, and breasts all should be checked because prolonged surgery in the prone position can result in injury to these areas. Adequate protection and padding of the eyes and head are essential. Blindness resulting from surgery performed with the patient in the prone position has been reported. Although its etiology probably is multifactorial but still is incompletely understood, prolonged surgery, anesthetic length greater than 6 hours, hypotension, large blood loss (>1 L), anemia, edema, and changes in intraocular perfusion pressure all may contribute to blindness.[69,70] Changes in ocular perfusion pressure resulting in decreased blood flow to the optic nerve may result in ischemic optic neuropathy. Increases in intraocular pressure or decreases in mean arterial pressure result in decreased ocular perfusion pressure.[71,72] Avoidance of prolonged periods of hypotension and perioperative anemia may reduce the risk of perioperative blindness in patients in the prone position.[73] In addition, direct pressure on the eye can result in injury to the eye. Tape marks and facial skin loss may result, especially in prone patients with significant facial edema and friable skin.

Table 65-3 Complications of Positioning for Spine Surgery

Endotracheal tube dislodgement/kinking	
Eye injury	
	Corneal abrasion
	Ischemic optic neuropathy
Edema (facial, orbital, or airway)	
	Facial skin damage
	Airway obstruction
Nerve damage (brachial/lumbar/sacral plexus)	
Compression	
Stretch	
Compression of vessels	
Ischemia	
Thromboembolic complications	
Compartment syndromes	

Figure 65-6.



Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

Proper positioning of the patient in the prone position.

The sitting position occasionally is used for surgery on the cervical spine. The risks and complications associated with surgery performed in the sitting position are described elsewhere in this textbook.

Anesthetic Technique

A standard preoperative assessment is essential in patients undergoing spinal surgery. In addition to standard American Society of Anesthesiologists monitoring, use of invasive monitoring depends on patient comorbidities and the anticipated complexity of the surgical procedure and anticipated blood loss.[66] Surgeries involving multiple levels, repeat operations, and procedures for treatment of trauma and neoplasms typically are associated with increased blood loss.

A thorough airway examination should be performed. This assessment is critical, particularly in patients presenting for cervical spinal surgery and in patients with disease processes that affect the vertebral column, such as rheumatoid arthritis, ankylosing spondylitis, or generalized osteoarthritis. In addition, patients who have undergone previous neck surgery may have increased difficulty at intubation. The aim is to safely secure the airway while avoiding any damage to the spinal cord. This can be achieved safely in both awake and anesthetized patients using a variety of techniques, such as standard laryngoscopy, intubating aids, manual inline stabilization, laryngeal mask airways (LMAs; LMA North America, Inc., San Diego, CA), and fiberoptic intubations. The precise technique depends on the clinical situation; management of the difficult airway is discussed in Chapter 36. The majority of movement in the cervical spine during intubation occurs at the atlantooccipital joint and between the first 2 cervical vertebrae.[74,75] Particular caution should be exercised in the airway management of patients with C1–C2 injury and at-risk patient populations (rheumatoid arthritis, Down syndrome) that are more prone to pathology of C1–C2. Use of rigid collars may increase the difficulty of intubation but does not affect the degree of cervical spine movement. After the airway is secured, the cervical collar alerts staff members that the patient may have a neck injury. Awake intubation allows neurologic examination after intubation and positioning of the patient, although this may be difficult in uncooperative patients. Thoracic spinal surgery may require use of a double-lumen tube or bronchial blocker if 1-lung ventilation is required with an anterior or lateral approach.

