Perioperative Pain Control in Pediatric Patients Undergoing Orthopaedic Surgery

Abstract

Management of perioperative pain is critical in the pediatric patient undergoing orthopaedic surgery. A variety of modalities can be used to manage pain and optimize recovery and patient satisfaction, including nonopioid and opioid analgesia; local anesthetic injection; and regional analgesia such as intrathecal morphine, epidural therapy, and peripheral nerve blocks. Acute pain management can be tailored based on the needs of the patient, the surgical site, and the anticipated level of postoperative pain. A preoperative discussion of the plan for perioperative pain control with the patient, his or her parents, and the anesthesiologist can help manage expectations and maximize patient satisfaction.

Despite modern diagnostic and evaluative tools, pain remains difficult to measure objectively. Acute pain refers to pain of short duration (hours to days) and is typically associated with trauma, illness, or surgery. Of particular concern to the surgeon is evidence that suggests that pain activates neuroendocrine responses, thus increasing tissue metabolism that may ultimately impair healing. Inadequate analgesia may have deleterious effects on postoperative pulmonary function and increase the risk of morbidity and mortality.\(^1\) Therefore, the surgeon should discuss postoperative pain management plans with the child and his or her parents prior to surgery to set appropriate expectations. This discussion is critical because poor pain control in the pediatric patient can lead to significant stress, prolonged hospital stay, and decreased patient satisfaction.\(^2,3\)

Postoperative pain control in pediatric patients has received much needed attention in the recent literature. Most pediatric hospitals now have a dedicated acute pain service whose primary focus is to assist with pain management.\(^2,3\) Various options are available for management of pain following pediatric orthopaedic surgery and can be tailored based on the needs of the patient, the surgical site, and the anticipated severity of postoperative pain.

General Considerations and Contraindications

Pharmacokinetic differences between children and adults are significant and have implications for the dosage and intervals of analgesic medication. Most analgesics are lipophilic substances and require transformation into water-soluble substances to enable the body to excrete them in the form of urine or bile. The medication’s volume of distribution is directly affected by body composition. Compared with adults, infants and...
neonates have a higher total body water content and lower levels of plasma binding proteins, which have opposing effects on drug dosing. Opioids and local anesthetics, which are highly protein bound, will be present in a higher concentration in children than in adults, increasing the risk of toxicity.

Hepatic metabolism of drugs varies with the child's age. Generally, drug clearance in the 2- to 6-year age group is higher than in adults because of the higher ratio of hepatic mass to body weight as well as smaller fat and muscle stores. These factors should be taken into account when planning for perioperative pain management in the pediatric patient.

Pain scales such as the visual analog scale and the Faces Pain Scale are especially useful for monitoring pain control in children; routine use of these assessment tools with all methods of pain control is strongly recommended. Child life specialists specialize in various methods of child and family support during pediatric hospitalization and are useful in distracting children preoperatively and postoperatively, resulting in improved patient cooperation with procedures and improved pain and anxiety control.

Contraindications for nonopioid analgesia include organ failure (hepatic failure due to acetaminophen [APAP], renal failure due to nonsteroidal anti-inflammatory drugs [NSAIDs]), gastrointestinal bleeding (NSAIDs), asthma (NSAIDs; however, they may be used in patients with asthma if a test dose does not cause symptoms), and any previous allergic reaction to the drug. Contraindications for opioid analgesia include significant hepatic, pulmonary, or renal dysfunction and a history of allergic reaction to the drug. Local anesthetic is contraindicated in patients with hypersensitivity to the drug, infection at the planned injection site, and uncontrolled bleeding disorder. Regional analgesia is contraindicated in patients with sepsis, infection at the insertion site, anatomic abnormalities (eg, sacral agenesis, myelomeningocele), and coagulopathy.

Extremity surgery in patients at risk for compartment syndrome is a relative contraindication for regional analgesia. Dunwoody et al12 described the development of compartment syndrome in two patients who underwent surgery with a continuous infusion of bupivacaine and fentanyl via an epidural catheter. This combination provided excellent postoperative analgesia but predisposed patients to injury because they were unable to feel excessive pressure in the operative limb. The authors concluded that an increased risk of compartment syndrome exists following epidural use and that clinical vigilance is necessary for prevention.

