Pain Management After Major Orthopaedic Surgery: 
Current Strategies and New Concepts

Raymond S. Sinatra MD, PhD, Jaime Torres, MD, and Arsenio M. Bustos, MD

Abstract

Several recently developed analgesic techniques effectively control pain after major orthopaedic surgery. Neuraxial analgesia provided by epidural and spinal administration of local anesthetics and opioids provides the highest level of pain control; however, such therapy is highly invasive and labor intensive. Neuraxial analgesia is contraindicated in patients receiving low-molecular-weight heparin. Continuous plexus and peripheral neural blockades offer excellent analgesia without the side effects associated with neuraxial and parenteral opioids. Intravenous patient-controlled analgesia allows patients to titrate analgesics in amounts proportional to perceived pain stimulus and provide improved analgesic uniformity. Oral sustained-release opioids offer superior pain control and greater convenience than short-duration agents provide. Opioid dose requirements may be reduced by coadministration of COX-2–type nonsteroidal analgesics.


Pain is one of the most common complaints made by patients, yet in some circumstances, pain is treated inadequately. Patients recovering from major orthopaedic and trauma surgery are among those who historically have experienced analgesic underadministration and inadequate pain relief. More than 75% of adult patients treated with on-demand doses of narcotic may experience moderate to severe pain as a result of delays or improper route of administration. Analgesic underadministration may be the result of inadequate pain assessment or lack of physician education. Many physicians have little knowledge of opioid pharmacology and underestimate effective dose ranges while overestimating analgesic duration and risks of overdose. This inadequacy of pain management should be addressed. Recent therapeutic breakthroughs, including the introduction of potent analgesics and more efficient methods of administration, have improved the safety and effectiveness of postoperative pain management.

Pathophysiologic Responses to Poorly Controlled Pain

The American Pain Society defines pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage.” Patient reaction to poorly controlled postoperative pain can include a wide range of physical and emotional responses. Physiologically, pain perception reflects the activation of nociceptors after thermal, mechanical, or chemical injury to tissue, afferent transmission to the spinal cord, and relay via the dorsal horn to higher cortical centers. Pain perception has two major components: the sensory discriminative component, which describes the location and quality of the stimulus, and the affective-motivational component, which underlies the emotional effects of pain and is responsible for learned avoidance and other behavioral responses.

In addition to ethical and humanitarian reasons for minimizing pain, lack of its control can result in anxiety, sleeplessness, and release of catecholamines (Fig. 1). All of these factors can have a deleterious effect on postoperative outcome, particularly in the elderly or critically ill. Pathophysiologic responses known to increase pain intensity while having adverse effects on key organ function include peripheral

Dr. Sinatra is Professor, Department of Anesthesiology, Yale University School of Medicine, New Haven, CT. Dr. Torres is Resident, Department of Anesthesiology, Yale University School of Medicine. Dr. Bustos is Resident, Department of Anesthesiology, Yale University School of Medicine.

Reprint requests: Dr. Sinatra, Department of Anesthesiology, Yale University School of Medicine, 333 Cedar Street, New Haven, CT 06520-8051.

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sensitization, neuroendocrine responses, sympathoadrenal activation, and chronic pain.

**Peripheral Sensitization**

Musculoskeletal injury is accompanied by the escape of intracellular potassium ions ($K^+$) and the release of bradykinin, serotonin, and prostaglandin E2. Bradykinin and prostaglandin stimulate release of a nociceptive chemical, substance P, which in turn sensitizes additional nociceptors at sites adjacent to the injury. This process of recruitment and sensitization of peripheral nerve endings underlies hyperalgesia, an altered state of sensibility in which the intensity of pain sensation induced by noxious stimulation is greatly increased. This situation may be exacerbated by movement or ambulation.

**Neuroendocrine Responses**

Nociceptive impulses alter the activity of the hypothalamus, adrenal cortex, and medulla. These changes, the neuroendocrine or “stress response” to injury, are characterized by an increased secretion of catabolic hormones such as cortisol, glucagon, growth hormone, and catecholamines. These alterations mediate enhanced mobilization of substrate, hyperglycemia, and a negative nitrogen balance. This catabolic response leads to muscle wasting, impaired immunocompetence, and decreased resistance to infection.