Anesthesia induction can be either IV or inhalational, with IV induction appropriate for the majority of patients. Intubation and muscle relaxation can be facilitated with either nondepolarizing muscle relaxants or succinylcholine. Use of succinylcholine should be avoided in patients with muscular dystrophies and in patients with spinal cord injuries in whom an exaggerated hyperkalemic response may be seen. Use of succinylcholine probably is safe in the 48 hours immediately after spinal injury and again 9 months after the injury.[76] Intraoperative use of muscle relaxants may be avoided depending on whether motor-evoked responses are monitored and surgeon preference. This is relevant in patients at risk for nerve root injury during surgery in which nerve root stimulation results in muscle movement. Anesthesia can be maintained using either a potent volatile anesthetic in a nitrous oxide–oxygen or air–oxygen mixture or IV anesthesia such as propofol infusions. Potent volatile agents may hinder the use of sensory and motor-evoked responses. If motor-evoked potentials are to be used by the surgeon, potent volatile agents are avoided completely, and a total IV infusion (TIVA) technique is used. Intubation can be accomplished with succinylcholine or under deep propofol-induced anesthesia. Nondepolarizing agents should not be used so as not to interfere with the motor-evoked potential. Many opioids have been used as part of a balanced anesthetic technique, with remifentanil having the advantage of providing potent analgesia and rapid offset of action. This may assist in the early assessment of the patient's neurologic status in the early postoperative period. Remember that all anesthetic agents may affect the use of somatosensory and motor-evoked potentials, which can be used to monitor spinal cord function (see Chapter 89). Changes in anesthetic concentrations and arterial blood pressure also affect the interpretation of evoked potentials. Spinal cord monitoring is discussed in Chapter 90.

Measures for minimizing intraoperative blood loss and reducing allogeneic blood transfusion in spinal surgery are particularly important. Careful positioning, avoidance of abdominal compression, surgical technique, hypotensive techniques, use of preoperative autologous donation, intraoperative normovolemic hemodilution, and use of intraoperative cell savers all may help avoid the use of allogeneic blood products. However, combinations of these techniques to reduce requirements for homologous blood products have not produced consistent results.[77,78] Use of antifibrinolytics may reduce intraoperative blood loss.[79] Hypotensive anesthesia is very effective at reducing blood loss, although it may be a contributory factor to the rare but devastating complication of posterior optic neuropathy. These techniques are particularly important in spinal surgeries associated with large blood loss. Minimally invasive spinal surgery has increased substantially. Primarily by using endoscopic, computer navigation and microsurgical techniques, surgeries to treat a wide variety of conditions ranging from spinal stenosis to tumor removal can be performed through much smaller incisions. These techniques allow for a quicker recovery time, reduced blood loss, and decreased opioid requirements with fewer postoperative complications.[80] Many of these new techniques use not only sensory-evoked potentials but also motor-evoked potentials. Many surgeons request the use of no muscle relaxants during the case as well as avoidance of potent inhalational agents to minimize disturbance on the motor-evoked potentials. To achieve this, a TIVA technique is required.

Postoperative Care

Postoperative analgesia can be a challenge, particularly in patients who have experienced chronic back pain. Postoperative pain management has shifted from opioid-only patient-controlled analgesia to a multimodal approach. This multimodal approach uses drugs of various classes (e.g., NSAIDs, acetaminophen, gabapentenoids, antidepressants, ketamine) along with regional anesthesia to reduce or eliminate the amount of opioids required by the patient. Ketamine has made a resurgence of use in the management of some of our chronic pain patients undergoing orthopedic procedures. Ketamine is typically administered as an infusion during the case and occasionally continued postoperatively with great success. Perioperative infusion rates of ketamine range from 0.15 mg/kg/h to 0.35mg/kg/h. Use of NSAIDs is controversial. They may reduce opioid requirements by up to 40% and reduce the incidence of opioid-related side effects such as nausea, vomiting, sedation, and respiratory depression.[81] However, they may interfere with bone healing.[82] Initial studies using COX-2 inhibitors suggest minimal effect on bone healing, particularly when used for short durations.

In some cases, surgeons insert a catheter under direct vision into the epidural space. Either epidural opioids or opioids in addition to local anesthetics may be infused. Low concentrations of local anesthetics typically are used to avoid a motor block, which may delay accurate diagnosis of motor dysfunction as a complication of surgery.[83]

The majority of patients undergoing spinal surgery can be managed in the postsurgical unit postoperatively. Those who have undergone extensive surgery, experienced significant blood loss, received large fluid resuscitation, or experienced fluid shifts should be monitored postoperatively in an intensive care or stepdown unit. Patients with significant facial and airway edema may require ventilation postoperatively. In addition, patients who have undergone certain cervical and thoracic spinal procedures may require postoperative ventilation; those requiring extensive neurologic monitoring should be cared for in a monitored bed postoperatively.