**Nonopioid Analgesia**

APAP is the only over-the-counter non-anti-inflammatory analgesic commonly available in the United States, and it is the most common nonopioid analgesic used in pediatric patients. The drug acts as a weak inhibitor of cyclooxygenase-1 and -2 in peripheral tissues, which accounts for its lack of anti-inflammatory effect and more profound analgesic and antipyretic properties. APAP has the same indications as intermediate-dose aspirin but is used preferentially in children because of the lower risk of side effects, especially Reye syndrome. APAP can be administered orally, intravenously, or rectally and is safe for use even in infants.

Intravenous (IV) APAP has the potential to fill an unmet need in inpatient treatment of pain and fever, especially if the patient cannot take oral medication. Findings from the initial report by Sinatra et al13 as well as the results of a more recent expanded analysis14 support the safety and efficacy of IV APAP for management of moderate to severe pain following major orthopaedic surgery.

NSAIDs are a group of agents that differ in their antipyretic, analgesic, and anti-inflammatory properties. Their primary mechanism of action is inhibition of cyclooxygenase, resulting in decreased formation of prostaglandins, which are a major component of the inflammatory response. NSAIDs are associated with a risk of gastrointestinal disturbance and renal damage, especially in patients with preexisting renal disease. These drugs can cause reversible platelet dysfunction and may worsen hemostasis or cause bleeding in patients with preexisting coagulopathy.

Guidelines for pediatric dosage of several oral pain medications are outlined in Table 1.

Ketorolac is a nonselective NSAID that can be used for short-term (≤72 hours) management of pain; longer administration is associated with risks of gastrointestinal and renal damage. The use of IV ketorolac in pediatric orthopaedic surgery has increased dramatically over the past decade. Studies have demonstrated its efficacy and low risk of complications.15 In a placebo-controlled study that compared the postoperative use of IV ketorolac with morphine, patients in the ketorolac group were discharged from the postanesthesia care unit earlier than those in the placebo group, and the incidence of emesis was significantly lower in the ketorolac group than in the morphine group.14 Eberson et al16 found that administration of ketorolac and opioid analgesia following long bone osteotomies and complex foot procedures resulted in significantly shorter hospital stays compared with administration of morphine alone. They found that ketorolac reduced IV nar-
cotic requirements and decreased narcotic-induced gastrointestinal distress with no increased bleeding risk. Although the literature on multidose use of ketorolac in infants is sparse, ketorolac administration in infants aged to 6 months should be minimal if employed at all.17,18

Ketorolac has proved to be successful in controlling perioperative pain associated with many types of pediatric surgery, but its use in pediatric orthopaedic surgery has been limited because of concern for potential detrimental effects on osseous and soft-tissue healing. However, Kay et al19 studied the use of ketorolac in 221 pediatric patients with fractures treated surgically and found no cases of delayed union, malunion, and wound or bleeding complications. The authors concluded that ketorolac was safe for use with surgical fracture management and should be considered as an adjunct for pain control in pediatric patients.

Benzodiazepines can also be used to assist with management of perioperative pain. These drugs are used to control inflammation of the muscle, which leads to spasm and pain. The most commonly used spasmylytic medication in pediatric orthopaedics is diazepam. Benzodiazepines act on the central nervous system and skeletal muscle. These medications have neither antipsychotic activity nor analgesic properties, they should be used with NSAIDs or opioids to provide adequate pain relief following orthopaedic procedures. Potential side effects of spasmylytic medication include impaired motor function, drug tolerance, and respiratory depression, especially when used in conjunction with opioids. In the neuromuscular patient, a combination of pain control therapies (eg, epidural analgesia, opioids, benzodiazepines) is often used to limit overmedication and side effects.

