understanding of the relevant anatomy. We will focus on specific techniques to perform procedural regional anesthesia with a “how to” organization. A basic review of local anesthetics will also be included.

Regional and Local Anesthetic Agents
Several effective techniques for local and regional anesthesia have been described in the pediatric population including hematoma, IV regional, and regional nerve blocks. As always, use of these medications requires a thorough understanding of the pharmacokinetics and appropriate dosing of these drugs as well as proficiency in the techniques of administering them safely. Local and regional anesthetic drugs work by blocking the conduction of nerve impulses. At the cellular level they depress sodium ion flux across the nerve cell membrane. This results in the inhibition of the initiation and propagation of action potentials. After injection, local anesthetics diffuse toward their intended site of action and also toward nearby vasculature where uptake is determined by the number of capillaries, the local blood flow, and the affinity of the drug for the tissues. Vasoconstrictors such as epinephrine are mixed with local anesthetics to decrease the vascular uptake and prolong the anesthetic effect.

Duration of action for the various local anesthetic medica-
tions is also determined in part by the type of regional block performed. For example, single-dose brachial plexus blocks tend to have a far longer duration than single-dose epidural or subarachnoid blocks. Adverse effects in the tissue surrounding injection sites have been described and include erythema, swelling, and rarely, ischemia when injected into tissues supplied by terminal arteries. Adverse systemic effects are caused by high blood levels of local anesthetics and include tinnitus, drowsiness, visual disturbances, muscle twitching, seizures, respiratory depression, and cardiac arrest. Bupivacaine can be particularly dangerous because it binds with high affinity to myocardial contractile proteins and can cause cardiac arrest.

Equipment
Before placing any anesthetic block it is important to consider ahead of time the equipment and medication that will be required for the procedure. Simple blocks may only require a weight-based dose of the preferred anesthetic agent, needle(s), syringe(s), and a sterile cleaning solution. For blocks that are placed in deeper planes such as the axillary and femoral nerve blocks and IV (Bier) blocks, additional equipment considerations include appropriate electrocardiographic monitoring, airway management equipment, and a double-cuffed tourniquet (Bier block). In addition, medications that should be readily available include IV diazepam to manage seizures and IV lipid to prevent potential cardiovascular collapse induced by accidental intravascular injection of the anesthetic (especially with bupivacaine). Again, a thorough understanding of the appropriate dosing and resuscitation procedures in the event of local anesthetic toxicity is necessary before performing these procedures. The use of nerve stimulators with insulated needles has gained in popularity. Their use as well as the use of ultrasound have dramatically improved efficacy of many regional blocks.

Local Anesthesia Toxicity
At least three types of adverse reactions can occur from local anesthetic agents. Clinically, the most important is systemic toxicity of the CNS and cardiovascular system from a relative overdose into the circulation (Table 3-7). This type of reaction is not a medication allergy, but is a function of having too much medication into the bloodstream. In the presence of a major artery, even a low dose of a local anesthetic can lead to seizure activity. In most cases, however, the severity of systemic toxicity is directly related to the concentration of local anesthetic in the bloodstream. Seizures and cardiac arrest may be the initial manifestations of systemic toxicity in patients who rapidly attain a high serum level of medication. Agents with greater intrinsic potency, such as bupivacaine and etidocaine, require lower levels for the production of symptoms. Dysrhythmias and cardiovascular toxicity may be especially severe with bupivacaine, and resuscitation of these patients may be prolonged and difficult. The prevention and treatment of acute local anesthetic systemic toxicity are outlined in Table 3-8. Although the potential for CNS toxicity may be diminished with barbiturates or benzodiazepines, given either as premedications or during the treatment of convulsions, these measures do not alter the cardio toxic threshold of local anesthetic agents. With rapid and appropriate treatment, the fatality rate from local anesthetic-related seizures can be greatly decreased. It is essential to stay within accepted dose limits when using any local anesthetic (Table 3-9). To aid in dose calculations, a simple formula for converting percent concentration to milligrams per milliliter is provided in Table 3-10. Local nerve damage and reversible skeletal muscle changes have also been reported from the use of local anesthetics.
TABLE 3-8 Prevention and Treatment of Acute Local Anesthetic Systemic Toxicity

Preventive Measures
1. Ensure availability of oxygen administration equipment, airway equipment, suction equipment, and medications for treatment of seizures (diazepam or midazolam, thiopental, succinylcholine).
2. Ensure constant verbal contact with patient (for symptoms of toxicity) and monitor cardiovascular signs and oxygen saturation.
3. Personally prepare the dose of local anesthetic and ensure it is within the accepted dosage range.
4. Give the anesthetic slowly, and fractionate the dose.