**Sympathoadrenal Activation**

Surgical injury is associated with marked increases in plasma epi-
nephrine and norepinephrine concentrations. Increased sympathetic tone has been associated with an increased risk of perioperative myocardial ischemia in patients with poorly compensated coronary artery disease. Severe pain is commonly associated with an impaired ability to ambulate and with decreased venous flow. Catecholamines, angiotensin (PAI-1), and other factors associated with surgical stress increase platelet-fibrinogen activation, while surgery, trauma, or even surgical positioning can impede venous return from the lower extremities. These factors underlie Virchow’s triad of venous stasis, hypercoagulability, and endothelial injury, increasing the risk of clot formation, deep vein thrombosis, and pulmonary embolus.

Chronic Pain
Humoral and neurologic alterations in and around the site of injury may be responsible for increased postoperative discomfort and disability. Continued activation of nociceptors secondary to neural compression, stretch, infection, hematoma, and tumor can explain ongoing or progressive worsening of acute pain as well as prolonged disability and impaired rehabilitation. In these settings, continued periosteal and muscle irritation may initiate reflex motor responses that lead to spasm and myofascial pain. Heightened reflex activity in sympathetic efferent fibers results in vasoconstriction and nociceptor sensitization. Alterations in blood flow and effluent outflow may be responsible for sympathetically maintained pain and persistent pain syndromes.

Variables That Influence Acute Pain Management
Although opioid analgesics are frequently administered on the basis of mg/kg of body weight, no evidence links body weight and individual dose requirement. Age and degree of pain relief after administration of a given dose are the most important variables in determining dose response. Advancing age is generally associated with enhanced opioid sensitivity and significant decreases in opioid consumption. Studies of patient-controlled analgesia (PCA) provide conflicting results of the importance of sex on opioid dose requirements. In addition, the site, extent, and duration of surgery can greatly influence the intensity of postoperative pain and of analgesic requirements. Ankle surgery, total knee replacement, and spinal fusion are among the most painful forms of orthopaedic surgery; pelvic and hip surgery are associated with lower pain scores.

Reaction to pain is a conditioned behavior that reflects cultural values; appreciating such cultural conditioning can help in assessing a patient in pain. Patients can be divided into two broad categories: stoic, in which the patient expresses minimal discomfort vocally, and emotive, in which the patient is quite vocal. Highly aggressive and angry patients tend to consume more medication than do patients whose coping styles are more passive. Patients with a history of chronic pain and notable opioid tolerance require increased amounts of drug to compensate for both baseline requirements and analgesic needed to control pain after surgery.

Caregivers tend to limit opioid administration in patients with a history of substance abuse. Because self-administered intravenous boluses may reinforce drug-seeking behavior, PCA is often withheld from these individuals and neural blockade or epidural analgesic techniques substituted. However, well-supervised self-administered therapy by patients with a history of alcohol, cocaine, and heroin abuse may be permitted because it does not appear that drug-seeking behavior is reinforced in these patients.

Declining levels of cardiac, hepatic, and renal function are often associated with notable alterations in the volume of distribution, clearance, and excretion of most analgesic agents. For analgesics with high hepatic uptake and clearance, reductions in hepatic blood flow are accompanied by proportional decreases in the overall extraction rate and prolonged pharmacologic effects. Agents that undergo biotransformation or are eliminated by the kidneys can produce serious adverse events in patients with renal failure unless dose adjustments are made.

Techniques of Pain Management
Optimal pain control is an individualized prescription that considers the following factors: the physiologic and psychological states of the patient, the pathophysiologic alterations that result from the surgery, and the technical and economic resources available during recovery. Oral and intramuscular administration of opioids, and intravenous patient-controlled analgesia (IV PCA), remain the therapies of choice for many patients recovering from orthopaedic surgery. Intermittent dose and continuous epidural analgesia may be offered to patients recovering from more extensive or painful surgery. These techniques use solutions of local anesthetics, opioid analgesics, or both. Patient-controlled epidural analgesia is used when epidural infusion plus on-demand dosing offers advantages, such as during vigorous physical therapy. Regional nerve blockade, including peripheral nerve blockade, continuous plexus block, and intra-articular techniques, may be used as primary therapy or as
supplementation to opioid analgesia.

Although prn analgesic regimes administered intramuscularly and orally are the mainstay of acute pain management, the results of several studies have documented inadequacies with such therapy. A major deficiency of this type of analgesia relates to the timing of the dosing; patients often wait too long to request pain relief and staff may not be able to deliver medication immediately. Prn dosing is not as effective as other methods for maintaining therapeutic plasma concentrations. Prn dosing every 3 to 4 hours involves an elaborate sequence of events that delays administration and results in repetitive cycles of increasing pain (Fig. 2). Because pain may not be considered an emergency, the length of time patients wait for analgesia depends on the nursing workload at the time of the request. Once the nurse has responded, he or she usually screens the complaint to assess whether the patient really needs additional pain medication. Despite published research indicating that physical dependence occurs in fewer than 0.1% of hospitalized patients, this screening is done presumably to avoid opioid abuse. When the level of pain is deemed sufficient to warrant treatment, the nurse must sign out the medication, prepare an injection, and administer the dose. These steps delay the onset of effective relief and worsen pain-induced anxiety, helplessness, and sleep deprivation. Because the dose administered is relatively large and the absorption erratic and prolonged, the initial analgesic effect is often followed by sedation and some degree of respiratory depression.