Neurogenic shock is characterized by loss of sympathetic tone, resulting in hemodynamic instability, as evident from significant hypotension and bradycardia. This may be accentuated by hypovolemia. Shock tends to occur in injuries above the T6 level caused by disruption of sympathetic outflow and unopposed vagal tone. Arterial and central venous pressure monitoring is helpful in the management of these patients. Fluid administration in addition to vasopressors may be required to treat the hypotension along with appropriate management of the bradycardia. Autonomic dysreflexia is a syndrome of sympathetic imbalance that may occur after the phase of spinal shock. It occurs more commonly in males and may result in hypertension associated with myocardial ischemia, retinal or cerebral hemorrhage, and seizures.

Ambulatory Orthopedic Surgery

The 1990s saw a dramatic increase in the number of surgical cases performed in the ambulatory setting. Nearly 60% of all cases now occur as outpatient procedures, with orthopedic surgery accounting for a large number of cases. This trend has huge socioeconomic implications, such as reduced costs, more rapid return to daily activity, and lower risk of nosocomial infections. Shoulder and knee procedures, including shoulder arthroplasty and anterior cruciate ligament repair, occur routinely on an outpatient basis. All ambulatory orthopedic surgical procedures can be performed under general anesthesia. However, these procedures may be most suited for a regional anesthetic technique, and improved analgesia seen in the perioperative period can be safely and effectively extended to the postoperative period with the use of perineural catheters.[84] With more complicated procedures occurring on an outpatient basis, adoption of a multimodal approach to postoperative pain management is essential. This will allow better pain control with the need for less opioid medication, thus reducing the potential for side effects such as nausea and vomiting, which often can derail a timely discharge from the ambulatory center. The cornerstone of these techniques is frequently a peripheral nerve block. New disposable infusion devices allow patients to be discharged with peripheral nerve catheter infusions, further prolonging the effect of a single shot of peripheral nerve block.[85] When general anesthesia is required, the aim should be to provide adequate anesthesia and analgesia while minimizing perioperative-related side effects such as nausea and vomiting.

Postoperative Analgesia in Orthopedics

Limited evidence indicates that improvements in postoperative pain control result in better functional outcome and reduced morbidity and mortality.[40,47] The best approach to postoperative pain management is a multimodal approach of different agents and routes of administration used in a synergistic manner.[86-88] Using a multimodal approach, we have the potential to reduce or eliminate the amount of opioids required by patients and thus reduce side effects such as nausea and vomiting, respiratory depression, and oversedation.[87,89] The cornerstone of any multimodal approach is a regional technique, including epidural and peripheral nerve blocks (see Chapter 48). Subcutaneous injection of local anesthetics is also widely used. Use of intra-articular opioids, such as morphine, after joint surgery is controversial, with some evidence of benefit.[90-95] Use of intra-articular morphine is based on the presence of opioid receptors on peripheral nerve endings within the capsule of joints. Administration of intra-articular opioids produces analgesia only in the presence of inflammation, and it has been postulated that the inflammatory process is necessary for activation of the opioid receptors.[96] Morphine doses between 1 and 5 mg have been shown to have an analgesic effect until 24 hours after intra-articular administration.[97] The side effects normally seen with systemic opioids are not seen with these doses of intra-articular opioids. Cryotherapy devices have been used in both shoulder and knee surgery to further augment postoperative analgesia.[98,99] Nonsteroidal agents play an important role in reducing postoperative opioid requirements.[100] COX-2 inhibitors have largely displaced the nonselective COX inhibitors because of their improved side effect profile with regard to the potential for gastric bleeds and coagulation disturbance. The controversy regarding rofecoxib (Vioxx, Merck & Co., Whitehouse Station, NJ), which was found to result in an increased incidence of death because of myocardial infarcts when used at high doses and for long periods, has significantly reduced the use of other COX-2 inhibitors in the perioperative period.[101] Data are insufficient to recommend the use of other COX-2 inhibitors, such as celecoxib (Celebrex, Pfizer, New York, NY), which should be given with caution in the perioperative period.[102,103] Another important issue with COX-2 inhibitors is their potential to reduce bone healing in animal models. In vitro studies have shown that the presence of COX-2, but not COX-1, is essential for adequate bone healing.[104,105] However, no clinical evidence in humans shows the effect of reduced bone formation, particularly when COX-2 inhibitors are used for short-term treatment.[100]