Treatment
1. Establish a clear airway; suction if required.
2. Give oxygen by face mask. Begin artificial ventilation if necessary.
3. Give diazepam 0.1–0.3 mg/kg IV in incremental doses until convulsions cease. Midazolam (0.05–0.1 mg/kg) may be used instead, also in increments until convulsions cease.
4. Thiopental in increments of 1–2 mg/kg IV may be used to control the seizures.
5. Succinylcholine (1 mg/kg IV) may be used if there is inadequate control of ventilation with the other medications. Artificial ventilation and possibly endotracheal intubation are required after using succinylcholine.
6. Use advanced cardiac life-support measures as necessary to support the cardiovascular system (more likely with local anesthetics of increased potency, such as bupivacaine).

Agent Plain With Epinephrine

<table>
<thead>
<tr>
<th>Injection Dose (mg/kg)</th>
<th>Lidocaine (Xylocaine)</th>
<th>Bupivacaine</th>
<th>Mepivacaine (Carbocaine)</th>
<th>Prilocaine</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 7</td>
<td>2.5 3</td>
<td>4 7</td>
<td>5.5 8.5</td>
<td></td>
</tr>
</tbody>
</table>

*The addition of epinephrine (vasoconstrictor) reduces the rate of local anesthetic absorption into the bloodstream, permitting use of a higher dose.

**For IV regional anesthesia (Bier blocks), the maximal lidocaine dose is 3 mg/kg. Preservative-free lidocaine without epinephrine should be used for either Bier blocks or hematoma blocks.

**Owing to its cardiotoxicity, bupivacaine should never be used for IV regional anesthesia or for hematoma blocks.

TABLE 3-9 Maximal Recommended Doses of Commonly Used Local Anesthetics in Children

TABLE 3-10 Conversion Formula from Percent Concentration to Milligrams/ Milliliter

Percentage concentration × 10 × Number of mg/mL.

Examples: 0.25% bupivacaine has 2.5-mg bupivacaine/mL; 2% lidocaine has 20-mg lidocaine/mL.

Decreasing the percent concentration of anesthetic (as is done in the mini-dose Bier block technique) permits the infusion of a larger volume (mL) of drug with lower risk of systemic toxicity because the total amount (mg) of lidocaine is lower.

Intravenous Regional Anesthesia

Bier Block

IV regional anesthesia was originally described in 1908 by August Bier who used IV cocaine to obtain analgesia. Although it declined in popularity as brachial plexus blocks were developed, it was revived in 1963, when its safe and successful use for the reduction of forearm fractures in adults was reported. Subsequently, a number of studies have described the effective use of this technique of anesthesia for the treatment of upper extremity fractures in children in an ambulatory setting. The block has also been described for use in lower extremity fractures, but is less commonly utilized for this indication.

The technique for administering the Bier block in the upper extremity involves placement of a deflated pneumatic cuff above the elbow of the injured extremity. Holmes introduced the concept of two cuffs in an effort to minimize tourniquet discomfort with prolonged inflation, but the practice has not proven to be necessary for the limited amount of time it takes for fracture reduction in a child (Fig. 3-1A). The cuff should be secured with tape to prevent Velcro failure. IV access is established in a vein on the dorsum of the hand of the injured extremity with a 22- or 23-gauge butterfly needle (Fig. 3-1B). The arm is exsanguinated by elevating it for 1 to 2 minutes. Although exsanguination with a circumferential elastic bandage is described classically, this method can be more painful and difficult to perform in an injured extremity and is no more efficacious than the gravity method (Fig. 3-1C). The blood pressure cuff is then rapidly inflated to either 100 mm Hg above systolic blood pressure or between 200 and 250 mm Hg. The arm is lowered after cuff inflation. Next, lidocaine is administered, the IV catheter removed, and reduction of the fracture performed. In the traditional technique, the lidocaine dose is 3 to 5 mg/kg, and, in the “mini-dose” technique, 1 to 1.5 mg/kg.