Oral Analgesics

Oral administration of analgesics is a safe, simple, and cost-effective method of controlling pain. It should always be considered in patients who experience moderate discomfort and tolerate oral diet. However, alterations in gastrointestinal function after general anesthesis or major trauma may reduce the reliability and effectiveness of oral therapy.

Oral opioids, as well as compounded narcotic preparations (containing acetaminophen or aspirin) provide effective relief for patients with moderate to severe pain. Orally administered morphine and meperidine are poorly absorbed and undergo substantial enterohepatic metabolism. Therefore onset is delayed, duration is less predictable, and dose requirements are high—two to three times higher than parenteral requirements. Oxycodone has higher oral effectiveness because it is more reliably absorbed and is less likely to undergo first-pass hepatic metabolism. Sustained-release opioid preparations offer less frequent administration intervals, avoid frequent peak-and-trough plasma levels, and provide greater analgesic uniformity. These preparations provide 8 to 12 hours of pain relief and are ideally suited for patients suffering discomfort during rehabilitation and those with chronic pain.

During the past 2 years, controlled-release oxycodone has been increasingly prescribed for pain control in acute postoperative settings. Ginsberg et al. determined the oral analgesic equivalency of controlled-release oxycodone to patient-controlled intravenous morphine in patients recovering from orthopaedic and other types of sur-

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**Figure 2** The traditional acute pain cycle as managed with intramuscular or intravenous prn doses of opioid analgesics compared with patient-controlled analgesia (PCA), which minimizes delays in dispensing analgesics (nursing variables) as well as in uptake and distribution variables, thereby eliminating the cycle. (Adapted with permission.)

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gical procedures. The dose of controlled-release oxycodone needed to maintain effective pain control was 1.3 times the previous day’s total dose of intravenous morphine. Others have suggested that the relationship is closer to 1:1. For example, if a patient requires a total of 40 mg of morphine, then the initial dose of controlled-release oxycodone would be 20 mg twice a day. Sustained-release opioids may be used as a transition analgesic in patients treated with epidural analgesics. In this setting, oral controlled-release oxycodone is started 1 to 2 hours after discontinuance of the epidural infusion or as soon as the patient notices a slight increase in pain intensity. Onset of analgesia is within 30 to 60 minutes, and highly uniform pain relief is maintained for 10 to 12 hours. The early introduction of controlled-release oxycodone is generally well tolerated and may allow the duration of epidural therapy to be shortened while minimizing the need for parenteral analgesics. Transdermal fentanyl in dosing ranging from 25 to 75 μg/h may be used in patients allergic to oxycodone.

The effectiveness of controlled-release oxycodone compared with doses of immediate-release oxycodone given prn and by the clock were evaluated in patients recovering from surgery for anterior cruciate ligament reconstruction. The patients who received the controlled-release formulation required less drug and experienced superior pain control as well as a reduction in opioid-related side effects such as nausea, vomiting, sedation, and sleep disturbance. However, patients treated with opioid preparations are at higher risk for ileus and constipation.

Less potent analgesics, including tramadol, a weak, nonhabituating opioid, and a variety of nonsteroidal anti-inflammatory drugs (NSAIDs), may be prescribed in patients with mild to moderate pain and as supplements to patients treated with regional neural blockade. Many orthopaedic surgeons avoid the use of NSAIDs, however, after total joint replacement, spinal fusion, and fracture fixation because data suggest that they may impair bone growth and repair, resulting in higher nonunion rates. The new class of NSAIDs, the cyclooxygenase-2 (COX-2) inhibitors, selectively block the COX-2 isoenzyme, thereby inhibiting prostaglandin synthesis after tissue injury. Unlike other NSAIDs, COX-2 inhibitors do not block COX-1, which maintains platelet function and gastric mucosal integrity. Following long-term use of COX-2 inhibitors, the incidence of gastric ulcer is similar to that observed with placebo and is substantially lower than that observed with nonselective NSAIDs. COX-2 inhibitors are contraindicated in patients with chronic renal failure and others with prerenal azotemia. The COX-2 inhibitors have no effect on bleeding time, and their safety and effectiveness, demonstrated in several postorthopaedic surgical models, are equivalent to those of NSAIDs in reducing pain intensity and opioid dose requirements in patients recovering from orthopaedic surgery.

