Chapter 21
PEDIATRIC REGIONAL ANESTHESIA

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Introduction

The modern practice of pediatric regional anesthesia has become complex. Ultrasound guidance, electrical stimulation, specialized needles and catheters, designer local anesthetics and adjuncts, etc., are now the *de facto* standards of care in the developed world. However, regional anesthesia has been practiced for many decades by a dedicated group of practitioners long before any of these modern developments occurred. In fact, some of the earliest anesthetics were regional anesthetics. While many nerve blocks have become more reliable, and somewhat safer with the application of new technology, many basic blocks are still manageable by traditional techniques and equipment.

Regional anesthesia is the generic term used to describe peripheral nerve, plexus, and neuraxial blockade, all of which are used to provide anesthesia and analgesia to a specific *region* of the body. Some of these techniques have existed for well over a century. However, as general anesthesia improved over that same century, and complication rates related to general anesthesia plummeted, the use of regional anesthesia, at least in the form of plexus and peripheral nerve blocks, waned significantly. While epidural and spinal anesthesia continued to be practiced routinely, plexus and peripheral nerve blocks struggled under the weight of imperfect success and modest, but significant, complication rates. The development of electrical nerve stimulation for nerve localization incrementally improved the success rate of peripheral nerve blocks, but still did not guarantee success. More recently the availability of portable, easy to use, and somewhat affordable ultrasound machines has fueled a wave of interest in performing peripheral nerve blocks. Affordable being a relative term of course. Ultrasound guided nerve blocks have a near perfect success rate in the hands of a well-practiced anesthesiologists. Some complication rates, however, have not measurably decreased despite this technology. And while certain incidents, such as intravascular drug injection, have decreased in the ultrasound era, other problems such as transient or permanent nerve injury, while very rare, still persist. Neuraxial blockade also improved gradually throughout this period, mostly due to equipment improvements, but also with increased knowledge of local anesthetic, opiate, and adjuvant drug pharmacology. While all these developments have clearly brought regional anesthesia into the mainstream of anesthetic practice, there continue to be challenges, especially where resources are limited.

This brief history, ignores the simple fact that much of the developing world is without even the most basic of anesthesia supplies, let alone special needles, catheters, drugs and equipment to localize nerves. Some sites may have an abundance of needles and local anesthetics, while others may have only ketamine or halothane available to provide anesthesia. And while a discussion of every conceivable combination of resources is not possible in this short chapter, my goal is to describe ways in which regional anesthesia may contribute to patient care, even when resources are limited.

This chapter will address the basic indications, contraindications, benefits, and risks of regional anesthesia in infants, children and young adults. It is not meant to be a step-by-step technical manual for the performance of every potential block, but will point out some important procedural details that differentiate these techniques from adult practice. Finally, this discussion is tempered by the knowledge that many sites are severely limited by the scarcity of equipment and human resources.

PEDIATRIC versus ADULT REGIONAL ANESTHESIA

The mantra of the pediatric anesthesiologist has historically been that "pediatric patients are not simply small adults." This principle can and should be applied when considering regional anesthesia as well. There are many anatomic differences other than simply "smaller." These differences necessitate alterations of technique when performing blocks in infants and children. Additionally, physiology, pharmacology, and behavioral issues specific to children will dictate many nuances. Block choice, drug choice, dosing, awake-versus-asleep block placement, likelihood of success, are some examples of decisions that are influenced by pediatric specific practice.

Pediatric anesthesiologists generally are accustomed to placing neuraxial, plexus and peripheral nerve blocks in patients under general anesthesia, or at minimum, when they are heavily sedated. This is a contentious topic with a great deal of opinion but little definitive evidence to support any position. Guidelines from the American Society of Regional Anesthesia (ASRA), do recommend performing both peripheral and neuraxial blocks in adults while awake. Recommendations from ASRA for children, however, agree with most pediatric anesthesiologists that careful application of regional anesthesia in anesthetized patients is safe and effective.[4] Large surveys documenting complications from pediatric regional anesthesia support this view. The complication rate of blocks performed on anesthetized pediatric patients does not exceed the complication rate of blocks performed on adults who are awake. Performance of most blocks in children, while certainly *possible* without heavy sedation or general anesthesia, can be a trying experience for the patient, staff, and anesthesiologist. Since most regional blocks are placed with the goal of

[4]*With the possible exception of interscalene nerve blocks, which ASRA suggests should never be performed on anesthetized patients.*

optimizing postoperative analgesia, most will be performed after general anesthesia is induced.