The tourniquet is kept inflated until the fracture is immobilized and radiographs are obtained, in case repeat manipulation is necessary. In any event, the tourniquet should remain inflated for at least 20 minutes to permit the lidocaine to diffuse and become adequately fixed to the tissues, thus minimizing the risk of systemic toxicity. The blood pressure cuff may be deflated in either a single stage or graduated fashion.
SECTION ONE
Basic Principles

FIGURE 3-1 A–C: Exsanguination with Esmarch bandage (A), application of the double-cuff tourniquet (B), and intravenous injection of local anesthetic into injured limb (C). (From: Military Advanced Regional Anesthesia Handbook, with permission. www.arispni.org/maraa-book-project.html)

Although single stage release has proven to be clinically safe and technically easier,\textsuperscript{43,61,90} during the entire procedure, basic respiratory monitoring is required, and cardiac monitoring is also suggested because of the potential cardiac toxicity. Routine IV access in the uninjured extremity is highly recommended because of the potential for cardiac effects, but is not required.\textsuperscript{13,55} Patients should be observed for at least 30 minutes following cuff deflation for any adverse systemic reactions. Motor and sensory function typically returns during this period, allowing assessment of neurovascular status of the injured extremity prior to discharge.\textsuperscript{117}

The literature within the past decade certainly speaks to the effectiveness of the traditional Bier block, utilizing a lidocaine dose of 3 to 5 mg/kg, in managing forearm fractures in children. \textsuperscript{13,29,90,115} Four large series with a total of 895 patients undergoing this technique demonstrated satisfactory anesthesia and successful fracture reduction in over 90\% of cases.\textsuperscript{13,29,90,115} The most common adverse effect of the procedure in these studies was tourniquet pain in about 6\% of patients.\textsuperscript{29,115} One patient experienced transient dizziness and circumoral paresthesias.\textsuperscript{115} One patient developed persistent myoclonic twitching following tourniquet deflation and was hospitalized for observation.\textsuperscript{10}

Despite the efficacy and relatively low number of complications with the “traditional” Bier block (lidocaine, 3 to 5 mg/kg), concerns and anecdotal reports of systemic lidocaine toxicity (i.e., seizures, hypotension, tachycardia, arrhythmias) have prompted the development of a “mini-dose” (lidocaine, 1 to 1.5 mg/kg) technique of IV regional anesthesia.\textsuperscript{10,43,61} Reports by Farrell et al.\textsuperscript{43} and Bolte et al.\textsuperscript{18} utilizing a lidocaine dose of 1.5 mg/kg and by Juliano et al.\textsuperscript{90} using a dose of 1 mg/kg in a total of 218 patients have shown the mini-dose Bier block to be effective in achieving adequate anesthesia in 94\% of children studied. Although the exact mechanism of action is uncertain, the primary site of action of the IV regional block is thought to be the small peripheral nerve branches. At this anatomic level, blockade is better achieved with a larger volume of anesthetic that can be distributed more completely to the peripheral nerve receptors. It appears to be the quantity (i.e., volume) and not the dose of anesthetic that predicates success of the block. For any given dose of lidocaine, diluting the concentration permits the administration of a larger volume of fluid (Table 3-4). This mechanism explains the success of the mini-dose technique.

In the series by Juliano et al.,\textsuperscript{90} forearm fracture reduction was pain free in 43 of 44 patients (98\%) following IV regional block performed with a very dilute lidocaine solution (0.125\%) and a relatively small total dose (1 mg/kg).\textsuperscript{61}

IV regional anesthesia, using either the traditional or mini-dose technique has several advantages. First, the technique is fairly easy to administer. Also the onset of action of the block is relatively fast (<10 minutes), but also of relatively short duration, which allows for the assessment of neurovascular function in the extremity after fracture reduction and immobilization. However, rapid recovery may also be considered a disadvantage as the analgesic effect of the local anesthetic is lost once the tourniquet is deflated. A recent report in adults examined the addition of the nonsteroidal anti-inflammatory drug (NSAID)
ketrolic to the local anesthetic solution and found that patients did obtain prolonged analgesia after the tourniquet was released. An empty stomach is not required. However, no pediatric studies have been performed on this technique.