Gimbel et al compared the safety and effectiveness of the COX-2 inhibitor celecoxib with those of an opioid compound. They reported that a single oral dose of celecoxib 200 mg provided a similar onset and overall quality of analgesia as those observed with hydrocodone 10 mg/acetaminophen 1,000 mg in patients with moderate to severe postorthopaedic surgical pain. Celecoxib was associated with a lower incidence of adverse events than was hydrocodone/acetaminophen. Reuben and Connelly evaluated the benefits of single preoperative doses of rofecoxib 50 mg or celecoxib 200 mg versus placebo in patients recovering from spinal fusion surgery. Both COX-2 inhibitors reduced patient-controlled intravenous morphine consumption and improved pain intensity during the first 4 to 8 hours after surgery. After this interval, analgesic effect in the celecoxib-treated patients was indistinguishable from that in patients who received placebo. However, patients treated with rofecoxib continued to benefit from reduced morphine requirements and lower pain scores for 24 hours. Of importance was the finding that patients treated with COX-2 inhibitors did not experience increased postoperative bleeding.

Parenteral Therapy

Morphine effectively blocks pain after severe musculoskeletal injury and is commonly used in patients recovering from orthopaedic surgery. Onset of analgesia occurs within 5 minutes after intravenous and 15 minutes after intramuscular administration; duration ranges from 2 to 4 hours depending on dose and site of administration. Administration of morphine may release histamine and has been associated with hypotension and biliary colic.

Meperidine and hydromorphone are useful alternatives in patients intolerant of the adverse effects of morphine. The parenteral potency of meperidine is one tenth that of morphine, with a duration of effect only two thirds as long. Doses exceeding 1 gm/day may result in seizures secondary to accumulation of its metabolite, normeperidine. Hydromorphone is approximately five times as potent as morphine and has a more rapid onset of analgesia and lower incidence of adverse effects. Fentanyl is a potent analgesic advocated for use in patients with marked hemodynamic instability or individuals highly tolerant of opioid analgesics. Bolus doses of fentanyl (50 to 200 μg) and intravenous infusions (50 to 200 μg/h) are particularly useful in pa-
tients who remain intubated. The major complications associated with parenteral opioids include constipation, increasing sedation, and progressive respiratory depression.

Ketorolac is a potent NSAID available as a parenteral formulation. Ketorolac reduces pain intensity by its nonselective reduction of prostaglandin synthesis at the peripheral site of injury as well as by its effects on pain processing in the central nervous system. Ketorolac in doses of 30 to 60 mg is as potent as morphine 10 mg and is particularly useful in managing posttraumatic musculoskeletal pain. Although ketorolac is not associated with excessive sedation or respiratory depression, major side effects include increased risk of hemorrhage, gastric ulceration, and renal toxicity. To minimize these complications, the ketorolac dose should be limited to 7.5 to 15 mg every 6 hours for a maximum of 48 hours (Fig. 3).

Intravenous Patient-Controlled Analgesia

IV PCA allows patients to titrate small doses of pain medication in amounts proportional to a perceived pain stimulus. The technique avoids cycles of excessive sedation and ineffective pain control observed with by-the-clock and prn intramuscular dosing and limits variability related to inappropriate screening and drug absorption (Table 1). Patients control dose frequency (within prescribed limits) and thereby correct for individual differences in pain perception, administration delays, and variabilities in pharmacokinetics (Fig. 4).

IV PCA systems are based on a number of assumptions, the first being that opioid side effects occur at higher brain concentrations than do those needed to produce analgesia. Although massive opioid doses theoretically could eliminate all pain (but with unacceptable levels of respiratory depression), an adequate level of analgesia usually represents a compromise between tolerable pain and troublesome side effects. A second assumption is that pain intensity is rarely constant. Postoperative pain is intensified by movement and physical therapy, and it seems to have a circadian rhythm, with increasing pain at night.

Commercially developed IV PCA systems incorporate microprocessors that allow the patient to interact with an infusion pump connected to his or her established intravenous line. Patients activate the pump by pressing a button connected to the apparatus. A preprogrammed amount of opioid (incremental bolus dose) is administered over 10 to 30 seconds. A lockout interval then begins, thereby preventing a second dose from being delivered within a preset time interval. A prolonged lockout interval or inadequate incremental bolus may diminish analgesic effectiveness. Conversely, too large an incremental dose increases the number of treatment failures related to intolerable side effects. Patients inevitably find themselves titrating pain against sedation, excessive nausea, or other opioid side effects. They are usually willing to accept some amount of pain to have a clear sensorium.