In some cultures and in this author's experience, many minor procedures, including regional anesthetic blocks, *can* easily be done with gentle persuasion and perhaps a hovering parent or authority figure on children as young as five years of age. This is an example of how local norms, when combined with patient and parent temperament, can influence the conduct of the anesthetic. Parental presence is more than enough persuasion to keep a school age child still in some parts of the world, while in other cultures this approach would have little hope of success. Regardless, even when the regional technique and conditions are perfect, most children cannot tolerate the psychologic demands of undergoing surgery while awake, and the stillness requirement is beyond all but the most calm and mature children. As a result, general anesthesia or heavy sedation is still usually required, and placement of blocks on children who are awake is rarely truly indicated or necessary.

Placement of nerve blocks and neuraxial block under moderate or heavy sedation is an alternative to general anesthesia in select patients. However, sedation can often have the opposite of the intended effect and result in an uncooperative, partially sedated or agitated child. Sedation often tends to be a more dynamic and difficult task than general anesthesia, and is usually best done in circumstances where another trained practitioner can dedicate him/herself solely to that task while the anesthetist can dedicate his/her attention solely to performance of the block.

BENEFITS OF REGIONAL ANESTHESIA

As discussed above, most regional anesthetics in children are placed with the patient heavily sedated or under general anesthesia. So if the patient needs a general anesthetic anyway, why bother adding a regional anesthetic? There are several significant benefits to adding regional anesthesia to the anesthetic plan, many of which have been demonstrated in adult studies. The pediatric literature is less clear, but despite this, some overall conclusions can be made about using regional anesthesia in children.

1. Use of regional anesthesia decreases the neuroendocrine stress response to surgery. There is a dramatic sympathetic, hormonal, and immunologic response to the barrage of afferent inputs resulting from the surgical insult. While high doses of opiates and general anesthesia attenuate the effects of these insults, the only reliable way to halt these responses is via regional blockade. It is likely that many perioperative complications, namely cardiovascular, pulmonary, coagulation related, and gastrointestinal events, are linked in part to the stress response. There is evidence for decreased morbidity and mortality in adults when regional anesthesia is used, though the evidence is not completely conclusive at present. However, even modest improvements in morbidity and mortality are relevant outcomes. Ongoing research continues

into the complex biology of the surgical stress response and its implications in both adult and pediatric patients.

2. Addition of regional anesthesia to general anesthesia can reduce the amount of general anesthetic agents required to maintain unconsciousness and stillness during surgery, and can significantly reduce the opiate requirements during and after surgery. Smaller doses and fewer medications generally mean less cost and fewer side effects. Opiates in particular, have a wide variety of side effects, which can be minimized by using regional anesthesia for postoperative pain control.
3. It is clear that regional anesthesia improves acute postoperative pain management. Improved pain control is a worthy goal in and of itself on the basis of humanitarian empathy. However, there may be benefits to decreased pain, other than patient comfort. Patients with less pain immediately after surgery are less likely to develop chronic pain syndromes. Neonates who are repeatedly exposed to painful events show evidence of detectable changes in behavior later in life. Finally, functional recovery from surgery is also a benefit of good acute pain management. Despite the fact that most functional recovery data come from the adult literature and rarely focus solely on regional blocks, better pain management certainly improves patient satisfaction and likely promotes more rapid and complete functional recovery. Fewer physiologic and behavioral complications are all likely benefits.
4. Economic benefits associated with regional anesthesia include avoidance of postoperative admission for pain management and decreased utilization of post anesthesia care units. The economic advantage of ambulatory surgery sometimes hinges on management of pain and the complications of that management. Given the cost of staffing post anesthesia care units, reduction in this need, even if only a few minutes per case, can have a significant cumulative cost saving.
5. Regional anesthesia, when used in lieu of general anesthesia, is indicated in a limited number of small, high-risk infants in whom general anesthesia carries an inordinately high likelihood of complications. In these cases, avoidance of a high-risk general anesthetic is of benefit. These specific situations will be pointed out below.