**Table 1**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dose for Patients &lt;60 kg (mg/kg)</th>
<th>Dose for Patients ≥60 kg (mg)</th>
<th>Interval (h)</th>
<th>Maximal Daily Dose for Patients &lt;60 kg (mg/kg)</th>
<th>Maximal Daily Dose for Patients ≥60 kg (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaminophen</td>
<td>10–15</td>
<td>650–1,000</td>
<td>4</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4,000</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>6–10</td>
<td>400–600&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6</td>
<td>40&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>2,400&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Naproxen</td>
<td>5–6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>250–375&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12</td>
<td>24&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1,000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Aspirin&lt;sup&gt;d&lt;/sup&gt;</td>
<td>10–15&lt;sup&gt;d&lt;/sup&gt;</td>
<td>650–1,000&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4</td>
<td>80&lt;sup&gt;b,c,d&lt;/sup&gt;</td>
<td>3,600&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> The maximal daily doses of acetaminophen for infants and neonates are a subject of current controversy. Provisional recommendations are that daily dosing should not exceed 75 mg per kilogram per day for infants, 60 mg per kilogram per day for term neonates and preterm neonates of more than 32 weeks of postconceptional age, and 40 mg per kilogram per day for preterm neonates 28 to 32 weeks of postconceptual age. Fever, dehydration, hepatic disease, and lack of oral intake may all increase the risk of hepatotoxicity.

<sup>b</sup> Higher doses may be used in selected cases for treatment of rheumatologic conditions in children.

<sup>c</sup> Dosage guidelines for neonates and infants have not been established.

<sup>d</sup> Aspirin carries a risk of provoking Reye syndrome in infants and children. If other analgesics are available, aspirin should be restricted to indications for which an antiplatelet or anti-inflammatory effect is required, rather than being used as a routine analgesic or antipyretic in neonates, infants, or children. Dosage guidelines for aspirin in neonates have not been established.


Opioids are the most powerful drugs available for pain relief, attenuating both emotional and sensory aspects of the pain experience. These drugs act on receptors within the brain, spinal cord, and peripheral tissues. Administration via oral or IV routes is most common, but opioids can also be administered via the intrathecal (IT) or epidural spaces. In children, intramuscular injection of opioids is avoided because absorption is unpredictable, and children dislike injections. IV administration of opioids results in rapid onset of action with a high level of efficacy for pain relief. Table 2 lists several commonly prescribed opioids as well as pediatric dosage guidelines.

Following orthopaedic surgery, the amount of pain experienced by children with similar conditions varies widely. Postoperative pain requirements fluctuate based on the activities being performed. In the perioperative period, a variety of options for supplying opioid medication are available. In adults and children older than age 6 years, patient-controlled analgesia (PCA) has been shown to be an effective way to treat varying levels of pain. PCA is safe, effective, and highly satisfactory to patients, families, and nursing staff.4 PCA by proxy (ie, nursing- and parent-controlled analgesia) has been shown to be safe and effective in
Continuous IV opioid infusion can be used in patients in whom PCA is contraindicated because of age, physical disability, or cognitive impairment. The advantage of continuous infusion over intermittent opioid administration is the attainment of stable plasma opioid levels without wide fluctuations. However, constant infusion will not cover breakthrough incident pain; therefore, rescue doses of opioid are still needed. Continuous infusion of an opioid must be carefully monitored because respiratory depression can occur with excessive drug accumulation. The infusion rate should be reduced in children at risk of central nervous system depression or respiratory depression.

**Local Anesthetic Injection**

Local anesthetics have been shown to be effective for management of postoperative pain by temporarily blocking conduction of the pain signal along nerve fibers. Herrera et al\textsuperscript{20} examined the efficacy of hematoma block in pediatric patients with isolated femoral fractures treated with flexible elastic intramedullary nailing. Thirteen patients (37%) received a hematoma block with 0.5% bupivacaine at the end of the procedure; 22 patients (63%) with similar fractures did not receive a block. The authors found that 36% of patients in the control group versus 8% in the block group required opioid administration within the first 2 hours postoperatively. The authors concluded that hematoma block is a safe and effective adjunct for pain control following elastic intramedullary nailing for femoral fractures. In a double-blind randomized control trial of 40 pediatric patients who underwent extremity surgery, Bulut

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**Table 2**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Equianalgesic Doses$^b$</th>
<th>Typical Starting Intravenous or Subcutaneous Doses and Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parenteral</td>
<td>Oral</td>
</tr>
<tr>
<td>Codeine</td>
<td>120 mg</td>
<td>200 mg</td>
</tr>
<tr>
<td>Morphine</td>
<td>10 mg</td>
<td>30 mg (long-term), 60 mg (single dose)</td>
</tr>
<tr>
<td>Oxycodone</td>
<td>NA</td>
<td>15–20 mg</td>
</tr>
<tr>
<td>Methadone$^c$</td>
<td>10 mg</td>
<td>10–20 mg</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>100 µg (0.1 mg)</td>
<td>NA</td>
</tr>
<tr>
<td>Hydromorphone</td>
<td>1.5–2 mg</td>
<td>6–8 mg</td>
</tr>
<tr>
<td>Meperidine (pethidine)$^d$</td>
<td>75–100 mg</td>
<td>300 mg</td>
</tr>
</tbody>
</table>