The key to successful initiation of IV PCA is the administration of an opioid loading dose, which provides a baseline plasma concentration of analgesic that can then be augmented by patient-controlled boluses. In general, a loading dose of 5 to 15 mg of morphine or 0.5 to 3 mg of hydromorphone is titrated to patient comfort (Table 2). Morphine remains the standard and most widely administered patient-controlled analgesic. Nevertheless, its delay to peak analgesic effect and associated adverse events, including...
sedation and histamine release, are drawbacks. Other opioids used for IV PCA are listed in Table 2.

More sophisticated IV PCA devices incorporate a continuous rate (basal) infusion plus patient-activated bolus doses on demand. This form of administration is generally offered to patients recovering from extremely painful procedures and individuals presenting with opioid tolerance and chronic pain. Patients receiving basal opioid infusions should be carefully observed because the continued delivery of opioid reduces the inherent safety of PCA and may result in patients becoming progressively more sedated.

Two common reasons why patients become dissatisfied and fail PCA include inadequate analgesia and excessive nausea/vomiting. Patients must be trained to treat pain before the stimulus becomes overwhelming. For example, incremental boluses should be administered before physical therapy or any form of movement that might increase discomfort. Patients also must understand that IV PCA may not completely eliminate their pain. They should ask for medication if side effects are experienced or call the nurse or pain service, but they should not stop using the device. Finally, concerned relatives should never push the device button for the patient.

**Spinal Opioid Analgesia**

Many studies confirm the high analgesic efficacy of intrathecal and epidural administration of opioids, and such therapy has gained favor for controlling severe pain after orthopaedic procedures. Following epidural injection, a portion of the dose crosses the dura to enter the cerebrospinal fluid. A small fraction of opioid molecules binds to receptors in the dorsal horn, effectively blocking pain transmission at the first synapse in the central nervous system. Epidural and intrathecally administered opioids provide greater analgesic potency than do similar doses administered parenterally. In general, hydrophilic opioids such as morphine and hydromorphone exhibit the greatest potency gain, whereas epidural doses of highly lipophilic opioids are similar to intravenous dosing requirements. A second advantage of spinal opioids is the "selectivity" of the analgesic effect, which is maintained in the absence of motor or sympathetic blockade.

**Single Boluses of Epidural or Intrathecal Opioids**

Morphine was the first opioid to receive US FDA approval for epidural and intrathecal use, and it remains the most widely investigated and extensively used spinal opioid. A single intrathecal bolus (0.25 to 0.5 mg) or multiple epidural boluses (2.5 to 5 mg) of morphine...
are commonly used to control pain after trauma and lower extremity surgery. Doses usually are administered via spinal needles or epidural catheters. The superiority of epidural morphine analgesia (as determined by descriptive and visual analog scores) over pain relief offered by parenteral opioids has been demonstrated in a variety of postoperative settings. In general, analgesic onset is appreciated after 30 to 60 minutes, peak effect is attained at 90 to 120 minutes, and duration ranges from 12 to 24 hours. On average, the 24-hour analgesic requirement is reduced to one tenth that of the parenteral dose. However, although this method of administration provides effective analgesia and does not require sophisticated delivery systems, cerebral spinal fluid concentrations of opioid rise abruptly after each epidural or spinal bolus and may result in a high incidence of annoying and occasionally serious adverse effects.

Continuous Epidural Analgesia

Continuous “low dose” infusion of epidural opioids has been advocated as a method to control postoperative pain. Continuous infusion permits analgesia to be more precisely titrated to the level of pain stimulus and rapidly terminated if problems occur. The technique avoids the peak cerebrospinal fluid concentrations that follow intermittent epidural boluses and reduces the risk of rostral cerebral spinal fluid spread and delayed respiratory depression. Other benefits, in comparison with intermittent dosing techniques, include decreased time spent administering agents and assessing effect, and a reduced risk of contamination and medication errors. Continuous infusion techniques also provide greater therapeutic versatility and a reduced side-effect profile.

Epidural infusion of local anesthetics such as bupivacaine or ropivacaine offers reliable, segmental, and effective analgesia. The technique is useful in patients who are exquisitely sensitive to opioid-related adverse events; however, such therapy may be associated with sensory/motor and sympathetic blockade. Hypotension and impaired micturition occur more frequently with epidural local anesthetics than with opioids. To maximize effective pain relief at rest and with movement, and to reduce unacceptable side effects, the epidural tip should be placed at the dermatomal level of the surgery (eg, L2-3 for hip surgery). Analgesia is maintained with dilute solutions of bupivacaine (0.1% to 0.125%) or ropivacaine (0.2%) continuously infused at rates of 5 to 12 mL/h.