Factors Related to Orthopedic Surgery

Tourniquets

Tourniquets (derived from the French *tourner*, meaning "to turn") are routinely used in orthopedic surgery to provide a bloodless field. This practice is purported to improve visualization of critical structures and decrease operative blood loss.[106] However, tourniquets have significant risks, and these risks and the strategies to minimize them should be part of the knowledge base of all practicing anesthesiologists.[107]

By inflating a cuff around an extremity, arterial inflow to the extremity distal to the cuff is eliminated. Careful exsanguination of the limb distal to the cuff immediately before cuff inflation, either via application of an elastic Esmarch bandage or elevation of the extremity for 5 minutes, empties the vascular system. The distal limb is thus rendered ischemic, which may have significant physiologic and biochemical implications.

Limb exsanguination causes an increase in central blood volume that is reflected as a transient rise in central venous pressure.[108] This increase in preload can be significant if multiple tourniquets are used, as in simultaneous bilateral knee arthroplasties. Tourniquet inflation also causes an increase in afterload. Patients with diminished cardiac function may not be able to tolerate this combined insult of increased preload and afterload. After tourniquet deflation, preload decreases acutely as blood reenters the affected extremity, which undergoes a period of postischemic reactive hyperemia. This is accompanied by an acute decrease in afterload that often produces hypotension.[109] Reperfusion of an extremity typically is associated with a decrease in core temperature of up to 1.0°C.

During limb ischemia, oxygen and high-energy phosphate stores decrease progressively, and carbon dioxide and lactic acid levels increase as ischemic tissues convert to anaerobic metabolism.[110] The pH of the ischemic limb decreases as the duration of ischemia increases.[111] After tourniquet deflation, aerobic metabolism resumes, with marked increases in oxygen consumption and carbon dioxide production.[112] Systemic partial pressure of carbon dioxide increases in this interval, and pH transiently decreases as a result of combined metabolic and respiratory acidosis.[113] Spontaneously breathing patients increase minute ventilation markedly to compensate. The minute ventilation of mechanically ventilated patients must be increased to minimize the duration and magnitude of hypercapnia. The increase in carbon dioxide tension can produce a marked increase in cerebral blood flow, with potentially deleterious results in patients with increased intracranial pressure.[114] In this setting, it is especially critical to increase minute ventilation in patients who are unable to compensate effectively.

Ischemia of the affected limb causes significant changes on the cellular level. Tissue becomes progressively acidotic while the cuff is inflated.[110] Ultrastructural changes within the endothelium of the ischemic capillaries lead to diffuse capillary leak after reperfusion.[110] In conjunction with reactive hyperemia, significant edema can develop after tourniquet deflation. This can even lead to a compartment syndrome in the affected extremity. The coagulation system undergoes significant changes in the setting of tourniquet use. Platelet aggregation is increased by both tissue compression and pain caused by the surgical insult and the tourniquet.[115] Capillary obstruction by red blood cells and platelets that accumulate during the period of stasis and the concomitant release of inflammatory mediators can lead to microvascular thrombosis, causing no-reflow phenomena and further exacerbating tissue injury.[110] Tissue acidosis also leads to release of tissue plasminogen activator, which causes a brief period of fibrinolysis after tourniquet deflation.[115] This is postulated to play a role in posttourniquet bleeding. Muscle is most susceptible to injury secondary to ischemia, with the duration of ischemia correlating with the severity of injury. Injury is most severe under the cuff as a result of the combined effect of tissue compression and ischemia.[116] Fortunately, these injuries are generally reversible when tourniquet time is not excessive. Rhabdomyolysis has been reported after tourniquet use. A practical guideline is to limit tourniquet time to 2 hours if possible. Experiments have shown that a 10-minute period of reperfusion every hour allows for disposal of accumulated waste products and regeneration of adenosine triphosphate stores in the involved limb, facilitating tissue recovery after completion of surgery and minimizing the extent of muscle injury.[110]