NA = not applicable, NR = not recommended

$^a$ Doses are for patients over 6 months of age. In infants under 6 months, initial per-kilogram doses should begin at roughly 25% of the per-kilogram doses recommended here. Higher doses are often required for patients receiving mechanical ventilation. All doses are approximate and should be adjusted according to clinical circumstances. Recommendations are adapted from previous summary tables, including those of a consensus statement from the World Health Organization and the International Association for the Study of Pain.

$^b$ Equianalgesic doses refer to proportional drug doses when switching from intravenous to oral medication forms.

$^c$ Methadone requires additional vigilance because it can accumulate and produce delayed sedation. If sedation occurs, doses should be withheld until sedation resolves. Thereafter, doses should be substantially reduced, the interval between doses should be extended to 8 to 12 hours, or both.

$^d$ The use of meperidine should generally be avoided if other opioids are available, especially with long-term use, because its metabolite can cause seizures.


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children younger than age 6 years and in cognitively impaired children.\textsuperscript{6} Its efficacy is due to maintenance of opioid concentrations within a narrower range than that of intermittent injections, with lower peak and higher trough levels.
et al \(^\text{11}\) compared 20 patients who received 0.5% bupivacaine via subfacial catheters postoperatively with 20 who received normal saline. Initially, no difference was found between the groups in terms of pain scores, but a substantial decrease in postoperative pain was reported in the local anesthetic group at hours 4 to 48. The authors reported few complications in both groups and concluded that catheter administration of local anesthetic was effective and prolonged postoperative analgesia.

Preoperative or intraoperative injection of botulinum toxin A into selected muscle groups can aid in preventing postoperative spasms in neuromuscular patients. Use of this injection has been shown to be beneficial in patients undergoing adductor release.\(^\text{22}\)

**Regional Analgesia**

Regional anesthesia offers several benefits for pain control following pediatric orthopaedic surgery, including decreased need for opioid medications, earlier return of postoperative gastrointestinal function, and attenuation of the stress response caused by surgical procedures.\(^\text{23}\) Several cohort series have confirmed that regional anesthesia is safe for use in children. A prospective 1-year study of more than 24,000 anesthetics (including regional blocks) reported that the overall incidence of complications associated with regional blocks was 0.9 in 1,000 blocks.\(^\text{7}\) In most cases, these complications involved either failure to place an effective block or failure of the block to provide adequate analgesia postoperatively. More serious complications, such as peripheral nerve injury and local anesthetic toxicity, were rare.\(^\text{24}\) Placing these blocks in deeply sedated or anesthetized patients, as is often necessary in pediatric patients, was found to be safe.\(^\text{7}\)

<table>
<thead>
<tr>
<th>Parenteral:Oral Dose Ratio</th>
<th>Weight &lt;50 kg</th>
<th>Weight ≥50 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:2</td>
<td>0.5–1.0 mg/kg every 3–4 h</td>
<td>30–60 mg every 3–4 h</td>
</tr>
<tr>
<td>1:3 (long-term)</td>
<td>Immediate release: 0.3 mg/kg every 3–4 h</td>
<td>Immediate release: 15–20 mg every 3–4 h</td>
</tr>
<tr>
<td>1:6 (single dose)</td>
<td>Sustained release: 20–35 kg: 10–15 mg every 8–12 h</td>
<td>Sustained release: 30–45 mg every 8–12 h</td>
</tr>
<tr>
<td>NA</td>
<td>35–50 kg: 15–30 mg every 8–12 h</td>
<td>5–10 mg every 3–4 h</td>
</tr>
<tr>
<td>1:2</td>
<td>0.1–0.2 mg/kg every 3–4 h</td>
<td>5–10 mg every 4–8 h</td>
</tr>
<tr>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1:4</td>
<td>0.04–0.08 mg/kg every 3–4 h</td>
<td>2–4 mg every 3–4 h</td>
</tr>
<tr>
<td>1:4</td>
<td>2–3 mg/kg every 3–4 h</td>
<td>100–150 mg every 3–4 h</td>
</tr>
</tbody>
</table>

NA = not applicable, NR = not recommended

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\(^\text{d}\) The use of meperidine should generally be avoided if other opioids are available, especially with long-term use, because its metabolite can cause seizures.