Continuous epidural infusions of morphine or hydromorphone, alone or in combination with dilute bupivacaine, offer effective epidural analgesia for patients recovering from a variety of surgical procedures. Chaplcn et al noted that patients treated with hydromorphone experienced effective pain relief and less sedation and pruritus than did patients who received continuous infusions of morphine. Lipophilic opioids are commonly administered as continuous epidural infusions because their rapid onset and short duration facilitate analgesic titration. Patients who receive continuous epidural infusions of fentanyl plus bupivacaine 0.1% to 0.3% after orthopaedic surgery experience highly effective pain relief.

Patient-Controlled Epidural Analgesia

Patient-controlled epidural analgesia offers higher analgesic efficacy and lower dose requirements than does IV PCA and provides greater control and patient satisfaction than do either single-dose or continuous infusions of epidural opioids. In studies comparing different analgesic techniques, epidural opioids provided the lowest pain scores; however, rather surprisingly, patients preferred IV PCA overall. The reason was that patients self-administering intravenous analgesics experienced fewer troublesome side effects, achieved more uniform and sustained analgesia, and enjoyed greater autonomy.

The latency-to-peak effect and risk of delayed-onset respiratory depression of morphine represent undesirable characteristics for patient-controlled epidural analgesia; therefore, hydromorphone and more lipophilic opioids such as fentanyl, which offer greater titratability, have become the agents of choice in this setting.

Adverse Events and Contraindications of Neuraxial Analgesic Techniques

Epidural and intrathecaly administered opioids are associated with a number of annoying and occasionally serious adverse effects, including pruritus, nausea, urinary retention, somnolence, and respiratory depression. Treatment protocols have been developed that can decrease the incidence and severity of side effects and improve patient safety while maintaining effective analgesia. The presence of side effects should be assessed frequently and treated quickly to minimize morbidity and patient dissatisfaction.

Pruritus and nausea are the most common side effects associated with the use of epidural or spinal opioids; however, respiratory depression is the most serious complication. Respiratory depression after administration of epidural or intrathecal morphine occurs at two different intervals. An early mild phase observed soon after administration is followed by delayed depression that occurs between 8 to 12 hours later. Mild depression of response to CO₂ is common after administration of 3 to 5 mg of mor-
Drug-Related Factors | Patient-Related Factors
--- | ---
The use of morphine | Age >60 yr
Excessive dose | Debilitated individuals
Large volume of injectant | Coexisting respiratory disease
Excessive dose frequency | Raised intrathoracic pressure
Concomitant administration of parenteral opioids | Trendelenburg position

Neural Blockade for Acute Pain Management

Peripheral neural blockade minimizes exposure to opioids and is ideally suited for patients sensitive to opioid-induced ileus and bowel obstruction. Other indications include avoidance of opioid-induced ventilatory depression, particularly in patients with underlying pulmonary disease. Peripheral neural blockade may be provided by infiltration techniques, intra-articular block, isolated nerve block, or plexus block. Infiltration techniques use injections of local anesthetic at the site of surgery and offer several hours of postoperative analgesia. A number of single-dose and continuous infiltration catheter techniques have been described. Injection into the wound requires surgical infiltration of concentrated local anesthetic solutions into the skin, subcutaneous tissues, or joint capsule. This technique is commonly used to control pain after superficial and arthroscopic procedures. Continuous infiltration techniques use multi-hole 19-gauge catheters to continuously infuse either 0.125% or 0.25% bupivacaine under the skin and muscle layers of the incision. Pain related to iliac crest–spine bone graft harvest may be effectively controlled with local infiltration. The technique requires a 19-gauge catheter to be placed into the donor bony graft site and 0.125% bupivacaine continuously infused at a rate of 5 to 8 mL/h. Additional analgesia may be safely provided with IV PCA.

Orthopaedic surgeons often instill local anesthetic solutions (0.25% bupivacaine or 0.2% to 0.5% levobupivacaine) for intraoperative and postoperative analgesia for patients undergoing knee arthroscopy procedures. Similar infiltration can be performed for shoulder procedures. In some patients, a catheter may be left in the joint space to continuously infuse dilute local anesthetic to prolong pain control.