Cuff pressure is the most significant risk factor for nerve injury after tourniquet use.[117] Use of a wider cuff allows arterial occlusion at lower cuff pressures. Conical rather than rectangular cuffs can produce the desired effect at lower inflation pressures.[118,119] Numerous methods for determining the inflation pressure to be used in a particular situation are recommended. Inflating the cuff 50 to 75 mm Hg above the systolic pressure for upper extremity procedures and 100 to 150 mm Hg above systolic pressure for lower extremity operations appears reasonable. Others have recommended empirically determining the appropriate inflation pressure by first ascertaining via Doppler ultrasonography the pressure at which arterial inflow is occluded and then setting the cuff pressure 50 mm Hg higher. Using the lowest pressure possible decreases the risk of nerve injury. The incidence of significant nerve injury in the upper extremity is estimated at 1 in 11000, with radial nerve palsy representing the most common injury; lower extremity nerve injuries are believed to occur at a much lower rate. Most nerve injuries are not permanent and resolve with time.[120] A detailed neurologic examination should be obtained in a timely fashion if such an injury is suspected to document any preexisting dysfunction.

Careful padding of the limb under the cuff with cast padding, with care taken to avoid any wrinkles, decreases the risk of skin injury from compression or pinching. The tourniquet should not be manipulated after it is applied to avoid bunching up the padding underneath the tourniquet. Creating an impervious barrier with adhesive plastic drapes to prevent cleaning solutions from seeping under the tourniquet is helpful in minimizing the risk of skin injury. The vascular system is not immune to injury from tourniquet application. Patients with atherosclerosis appear to be at highest risk for this type of injury. Mechanical forces applied to these vessels are believed capable of fracturing calcified plaque within the vessel wall.[121] This can lead to vascular compromise and potentially to limb loss. Tourniquet use is relatively contraindicated in patients with risk factors for peripheral vascular disease, absent distal pulses, and previous vascular surgery on the operative extremity.[122]

Use of a tourniquet can affect the pharmacokinetics of other drugs given during an anesthetic procedure. Drugs administered before tourniquet inflation can become sequestered in the ischemic limb. When the tourniquet is deflated at the end of surgery, a bolus of that particular drug is delivered to the central circulation.[123] This effect can be significant in elderly patients who have received opioids or benzodiazepines before tourniquet inflation. The volume of distribution is decreased for drugs administered after the tourniquet is inflated. This can produce a greater-than-expected effect from a given dose. Antibiotic administration must be coordinated with tourniquet inflation to ensure that adequate tissue penetration occurs at the surgical site. For most antibiotics, a minimum interval of 5 minutes is recommended between completion of drug administration and tourniquet inflation.[124] Muscle relaxants sequestered in an ischemic limb have not proved to be as significant a problem upon tourniquet release as anticipated.

Tourniquet pain is the final major issue that complicates use of a tourniquet. In an unsedated patient, it presents as dull, aching pain that becomes intolerable within approximately 30 minutes. This time period can be extended somewhat by IV administration of sedatives and analgesics.[125] During a general anesthetic, tourniquet pain manifests as increases in heart rate and both systolic and diastolic blood pressures 45 to 60 minutes after tourniquet inflation.[126] This typically is treated with only limited success by increasing the depth of anesthesia or administering additional analgesics. Ultimately, tourniquet deflation is the only factor that eliminates tourniquet pain, with resolution within 30 minutes. This phenomenon also has been reported during spinal and epidural anesthetics, with an apparently adequate level of anesthesia to pinprick.[127] An adequate level of anesthesia to touch is more predictive of prevention of tourniquet pain. The postulated mechanism for tourniquet pain is a differential conduction block of large myelinated A-δ fibers and small unmyelinated C fibers.

Fat Embolism Syndrome

Fat embolism syndrome (FES) was first described by Zencker in an article published in 1862. Nearly all patients with long bone fractures or patients who have undergone hip or knee replacement surgery experience some degree of fat embolization.[128,129] However, the incidence of clinically significant FES is only 0.5% to 3%.[130,131] The incidence may be higher (30%) in patients with multiple long bone fractures. FES is much more likely to occur with long bone fractures of the lower limb than with fractures of the upper limb. Likewise, the incidence of FES in children is much lower than in adults. Changes in surgeons' preference for early operative reduction and fixation of fractures have led to a marked decreased in FES incidence.