It is often difficult to objectively establish the risk-benefit ratio of such interventions. While complication rates have been published and reveal very low overall risk, the benefit is more difficult to quantitate, as there are few high quality studies. Practitioners who routinely use regional anesthesia have no doubts as to its benefits, especially with regards to its superior pain control. However, for some, it may be difficult to justify even rare potential complications for pain control alone. Since the experience of pain has such a profound emotional component, it is often difficult to prejudge the importance of good pain control for a specific patient or family. Additionally, pain is much more of an emotional event in children, and as such may take on a level of importance that is beyond what we can objectively understand. The risk-benefit ratio for every patient should be determined individually, and with as much input from the patient (if old enough) and/or family members as possible. Again, cultural norms play a significant role in this regard. People from traditionally “stoic” cultures may be less willing to accept complication risk for the benefit of short-term pain alleviation, while those from other cultures may have significantly different attitudes on this subject.

GENERAL RISK CONSIDERATIONS

Infectious Complications

All neuraxial and peripheral nerve blocks are invasive procedures that carry a small risk of infection. While infectious risk is quite low, infections, especially those occurring in the neuraxis, are potentially catastrophic. Meningitis and epidural abscess have both been reported after neuraxial anesthesia. Fortunately, basic sterile technique is usually all that is required to prevent most infections. Obviously, needles and catheters must be sterilized. Skin preparation with iodine, chlorhexidine, or alcohol-based solutions is adequate when used appropriately. Alcohol and chlorhexidine solutions must be allowed to dry in order to be effective anti bacterial agents, and there is a theoretic risk of neurotoxicity if they are transported by the needle and neural structures are exposed to these agents. Since some neuraxial infections can be caused by respiratory flora, it is appropriate for the anesthetist to wear a facemask when performing neuraxial blockade. When inserting neuraxial and peripheral indwelling catheters, the operator should maintain a sterile field and wear sterile gloves. Single shot blocks, however, can usually be performed safely using skin prep, followed by a “no touch” technique using a sterile needle.[5]

Bleeding Complications

In otherwise normal patients, the risk of bleeding is quite low. Epidural hematoma after neuraxial blockade has been reported in otherwise normal adults but is extraordinarily rare. There are no equivalent reports in pediatric patients. However, patients with bleeding disorders are at a significantly higher risk for epidural hematoma, and *should not receive any sort of neuraxial block*. This includes patients with hematologic or systemic disorders that lead to bleeding, or patients being treated with anticoagulant medications. Most case reports of epidural hematoma after neuraxial blockade are in adult patients being treated with low molecular weight heparin. Epidural hematoma must be treated aggressively and rapidly, usually with neurosurgical intervention to decompress the spinal cord, in order to avoid permanent neurologic deficit. There

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[5] In the *“no touch” technique an area of skin that has been prepped with antiseptic remains untouched by any non-sterile items, including hands, gloves, or equipment for the entire performance of the procedure. Since infective agents do not “jump” from non-sterile areas to sterile areas without direct contact, this technique is considered acceptable to prevent inoculation of a puncture site.*

are few data in the pediatric population, but the safest approach for patients know to have bleeding disorders is to avoid spinal or epidural anesthesia altogether.