Femoral nerve block offers effective analgesia for femur fracture and pain after arthroscopic knee surgery. Continuous femoral techniques involve the placement of 19-gauge catheters into the fascial compartment of the femoral nerve and infusion of dilute bupivacaine. Low concentrations of bupivacaine delivered by femoral nerve catheter can provide excellent postoperative pain control after anterior cruciate ligament reconstruction. The addition of a femoral nerve block or three-in-one femoral-obturador-lateral femoral block provides superior pain control, decreased morphine consumption, and faster recovery than does IV PCA with morphine alone (Fig. 5). Allen et al reported that femoral block significantly ($P < 0.05$)
reduced pain scores and analgesic requirements among patients recovering from knee surgery. Of importance was that adding the technically difficult sciatic nerve block (to the femoral nerve block) did not further improve analgesic efficacy.

Continuous brachial plexus blockade provides effective pain control for extended periods after shoulder and rotator cuff procedures. The technique uses dilute bupivacaine 0.125% to 0.25% infused through catheters placed within the neurovascular sheath. Brachial plexus block for shoulder surgery is best accomplished through the interscalene approach, while supraclavicular or axillary block is used for forearm and hand procedures.

Other Analgesic Techniques

Oral transmucosal and transdermal fentanyl delivery systems have been introduced for acute pain management. Although transdermal fentanyl preparations provide effective postoperative analgesia, the prolonged latency in onset and progressive increases in narcosis and nausea/vomiting limit their overall usefulness postoperatively. This preparation can be used as an adjunct to epidural or peripheral blockade in patients who present with opioid tolerance. Oral transmucosal fentanyl has been advocated for acute pain management. The lozenge-shaped preparation releases between 100 to 400 µg of fentanyl within 15 minutes with high bioavailability. In a preliminary evaluation, Lind et al. reported that transmucosal fentanyl provided rapid and effective analgesia in patients recovering from major orthopaedic surgery. It has been used for pain associated with closed reductions and removal of orthopaedic hardware.

The use of transcutaneous electrical nerve stimulation (TENS) represents a conservative method of reducing posttraumatic and postoperative pain. Although TENS cannot relieve the most intense aspects of acute pain, it may provide useful analgesic supplementation. TENS in combination with IV PCA offers effective analgesia with acceptable levels of sedation and a notable reduction in self-administered opioid requirements.

New Concepts in Pain Management

Pain Services

The recent development of new treatment protocols and more effective methods of drug administration have made optimal pain relief a realistic goal in the majority of circumstances. Acute pain management services include caregivers trained to formulate and provide safe and effective therapy. A pain service director or clinical nurse coordinator is responsible for the introduction and maintenance of specialized therapy, standardized protocols, nursing education, and pharmacy interactions. The pain service generally is multidisciplinary and multid部mental. Surgeons, nurses, pharmacists, and nursing assistants play important roles in providing safe and efficient pain management.
Joint Commission on Accreditation of Healthcare Organizations guidelines state that pain intensity should be monitored as the fifth vital sign and documented per shift. A patient observation form should be developed and used to gauge pain control and assure quality of care. In addition, a standardized consultation form; orders for IV PCA, regional blockade, and epidural analgesia; and daily follow-up forms must be prepared and approved by the hospital administration.

**Preemptive Analgesia**

Preoperative administration of opioids and nonsteroidal anti-inflammatory drugs alone or in combination with local anesthetic block offer alternative forms of preemptive therapy. McQuay et al reported striking variation in patients’ first requests for pain medication during recovery from orthopaedic surgery, with the median time to first request <2 hours in untreated control subjects but >5 hours in patients who received opioid premedication plus local anesthetic block.

Although most clinical studies have concentrated on decreasing postoperative pain and acute disability, preemptive analgesia may also provide long-term convalescent-rehabilitative benefits and either prevent or minimize the severity of persistent pain syndromes. Patients recovering from back-fusion surgery, in which donor bone is taken from the iliac crest, can develop chronic periosteal pain that persists for months to years after the operation. Injection of bupivacaine or bupivacaine plus morphine (5 mg) into the iliac crest donor site attenuates the intensity of acute postoperative pain and appears to minimize the development of chronic sensitivity. Neuralgias, phantom limb pain, and deafferentation syndromes are common after amputation. Preemptive analgesia provided by perioperative epidural conduction blockade can prevent the development of chronic stump and phantom limb pain in patients recovering from below-knee amputation.