Fracture of the long bone causes an increase in intramedullary pressure. This coupled with disruption of the venous sinusoids within the long bones results in fat and bone debris entering the venous circulation. Manipulation and surgical preparation of the long bones, such as reaming, also can cause an increase in intramedullary pressure and result in fat embolization. Careful attention by the surgeon in clearing the femoral canal with adequate lavage can reduce the incidence of fat embolization (see Methylmethacrylate). Commonly, fat globules lodge in the pulmonary vasculature, resulting in obstruction of pulmonary circulation. Fat globules are hydrolyzed into free fatty acids that are directly toxic to the pulmonary endothelium and pneumocytes, resulting in endothelial damage, platelet adhesion with clot formation, capillary leakage, and perivascular bleeding. Some evidence indicates that elevated C-reactive protein levels resulting from trauma may cause chylomicrons to coalesce and form fat globules. These fat particles may pass into the systemic circulation via intracardiac (foramen ovale) and pulmonary shunts, resulting in cerebral and cutaneous manifestations.

Fat embolism syndrome may present intraoperatively as cardiorespiratory collapse after femoral reaming, insertion of intramedullary cemented prosthesis, or tourniquet release. FES also may present postoperatively as a variety of clinical signs and symptoms. Gurd and Wilson[132] described major and minor features of FES (**Table 65-4**). To make the diagnosis of FES, at least 1 major and 4 minor features must be present. The 3 major symptoms of FES are respiratory distress, cerebral manifestations, and petechial rash. The minor symptoms are fever, renal damage, retinal changes, hemolysis, lipuria, and jaundice. The Gurd and Wilson criteria were criticized for not including assessment of the patient's oxygenation with the use of an arterial blood gas, which may be a useful early indicator of FES. The criteria of both Schonfeld et al[133] and Lindeque et al[134] include the measurement of arterial blood gases to determine the presence of hypoxemia. Respiratory distress consists of tachypnea, hypoxia, and hyperventilation and is seen in 75% of patients with the syndrome.[135] The majority of patients present with Po_2 below 50 mm Hg. Chest radiographs classically show bilateral diffuse infiltrates, especially in the upper and middle lobes of the lung. Pulmonary function usually resolves in 7 days. Approximately 10% of patients require mechanical ventilation for respiratory failure. Cerebral involvement consists of a wide range of clinical symptoms, such as confusion, convulsions, drowsiness, and coma, and normally is present in 86% of presenting cases.[129] Petechial rash classically involves the conjunctiva, mucous membranes, and skin on the anterior aspect of the chest and neck and likewise is seen in 50% to 60% of cases.[132] Classically, these symptoms and signs do not present within the first 6 to 12 hours after the insult. Onset after 72 hours from the insult is unusual. The best treatment of this condition is prevention by early surgical reduction and immobilization of the fracture site. Management consists of supportive care that may include ventilation. Adequate fluid resuscitation is essential and may lessen the severity of the presentation. Steroids to reduce the inflammatory response caused by free fatty acids have long played an important role in the management of this condition, but studies that steroids are not as effective as previously believed.[136,137] There is no evidence supporting the use of heparin or IV alcohol in the management of FES. The overall mortality rate is high (7%-20%), and death normally is related to pulmonary involvement.[129]

Table 65-4 Major and Minor Features of Fat Embolism Syndrome[a]

Major features	
	Respiratory distress
	Cerebral changes
	Petechial rash
	Arterial blood gas[b]
Minor features	
	Fever
	Renal damage
	Retinal changes
	Hemolysis
	Lipuria
	Jaundice

[a]As described by Gurd and Wilson.[132]

[b]Not an original major feature but added by Schonfeld et al[133] and Lindeque et al[134] in their classifications.