Intrathecal Morphine Injection

Injection of preservative-free morphine into the IT space can provide up to 24 hours of pain control following extremity surgery.25 Spinal injections can be performed following the induction of general anesthesia and before the surgical incision is made. Alternatively, morphine can be injected directly into the dura in patients undergoing spinal fusion.26,27

As with IV morphine, side effects associated with IT morphine injection include nausea, pruritus, and urinary retention. However, the most concerning side effect is respiratory depression, which can occur up to 24 hours after injection. Therefore, respiratory monitoring (continuous pulse oximetry) and limited use of other respiratory depressants are recommended following this technique.

A recent study evaluated the use of low-dose IT morphine following a variety of surgical procedures in 187 children and found that 81% of patients did not require opioid rescue medication in the first 8 hours postoperatively and that 37% of patients had sustained pain relief 24 hours after the spinal injection.28 Thus, IT morphine is ideally suited for patients who are expected to transition to oral analgesics shortly after surgery.

Epidural Therapy

Injecting local anesthetics and/or opioids into the epidural space can provide effective analgesia for thoracic, pelvic, and lower extremity surgery. Advantages of epidural therapy include decreased intraoperative blood loss, prolonged pain control, and minimal sedation required postoperatively. Side effects associated with epidural injections include pruritus, urinary retention, and nausea.29 Additionally, depending on the concentration of local anesthetic used, varying degrees of motor block can occur with epidural infusions.

A single injection into the epidural space via the sacral hiatus, commonly known as a caudal injection, may provide several hours of postoperative analgesia for pelvic and lower extremity surgery and is a useful technique for outpatient procedures. For patients who are scheduled to be admitted, epidural catheters can be placed into the lumbar or thoracic regions for continuous administration of local anesthetics and/or opioids. These catheters can be maintained for several days, and the concentration and volume of the infusion can be altered to optimize pain control.

Peripheral Nerve Block

This technique involves placement of local anesthetic near a peripheral nerve to block conduction of the pain signal to the central nervous system. A successful peripheral nerve block requires minimal amounts of anesthesia and opioid and provides excellent postoperative pain control. Nerve blocks can be performed as a single injection, or catheters can be placed in proximity to relevant nerves to provide prolonged pain relief following surgery.

Ultrasoundography can be used to aid in the placement of peripheral nerve blocks and, as a result, the use of these blocks has expanded in recent years. Real-time imaging of the relevant nerve and vascular structures facilitates precise needle placement such that smaller amounts of local anesthetic can be used, thereby limiting the risk of local anesthetic toxicity.30

Implementation of various approaches to the brachial and to the lumbar and sciatic plexuses can effectively anesthetize the nerves of the upper and lower extremities, respectively, providing excellent postoperative analgesia. Additionally, the complication rate associated with peripheral nerve blocks has been shown to be small. DeVera et al31 retrospectively reviewed 1,657 nerve blocks placed in patients (age range, 2 months to 20 years) over a 5-year period following induction of general anesthesia. In this large series, only two self-limiting nerve injuries were reported. The ability to target the specific innervation of the surgical site using a minimal amount of local anesthesia to avoid the side effects of systemic opioids makes peripheral nerve block an integral technique for providing effective analgesia for orthopaedic procedures.

Pain Control Following Spine Surgery

A growing body of literature regarding pain control following spine surgery has evolved over the past 10 years (Table 3). Traditional treatment regimens include APAP, NSAIDs, and PCA or nurse-controlled IV analgesia with opioids and benzodiazepines to treat muscle spasms. Recent studies have examined the role of regional analgesia in the context of perioperative control of pain associated with spine surgery. Applicable techniques include IT injection of opioids or continuous epidural analgesia (CEA) and patient-controlled epidural analgesia with local anesthetics, opioids, or both.