Plexus and peripheral blocks are a bit more of a gray area. The risk of bleeding from most peripheral blocks is relatively low, even in patients with inherent or acquired coagulation defects. A vessel puncture is usually well tolerated and easily dealt with. Some peripheral blocks may have a higher incidence of vessel injury and hematoma formation than others (e.g., axillary versus ilioinguinal block.) Additionally, peripheral blocks have a far lower potential for injury, even if a large hematoma is created during the block, as the hematoma does not typically occur in non-compliant spaces. The use of ultrasound (when available) is the best way to avoid puncturing vessels during plexus and peripheral nerve blocks. For those not using ultrasound, the most conservative approach would be to avoid peripheral blockade in patients with a known bleeding diathesis. The benefit of a peripheral block in a coagulopathic patient must be balanced against the risk of bleeding on a case per case basis.

Nerve Injury

Several very large studies in children have documented a very low rate of temporary nerve dysfunction or permanent neurologic deficits from any regional anesthetic. The permanent deficit rate from nerve injury in adults undergoing neuraxial anesthesia is estimated to be 0.04%, whereas in children, the rate is reported as essentially zero. Despite this overall safety record, there *are* several case reports (outside of the above mentioned large scale studies) of severe permanent neurologic deficits due to spinal cord injury occurring during placement of regional anesthetics in children (both epidural and interscalene blocks). After peripheral blockade in adults, the temporary nerve dysfunction rate is significantly higher (0.3 - 3%), with the vast majority of those dysfunctional symptoms disappearing within several weeks to months. A similar low rate of neurologic complications has been demonstrated for children undergoing peripheral nerve blocks, with few if any true permanent injuries.

Post block nerve dysfunction may be the result of local anesthetic toxicity rather than mechanical injury from needle trauma or pressure injury from injection. The most compelling evidence to support this is that the relative rate of nerve injury in the pre versus post ultrasound era appears to be similar. It is highly likely that before ultrasound was used routinely, passage of needles through nerve bundles was common, if not desired (i.e. paresthesia seeking techniques). Additionally, when using ultrasound and nerve stimulation together, we often see that contact of the nerve by the tip of the needle does not always result in a motor response or a paresthesia. Again, this implies that prior to using ultrasound, nerve-needle contact was likely common while seeking muscle twitches. Pressure injuries which are caused by direct injection of drugs into nerves has been speculated to occur; we would expect this type of event to be far less likely in the ultrasound era and there are studies which place significant doubt on this mechanism of damage.

Ischemia from epinephrine containing solutions has also been suspected as an additional possible mechanism of nerve injury, though the data are not conclusive. And finally, there are numerous case reports associating preservatives used in local anesthetic preparations (especially benzyl alcohol) as the causative agent in nerve injury after neuraxial blockade. Most of these observations indirectly implicate the local anesthetic itself as the problem. At present, however, there is not enough evidence to support one particular mechanism for nerve injury over another. Thus, it would seem prudent to avoid multiple needle passes, high-pressure injections of drugs, very large doses of local anesthetics, and medications containing preservatives.

LOCAL ANESTHETIC PHARMACOLOGY

Local anesthetics are most easily classified by their chemical structures, that is amides or esters. However, it is far more useful to classify these drugs by their clinical properties, the most relevant being onset time, duration of action, and potential for toxicity. A few of their clinical differences are of particular interest to us. Lidocaine and bupivacaine are the most commonly used local anesthetics and are readily available throughout the world. While there are locations where tetracaine, chloroprocaine, ropivacaine, levobupivacaine and mepivacaine may be available, this chapter will focus primarily on lidocaine and bupivacaine.

Table 21-1: Most Common Local Anesthetics Classified by Duration of Action

Short	Medium	Long
chloroprocaine procaine	prilocaine lidocaine mepivacaine	tetracaine bupivacaine ropivacaine levobupivacaine

All local anesthetics impart their biologic effects, both therapeutic and toxic, by binding to voltage gated Na^+ channels in nerve and other specialized tissue (e.g., conduction fibers in cardiac muscle). Local anesthetic systemic toxicity is usually the result of an inadvertent intravascular injection of drug, but occasionally can result from over dosage and uptake of drug. This is a feared complication of most types of regional anesthesia. The tighter range of doses and narrow therapeutic window for these drugs in neonates, infants and small children magnifies the problem. Additionally, limited clearance of local anesthetics by neonates and infants, as well as decreased serum protein binding, further narrows the therapeutic window of these drugs. Great care should always be taken to calculate the absolute maximum dose of the drug when administering local anesthetics.