Methylmethacrylate

Use of cement, with its main component of methylmethacrylate (MMA), has been linked to a clinical scenario consisting of hypotension, bronchoconstriction, hypoxia, cardiac arrest, and sudden death. The terms *bone implantation syndrome* and *bone cement implantation syndrome* have been coined to describe this phenomenon. A study has shown rates of death in hip arthroplasty procedures between 0.02% and 0.5%.[138] These rates initially were believed to be attributable to a hypersensitivity reaction to the MMA, resulting in acute vasodilatation and cardiac collapse. MMA given during in vitro studies has been shown to result in vasodilatation; however, plasma levels during use of MMA in clinical practice have been found to be 10- to 20-fold below the levels required to cause clinically significant vasodilatation and hypotension.[139] It has become clear that the phenomenon is caused by embolization of fat particles and debris from the intramedullary canal of long bones during their manipulation, reaming, and cementing. During these procedures, intramedullary pressures may exceed pressures within the medullary venous plexuses, resulting in fat and debris entering the venous system. Use of transesophageal echocardiography can clearly demonstrate the increased load of debris entering the right atrium during cementing of the long bones.[140] Intramedullary pressure peaks are 680 mm Hg in humans with cement use compared with peaks below 100 mm Hg with noncemented arthroplasties.[141] In an attempt to minimize increased intramedullary pressure, orthopedic surgeons have used various techniques, such as new cementing devices, drilling distal venting holes within the long bones, and aggressive lavage of the canal before insertion of the cement and prosthesis to reduce the amount of intramedullary debris. The technique of venting results in significant extravasation of cement, and none of the techniques has been found to reliably prevent this phenomenon. Some surgeons use uncemented techniques for joint replacement procedures. Cemented prosthesis and the need for revision procedures have made the use of uncemented devices more appealing to surgeons. Clinical signs of bone implantation syndrome or bone cement implantation syndrome are similar to those found in PE or fat embolism. They include fever, tachycardia, hypotension; hypoxemia, and, in spontaneously breathing patients, dyspnea and tachypnea; end-tidal carbon dioxide may decrease with a large embolus. Other signs of fat emboli also may be seen. The electrocardiogram may show right-axis deviation or right bundle branch block. These signs reflect increased pulmonary artery pressure and intrapulmonary shunt, potentially leading to right ventricular failure and cardiac arrest.

Management of this phenomenon is similar to that caused by fat emboli. It requires both support of the cardiovascular system with aggressive fluid management and inotropic and vasopressor support. Oxygen therapy and ventilation often are required, depending on the severity of the response.

Deep Vein Thrombosis

The incidence of DVT in unprotected patients can be extremely high, varying between 80% and 90%, with a 2% incidence of fatal PE in hip and knee replacement surgery.[142] Hip fractures have an even higher occurrence of fatal PE with an incidence of 4% to 7%.[143] Whereas hip replacement surgery typically results in thrombosis of vessels above the knee, knee replacement surgery commonly involves vessels below the knee. Fatal PEs are normally associated with thrombosis above the knee. The Virchow triad has classically been used to describe the etiology of DVT. The 3 main causes of DVT are prolonged stasis, damage to the intima of blood vessels, and increased viscosity of blood. All of these factors may play a role in causing DVT in joint replacement surgery, but the problem is increased greatly for 2 reasons: extended use of tourniquets in total knee replacements, and distortion of lower limb blood vessels during manipulation and preparation of both the femur and tibia. This increase has necessitated the use of a variety of pharmacologic drugs and pneumatic devices to reduce the high incidence of DVT. Different regimens are used at various of institutions, with no best way to manage this problem. Whether warfarin (Coumadin) is superior to LMWH or vice versa is controversial.[143-145] In a study by Freedman et al,[143] the risk of proximal DVT was lowest with warfarin (6.3%) compared with LMWH (7.7%), but no differences in the incidence of PE and mortality were noted. Miric et al[144] found that LMWH was better than warfarin in preventing DVT in total hip replacements (4% vs 12%, respectively). What is clear is that use of unfractionated heparin does not offer sufficient DVT prophylaxis in patients undergoing joint replacement procedures and that LMWH compared with warfarin is classically associated with an increased incidence of minor and major wound blood loss.[143,146] According to the latest recommendations from The Seventh American College of Chest Physicians Consensus Conference, only warfarin, fondaparinux, and LMWH are adequate forms of DVT prophylaxis when used alone for hip or knee replacement surgery.[147] Pharmacologic agents should always be combined with mechanical prophylaxis, which should begin intraoperatively if possible. Mechanical prophylaxis should be used alone only when there is a significant risk of bleeding. Use of the newer anticoagulants, particularly LMWH, has resulted in the need for anesthesiologists to modify their anesthetic plan. Vandermeulen[148] demonstrated a significant increase in the incidence of epidural hematomas if epidural anesthesia is used in conjunction with LMWH. This finding resulted in the addition of an FDA black box warning to LMWH prescribing information and a review of the current practice of regional anesthesia, particularly neuroaxial anesthesia and analgesia in the presence of certain anticoagulants.[149] The ASRA has developed guidelines for the use of regional techniques in the presence of a variety of anticoagulants.[34] The guidelines include not performing a neuroaxial technique within 12 hours after a dose of LMWH and waiting 2 hours after removal of an epidural catheter before initiating LMWH. This guideline has severely limited the use of epidural anesthesia for postoperative pain and resulted in the development of a number of new techniques (discussed earlier in this chapter in the section on anesthesia for extremity surgery and in the section on blood loss).