We have addressed the use of APAP and NSAIDS in pediatric orthopaedic surgery; however, the use of ketorolac in spinal surgery must be discussed specifically. NSAID use following spinal fusion has been discouraged in the adult population due to concerns regarding postoperative bleeding and pseudarthrosis.32 Multiple studies have demonstrated the efficacy and low risk of complications associated with IV ketorolac following pediatric spine fusion.15,32 In one
study, 35 patients received a bolus of either ketorolac or saline at the end of their spinal fusion and then every 6 hours for 36 hours. Patients in the ketorolac group consistently rated their pain lower than did those in the placebo group up to the afternoon of the second postoperative day. Fourteen patients were followed for a minimum of 2 years and no pseudarthrosis was found in either group. Sucato et al compared 158 patients who received ketorolac following posterior spinal fusion and instrumentation for adolescent idiopathic scoliosis with 161 patients who did not receive ketorolac and found no difference between the two groups in terms of the rate of pseudarthrosis (1.9% versus 3.1%) as well as no increased risk of other surgical complications. Despite these supportive studies, there continues to be a reluctance to use ketorolac in this patient population. Hayes et al surveyed a group of international anesthesiologists regarding the use of NSAIDs in pediatric patients following spine fusion and found that there remains to be a wide discrepancy in the use of these drugs in this population despite the fact that postoperative NSAIDs can reduce morbidity associated with opioid consumption, specifically respiratory depression.

In 1988, Dalens and Tanguy published their results of the use of IT morphine in 20 pediatric patients who underwent spinal fusion. The authors found that IT morphine (25 µg/kg) administered at the lumbar level before the start of the surgical procedure was safe and provided 36 hours of analgesia. Although IT morphine has been found to be beneficial, current protocols vary regarding time of administration (beginning or end of surgical procedure), dosage (2 to 25 µg/kg), additives, volume of injectant, outcome variables measured, and documented side-effect profile.

Despite the benefits associated with IT morphine (eg, reduced intraoperative blood loss, decreased pain scores 24 hours postoperatively), its use is hindered by the side-effect profile. The hydrophilic nature of this opioid allows cephalad migration within the cerebrospinal fluid, where morphine can act upon the brainstem, resulting in respiratory depression, pruritus, nausea, and vomiting. Because the incidence of these side effects is thought to be dose-dependent, current studies are designed to determine the optimal dosing regimen. Eschertzhuber et al compared the effects of low- and high-dose IT morphine (5 µg/kg and

### Table 3

<table>
<thead>
<tr>
<th>Study</th>
<th>Route</th>
<th>Medication/Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dadure et al</td>
<td>IV</td>
<td>Ketoprofene 2 mg/kg IV every 12 h and paracetamol 15 mg/kg IV/PO every 6 h</td>
</tr>
<tr>
<td>Munro et al</td>
<td>IV</td>
<td>Ketorolac 0.5 mg/kg every 6 h for 36 h w/morphine PCA (maximum ketorolac dose 15 mg for weight &lt;50 kg)</td>
</tr>
<tr>
<td>Khoury et al</td>
<td>Peripheral nerve block</td>
<td>0.25% bupivacaine 0.5–1 mL/kg, clonidine 1 µg/kg, epinephrine 1:200,000 if &gt;6 months of age (single injection)</td>
</tr>
<tr>
<td>Dadure et al</td>
<td>Peripheral nerve block</td>
<td>1% lidocaine 0.5–1 mL/kg bolus, then 0.1–0.2 mL/kg/h (continuous injection)</td>
</tr>
<tr>
<td>Gall et al</td>
<td>Intrathecal</td>
<td>Morphine 5 µg/kg followed by morphine PCA</td>
</tr>
<tr>
<td>Poe-Kochert et al</td>
<td>Intrathecal</td>
<td>Morphine 9–19 µg/kg followed by continuous IV morphine infusion</td>
</tr>
<tr>
<td>Tripi et al</td>
<td>Intrathecal</td>
<td>Morphine 9–19 µg/kg</td>
</tr>
<tr>
<td>Ganesh et al</td>
<td>Intrathecal</td>
<td>Morphine 4–5 µg/kg</td>
</tr>
<tr>
<td>Sucato et al</td>
<td>Epidural</td>
<td>Hydromorphone 20 µg/mL and 0.1% bupivacaine at 0.1–0.2 mL/kg/h</td>
</tr>
<tr>
<td>Shaw et al</td>
<td>Epidural</td>
<td>Hydromorphone/fentanyl/morphine and 0.0625 to 0.125% bupivacaine at 2–8 mL/h</td>
</tr>
<tr>
<td>Reinoso-Barbero et al</td>
<td>Epidural</td>
<td>Fentanyl 1 µg/mL and 0.4% lidocaine at 0.1–0.35 mL/kg/h</td>
</tr>
<tr>
<td>Gauger et al</td>
<td>Epidural</td>
<td>0.1% bupivacaine and hydromorphone 10 µg/mL at 8 mL/h</td>
</tr>
<tr>
<td>Arms et al</td>
<td>Epidural</td>
<td>0.0625% to 0.125% bupivacaine with morphine 5–10 µg/kg at 4–10 mL/h</td>
</tr>
<tr>
<td>Lowry et al</td>
<td>Epidural</td>
<td>0.1% ropivacaine and hydromorphone 10 µg/mL at 0.2 mL/kg/h</td>
</tr>
<tr>
<td>Antok et al</td>
<td>Epidural</td>
<td>0.2% ropivacaine 1.6 mL/h with 2 mL every 10 min (patient-controlled epidural)</td>
</tr>
</tbody>
</table>