Tourniquet discomfort is the most common adverse side effect. Inadvertent cuff deflation with loss of analgesia or systemic toxicity is a potentially significant problem. Compartment syndrome has also been reported. Technically, placing the tourniquet and obtaining IV access in the injured extremity can be a challenge in the uncooperative child, and application of the splint or cast can be cumbersome with the tourniquet in place. IV regional anesthesia is unsuitable for lesions above the elbow. This technique is contraindicated in patients with underlying heart block, known hypersensitivity to local anesthetic agents, and seizure disorders. Although not completely contraindicated, caution is urged when using this technique in patients with underlying hemoglobinopathies such as sickle cell disease.

**AUTHOR’S PREFERRED TREATMENT**

The basic steps involved in performing an IV regional block are as follows:

1. Confirm the immediate availability of a functioning positive-pressure oxygen delivery system, as well as appropriate airway management equipment. Also, confirm the immediate availability of medications for the treatment of anesthetic-induced convulsions (Table 3-8).

2. Place an IV in the contralateral, uninjured, arm. A patent IV line is of paramount importance in treating the complications of this block. Obtain a baseline set of vital signs, including heart rate, respiratory rate, oxygen saturation, and blood pressure. Pulse oximetry as well as cardiorespiratory status should be monitored continuously.

3. Select an appropriate tourniquet. An orthopedic tourniquet that can be fastened securely should be used. Because Velcro may become less adhesive with time, check the tenacity of the tourniquet before use. As an added safety measure, the tourniquet may be covered with strong adhesive tape or an elastic bandage after application. The tourniquet should fully encircle the arm and overlap back on itself by at least 6 cm. The arm may be minimally padded with cast padding underneath the tourniquet. If a pneumatic tourniquet is used, the provider must be familiar with the location of the tourniquet pressure gauge and valves, because these features vary in location from model to model. Narrow-cuffed double tourniquets may not effectively occlude arterial flow, and their use has been discouraged. Tourniquet discomfort should not be a problem during short procedures, but if this develops, a second tourniquet can be applied distally over the anesthetized area of the arm.

4. Palpate the radial pulse of the injured limb.

5. Place and secure a short 22-gauge cannula or 23-gauge butterfly needle in a vein on the dorsum of the hand of the fractured limb. IV catheters can be secured more readily. If a distal vein is unavailable, a proximal vein or even an antecubital vein can be used, but may result in a less effective block.

6. With the tourniquet deflated, exsanguinate the limb by vertically elevating it above the level of the heart for 60 seconds.

7. Rapidly inflate the tourniquet to a pressure of 225 to 250 mm Hg or 150 mm Hg above the patient’s systolic blood pressure. Check for disappearance of the radial pulse. Cross-clamping the tubing of the cuff after inflation is discouraged because it might prevent detection of a small leak. Constant observation of the cuff pressure gauge is recommended.

8. Lower the extremity and slowly inject the local anesthetic. This injection should be done over a period of 60 seconds. A concentration of 0.125% to 0.5% plain lidocaine (1.25 to 5 mg/mL) is used. Bupivacaine is contraindicated for this block because of its cardiotoxicity. To prevent thrombophlebitis, the local anesthetic solution must be free of any additives or preservatives. In different studies, the recommended dose of lidocaine has varied from 1.5 to 3 mg/kg. A dose of 1.5 mg/kg appears to be safe and effective and may be associated with a decreased rate of complications. One study has recommended a maximal lidocaine dose of 100 mg for this block. The skin of the extremity becomes mottled as the drug is injected. The patient, unless he or she is very sedated, and the parents, if they are watching, should be warned that the extremity will look and feel strange. Analgesia and muscle relaxation develop within 5 minutes of injection. For fractures at the wrist, placement of a regular Penrose drain tourniquet around the distal forearm may improve distribution of the local anesthetic solution at the fracture site.