**Multimodal Analgesia**

Complete abolition of postoperative pain (pain prevention) is difficult to achieve with a single drug or analgesic technique. To avoid high dose requirements, dose-dependent adverse effects, and potential toxicity associated with reliance on one agent or technique, “balanced” or multimodal analgesic regimens have been advocated. The combination of ketorolac, which blocks pain at the peripheral receptor, plus intra-articular administration of bupivacaine, which can be given continuously through an intra-articular catheter, will block nerve conduction and substantially reduce pain scores and postoperative opioid requirements in patients recovering from arthroscopic knee surgery. Similarly, the addition of bupivacaine or clonidine may potentiate epidural opioid-mediated analgesia.

At Yale-New Haven Hospital, individuals recovering from major orthopaedic surgery are treated with a multimodal analgesic regimen of continuous epidural infusions of opioids plus local anesthetics and oral COX-2 inhibitors. Epidural fentanyl and hydromorphone are used for large painful procedures (e.g., knee surgery, femoral rodding). Unless contraindicated, opioid loading doses (fentanyl 100 µg or hydromorphone 500 to 1,000 µg) are combined with 0.5% bupivacaine or 2% lidocaine (10 to 20 mL) to effectively blunt the stress response during surgery. On completion of surgery, infusions of epidural fentanyl (5 µg/mL) or hydromorphone (10 to 20 µg/mL) are administered through lumbar catheters and supplemented with extremely dilute concentrations of bupivacaine or ropivacaine (either 0.1% or 0.05%). Bupivacaine is omitted from the epidural infusate in patients at risk for hypotension. The infusion rate ranges from 8 to 12 mL/h depending on patient age, height, and degree of opioid tolerance. Patient-controlled epidural boluses of 2 to 5 mL every 6 to 10 minutes are also provided to minimize pain during movement and ambulation. Intravenous ketorolac 7.5 mg every 6 hours or rofecoxib 50 mg/day (in patients tolerating diet) is combined with epidural patient-controlled analgesia unless medical or surgical contraindications exist. Side effects, especially pruritus, nausea, and sedation, are equivalent to those observed with patient-controlled intravenous morphine.

**Pain Control and Postoperative Outcome**

Appreciation of the severity and character of the pain stimulus allows optimal control to be provided at each phase of the recovery process. Patients who benefit most from spinal/epidural opioid analgesia are those recovering from extensive surgical procedures in which parenteral opioid dose requirements are high. Therapeutic gains are dramatic in patients with underlying cardiovascular and pulmonary disease but less obvious in healthy individuals recovering from minimally invasive procedures. Optimally administered epidural analgesia can suppress the release of catecholamines, maintain hemodynamic stability, reduce myocardial oxygen requirements, improve respiratory function, and facilitate physical therapy. Such therapy has also been shown to reduce mortality, hospital stay, and overall costs. These desirable attributes outweigh the greater invasiveness and potential side effects.
associated with epidural placement and indwelling catheters.

Epidural infusions of local anesthetic (0.25% to 0.5% bupivacaine) can suppress the sympathoadrenal and neuroendocrine responses that accompany surgical trauma. Suppression is most effective after lower abdominal and extremity procedures. Epidural conduction blockade has been shown to markedly reduce thromboembolic complications in patients recovering from hip surgery. In a study of critically ill patients recovering from major surgery, Yeager et al. noted that patients treated with epidural morphine benefited from notable reductions in cardiac and respiratory failure and incidence of major infections compared with individuals administered intravenous opioids. Seventy-six percent of patients in the general anesthesia parenteral opioid group (19 of 25) developed some form of organ failure versus 32% (9 of 28) in the epidural anesthesia-analgesia group. Similar results were reported by Christopherson et al. in patients who underwent major vascular surgery and were randomized to receive epidural anesthesia-analgesia or general anesthesia with parenteral opioids for postoperative pain relief. Patients in the general anesthesia group experienced greater postoperative morbidity, in particular cardiovascular and infectious complications.

Whether efforts to minimize postoperative pain and associated stress responses result in improved postoperative outcome is undetermined. Costs associated with IV PCA and epidural infusion devices, drug preparation, and supervision are considerably higher than those for traditional forms of analgesia. To justify this increased expenditure, studies are underway to determine whether optimal postoperative analgesia can decrease morbidity and duration of hospital stay.

Summary

Poorly controlled pain after orthopaedic surgery incites several pathophysiologic responses that increase postoperative morbidity. Analgesic regimens including opioid infusions, intravenous and epidural patient-controlled analgesia, and continuous regional blockade not only provide effective pain relief and high patient satisfaction but also result in improved functionality, decreased recovery time, and shortened hospitalization. Large-scale investigations are needed to compare analgesic efficacy and outcome benefits versus cost and inherent risks associated with each form of therapy.

References