IV = intravenous, PCA = patient-controlled analgesia, PO = oral
et al were the first to report its suc-
chronic pain; however, Amaranath
phine in patients with severe acute or
ported the efficacy of epidural mor-
ministered following pediatric spinal
Vacaine, bupivacaine) and narcotic
combination of local anesthetic (eg, ropi-
are then typically dosed with a com-
limited duration of analgesia pro-
cantly better analgesia compared
with moderate doses and that higher
doses were associated with greater
frequency of respiratory depression.

Given the side-effect profile and
limited duration of analgesia pro-
vided by a single injection of IT mor-
phine, some orthopaedic surgeons
may prefer the use of epidurals in pe-
diatric patients. Behar et al first re-
ported the efficacy of epidural mor-
phine in patients with severe acute or
chronic pain; however, Amaranath
et al were the first to report its suc-
cessful use in pediatric spine surgery.

In patients who receive epidural an-
algies, the catheter is inserted under
direct visualization at the end of the
surgical procedure. For single cath-
ter techniques, the catheter is placed
at the middle of the incision. For
dual catheter techniques, one cath-
teter is placed in the proximal incision
and the other is placed in the distal
incision. Following a thorough neu-
rologic examination, the catheters
are then typically dosed with a com-
bination of local anesthetic (eg, ropi-
vacaine, bupivacaine) and narcotic
(eg, fentanyl, morphine, hydromor-
phone).

In the only randomized, double-
blind study of epidural analgesia ad-
ministered following pediatric spinal
fusion, O’Hara et al compared the
use of IV morphine with that of epi-
dural bupivacaine plus fentanyl in
patients with idiopathic scoliosis and
found no difference in analgesic ef-
ectiveness. However, in the largest
study to date, Sucato et al evaluated
613 patients who received either
CEA or PCA following spine fusion
and found that average and overall
pain scores in the first 48 hours were
significantly lower in the CEA group.

In addition to epidural safety and
efficacy, other postoperative parame-
ters have been evaluated. Van
Boerum et al compared epidural in-
fusion with PCA and found pain
control to be comparable; however,
patients in the epidural group toler-
ated full diet earlier and were dis-
charged an average of 0.5 days
sooner than those in the PCA group.
Cassady et al found that the safety
and efficacy of CEA were comparab-
le to that of PCA, with a more
rapid return of bowel sounds in pa-
ients treated with CEA.

Concerns regarding the adequacy
of epidural analgesia in this patient
cohort were that catheter place-
ent and leakage of the solution
from the epidural space. Turner
et al studied epidural catheter
placement in 14 patients who under-
went spinal fusion. The authors in-
jected an omnipaque contrast agent
into the catheter before obtaining a
postoperative radiograph of the
chest. Contrast medium was visual-
ized in the spinal canal in seven pa-
tients who reported satisfactory anal-
gesia; however, no contrast was seen
within the spinal canal or paraverte-
bral gutter space in five (36%) who
had inadequate analgesia. Lavelle
et al evaluated pain control with
epidural analgesia in patients who
had spine procedures that violated
the epidural space. The authors com-
pared 29 patients who received epi-
durals with 26 patients who received
PCA following Smith-Petersen os-
terotomies and instrumentation using
multiple sublaminar wires. The au-
ths found that epidural analgesia
resulted in lower pain scores during
the first 24 hours postoperatively.
Counterintuitively, patients with vi-
olated canals had lower pain scores
than those with an intact epidural
space.