9. To improve analgesia for fracture reduction, the last 2 mL of local anesthetic solution may be injected directly into the fracture hematoma. The technique of local infiltration anesthesia, or hematoma block, is discussed later in this chapter.

10. Reduce the fracture and apply the cast or splint.

11. Leave the cuff inflated for at least 15 minutes, even if the surgical procedure takes less time to prevent significant entry of local anesthetic into the general circulation.

12. Monitor the patient closely for at least 15 minutes for any complications related to the block. The treatment of local anesthetic-induced systemic toxicity has been discussed (Table 3-8).

13. Depending on whatever sedation has been administered, the patient should be monitored until discharge criteria are met (Table 3-5). An assistant must be present to watch the patient, the tourniquet, and the monitors at all times.

**REGIONAL NERVE BLOCKADE OF THE UPPER EXTREMITY**

Regional nerve blockade can be administered at several levels of the upper extremity from the axilla to individual digits. In the following section, various nerve blocks will be described based upon anatomic level.
Axillary Block

The axillary block is the most common method to anesthetize the majority of the brachial plexus. This can be used for procedures at, or below the elbow. The only sensory nerve not reliably anesthetized with an axillary nerve block is the musculocutaneous nerve, from which the anterolateral cutaneous nerve of the forearm arises. Therefore, achieving a complete block of the forearm may require an additional, separate injection to anesthetize this nerve (see musculocutaneous nerve block below). A single infraclavicular injection could be utilized to obtain the same result, but usually requires ultrasound guidance. As there are easily palpable landmarks for an axillary block, this block can be performed without ultrasound.

Potential complications of an axillary nerve block include systemic lidocaine toxicity, hematoma formation, and persistent neurologic symptoms. During injection for an axillary nerve block, the provider should continue to inject if they feel any resistance, as this may be a sign that the needle is within the nerve substance. Horner syndrome has also been reported. In actuality, complications of axillary block anesthesia are rare. None were encountered in the series reported by Cramer et al. of 111 children with displaced forearm fractures treated in an ED setting. Contraindications to axillary block anesthesia are the presence of a coagulopathy of any type, a pre-existing neurologic or vascular abnormality of the extremity, axillary lymphadenitis, or an uncooperative or combative patient.

AUTHOR’S PREFERRED TREATMENT

The basic steps involved in performing an axillary block are as follows:
1. The axillary artery is the primary landmark for this block. The child is positioned supine with the injured arm abducted and externally rotated 90 degrees. Procedural sedation may be required for block placement in children.
2. The axilla is prepped with a bactericidal solution and draped with sterile towels.
3. The axillary artery is palpated in the axillary fossa and trapped between the index and long fingers against the humerus. If difficult to find, asking the patient to gently adduct the arm against resistance highlights the groove between the coracobrachialis and the pectoralis muscle where the artery can be located (Fig. 3-2).
4. A 1% lidocaine solution at a dose of 3 to 5 mg/kg is used for injection. The target for delivery of the anesthetic agent is the axillary sheath, which contains the axillary artery and vein surrounded by the radial nerve (posterior), median nerve (anterolateral), and ulnar nerve (medial). The musculocutaneous nerve courses outside of this sheath through the coracobrachialis muscle on its way to run between the biceps and the brachialis, and therefore, may escape blockade. Proper placement of the needle can be confirmed by several methods. If available, ultrasound and/or nerve stimulator can be very helpful in placement. If a nerve stimulator is available, it is attached to a 22-to 25-gauge insulated needle, set to 1 mA current, and the needle is inserted in line with the artery at a 45-degree angle until one of the three things happen: Blood returns, paresthesias are noted by patient, or distal muscle twitches are elicited. If local muscles are stimulated you need to back out and redirect as you have penetrated nearby muscles and will miss the desired nerves. Following this, the stimulator is switched off, and a weight-based dose of anesthetic is injected, stopping every 5 mL to aspirate to check for intravascular needle migration.
5. Alternatively, the transarterial method of axillary block has also been shown to be efficacious in a pediatric setting.