Compartment Syndrome

Volkmann first described compartment syndrome in 1881. The disfigurement of the upper limb that may result from the condition is still called a Volkmann contracture. Compartment syndrome is one of the most litigated topics in orthopedic surgery. A variety of injuries and medical conditions may initiate an acute compartment syndrome, including fractures, contusions, bleeding disorders, reperfusion injuries, burns, and trauma. Fractures of the tibial shaft are the most common fractures associated with compartment syndrome, accounting for 40% of cases, followed by forearm fractures, which account for 18%.[150] However, many cases of compartment syndrome can occur in the absence of a fracture and are solely related to soft tissue damage (23%). Compartment syndrome occurs when the pressure within an osseofascial compartment increases to a level that decreases the perfusion gradient across tissue capillary beds, leading to cellular anoxia, muscle ischemia, and death, with eventual replacement of the muscle with fibrous tissue, leading to contractures and a nonfunctional limb. The normal compartmental pressure is less than 10 to 12 mm Hg, with compartmental perfusion pressures normally greater than 70 to 80 mm Hg. Compartmental perfusion pressures can be calculated by subtracting compartmental pressures from mean arterial pressures. Thus, increasing compartmental pressures and decreasing mean arterial pressures can lead to a situation in which the compartment perfusion pressure is inadequate. It is not possible to determine the compartmental pressure value critical to perfusion because compartmental pressure at which perfusion problems occur can vary greatly among individuals. Delta p (Δp), which is diastolic pressure minus intracompartmental pressure, is much more reliable in determining the need for fasciotomy.[151] Δp below 30 mm Hg in the presence of clinical signs of compartment syndrome requires a fasciotomy. Diagnosis is primarily clinical, supplemented by compartment pressure monitoring (**Fig. 65-7**). Signs include pain, especially with passive stretching of the involved muscle group, pallor of the limb, lack of a distal pulse, a cold limb, paresthesia, paralysis, and a swollen and tense compartment.[152] The presence of a distal arterial pulse does not exclude the presence of compartment syndrome. These signs can be reliably diagnosed only in fully conscious patients. Patients who are unconscious or sedated should be monitored with continuous compartment pressures, and sometimes a prophylactic fasciotomy is needed. Complete fasciotomy of all compartments involved is required to reliably normalize compartment pressures and restore perfusion to affected tissues. Recognizing compartment syndromes requires having and maintaining a high index of suspicion, performing serial examinations in patients at risk, and carefully documenting changes over time. The earlier the diagnosis, the better the outcome, with neural structures being much more at risk than muscle. Anesthesiologists must be aware of this condition to allow for early diagnosis. Compartment syndrome should be considered in any patient in whom the intensity of pain is out of proportion to the injury and in any patient with a long bone fracture who is not responding to normal amounts of analgesia. In choosing the anesthetic technique for cases that normally are associated with compartment syndrome, the anesthesiologist must avoid any postoperative technique, such as epidurals or peripheral nerve blocks, that may delay diagnosis of the syndrome. If these techniques are used and there is a potential for compartment syndrome, consideration should be given to continuously monitoring compartment pressures. The effect of anesthetic techniques, such as spinals and epidurals, that cause sympathectomy (and thus vasodilatation) is unclear. The increased blood flow to muscle compartments may cause a further increase in compartment pressures. What is clear is that in cases of suspected or potential compartment syndrome, the anesthesiologist should maintain a high mean arterial blood pressure during the case. Use of mannitol has been shown to reduce the occurrence of compartment syndromes in revascularization cases and may be of help in other patients with compartment syndrome.

Figure 65-7.

Source: Longnecker DE, Brown DL, Newman MF, Zapol WM: *Anesthesiology, 2nd Edition*: www.accessanesthesiology.com

Compartment pressure monitoring.

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