To date, only one study has com-
pared the three most common meth-
ods of postoperative pain control in
pediatric patients treated with poste-
rior spinal fusion. Milbrandt et al
compared the efficacy and side-effect
profile of PCA alone (41 patients),
IT morphine injection with PCA (42
patients), and epidural catheter in-
fusion (55 patients) for pain control
following posterior spinal fusion and
segmental spinal instrumentation for
adolescent idiopathic scoliosis. Al-
though IT morphine with PCA pro-
vided better immediate pain control
than did the other modalities, pa-
tients who received epidural catheter
infusion had the lowest pain scores
for the longest period of time, with
faster return to solid foods and sig-
nificantly less vomiting, but more
pruritus.

Complications

Postoperative pain control modal-
ties have a wide range of adverse
effects. The most common side effects
of opioid analgesia include itching,
nausea, and sedation. Pruritus can be
irritating and can prevent adequate
patient comfort. The incidence of
pruritus associated with the use of
peripheral nerve blocks has been
found to be low (0.9% to 8%) and
higher with morphine PCA (11% to 17%).
Following IT morphine or epidural injection, the
incidence of pruritus has been reported to be as high as 37% and
49%, respectively.

Postoperative nausea and vomiting
(PONV) causes discomfort in the recovery period and prevents appropriate oral intake. PONV is dependent on both the type of anesthetic and the postoperative pain regimen. In a large retrospective study, 13% of patients treated with continuous IV morphine infusion had PONV, whereas up to 54% of patients treated with CEA in a separate study had nausea. In a prospective study of 60 children who received regional and general anesthesia for orthopaedic surgery, the risk for PONV dramatically diminished (6.7%) with the use of regional analgesia. 

Respiratory depression is a dangerous and potentially fatal complication in the postoperative period that is often dependent on postoperative opioid use and the route of administration. Multiple studies have demonstrated a decreased risk of respiratory depression with the use of IT morphine, especially when given in low doses. This risk is transient and typically subsides without the need for reintubation. Moreover, it has been suggested that patients treated with IT morphine postoperatively can be safely monitored on regular surgical hospital floors. The use of epidural opioids also may cause respiratory depression. One study reported that the risk of respiratory depression associated with epidural analgesia with opioids was as high as 58%; other studies demonstrated no significant difference in the risk of respiratory depression associated with epidural analgesia and PCA.

Neurologic deficit following spinal fusion can be either transient or permanent and is a major concern. Postoperative pain modalities that can mask this dangerous morbidity should be avoided. To avoid motor block, some authors have advocated against the use of local anesthetic in the epidural solution and have switched from bupivacaine to ropivacaine due to the decreased incidence of motor block associated with the latter. Several studies have proposed that following spinal fusion, an epidural bolus should not be given until the postoperative neurologic examination has been documented.

### Summary

A variety of safe and effective options are available for management of perioperative pain following pediatric orthopaedic surgery. Regional analgesia such as peripheral nerve blocks and epidural analgesia can provide excellent pain control with low risk of complications and few side effects. Following pediatric orthopaedic surgery, IV ketorolac is an excellent adjunct for pain control that is associated with low morbidity. The plan for management of perioperative pain in the pediatric orthopaedic patient is best orchestrated in the preoperative period. Discussion among the patient, caregivers, anesthesiologist, and surgeon is critical to set expectations and maximize patient satisfaction.

### References

Evidence-Based Medicine: Levels of evidence are described in the table of contents. In this article, references 5, 11, 13, 14, 21, 26, 40, 46, 52 and are level I studies. References 4, 7, 8, 23, 27, 30, 33, 34, 40, 41, 44, 47, 49, and 50 are level II studies. References 6, 15, 16, 18-20, 29, 31, 32, 35, 38, 48, 51, 54, and 55 are level III studies. References 2, 3, 9, 28, 34, 42, 45, and 53 are level IV studies. References 1, 10, 17, 22, 24, 25, and 43 are level V expert opinion.

References printed in bold type are those published within the past 5 years.

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