Table 21-2: Maximal Allowable Doses for Common Local Anesthetics

Drug	Single Dose (mg/kg)	Continuous infusion rate in patients > 6 months old (mg/kg/hr.)	Continuous infusion rate in patients <6 months old (mg/kg/hr.)
bupivacaine	2.5-3	0.4-0.5	0.2-0.25
lidocaine	4-7	1.6	0.8
lidocaine w/epi	6-10	n/a	n/a

Epinephrine has little influence on plasma levels for bupivacaine, probably because bupivacaine has some inherent vasoconstrictor effect on its own. There is a notable idiosyncrasy about lidocaine in patients with right-to-left shunting congenital cardiac lesions. Since lidocaine is normally heavily sequestered in pulmonary tissue, plasma lidocaine levels are significantly higher in patients with right-to-left cardiac or pulmonary shunts. The wide range of maximal allowable doses reflect the fact that anesthetic uptake is significantly different with different blocks. Intrapleural and intercostal blocks, for example, are associated with the highest uptake of drug. Conversely there is little drug uptake following wound infiltration with local anesthetics or spinal blocks. Plexus blocks and epidural blocks are somewhere in between these extremes.

In neonates and infants, incomplete myelination of most nerves allows the use of lower doses of local anesthetic than those required for a similar block in an adult. After two years of age the dose of drug required (per kg) appears to approach that required for older children and adults. Neonatal animals also appear to be relatively resistant to the direct cardiac toxicity of these drugs. Whether this resistance to direct cardiotoxicity also exists in human infants is not known, so it is probably best to assume there is no difference in the response of adults and infants to the systemic effects of these drugs. The practitioner should always take appropriate precautions to prevent inadvertent intravascular injection of local anesthetic, and to avoid administering local anesthetics in excess of the recommended dose ranges.

While measuring drug levels is potentially useful, it is expensive, and seldom available. The diagnosis of local anesthetic toxicity is primarily clinical. All local anesthetics demonstrate the same basic sequence of toxicity when the plasma level rises to toxic levels, with the notable exception that bupivacaine's cardiac toxicity is particularly difficult to treat. The central nervous system manifestations of local anesthetic toxicity have a typical prodrome. These symptoms and signs, in order of lowest to highest plasma concentration of local anesthetic, are vertigo/dizziness, anxiety, tinnitus, circumoral numbness, tremors, myoclonic movements, seizures, and coma. Cardiovascular toxicity usually occurs at approximately three times the plasma concentration required for seizure activity. At lower drug plasma concentrations, CNS excitement is associated with tachycardia, hypertension, and increased cardiac output. As plasma concentrations rise, true cardiovascular depression ensues with the occurrence of hypotension, decreased cardiac output, arrhythmias and finally cardiac arrest.

It is important to remember that this typical sequence of events is not absolute. It is possible, for instance, to see seizures or arrhythmias as the first sign of local anesthetic toxicity, especially when the plasma concentration rises rapidly. Treatment of local anesthetic toxicity has traditionally been supportive: manage the airway, control seizure activity with benzodiazepenes (e.g. diazepam, lorazepam, midazolam) or a hypnotic (e.g. barbiturate, propofol), and treat specific cardiovascular issues as they arise. More recently it has been shown that many manifestations of toxicity can be halted or reversed by the administration of a 20% intralipid emulsion intravenously (i.e., 1.5 ml/kg followed by an infusion of 0.25 ml/kg/min; rebolus 0.5 ml/kg/min of intralipid if necessary). In the developed world, the standard of care is to have intralipid immediately available in any setting where regional anesthesia is performed. Even though intralipid emulsion is inexpensive, its availability may be limited in some parts of the world. Propofol is not an acceptable alternative to intralipid (even though propofol preparations contain intralipid), since the volume of the preparation required to attain the appropriate intralipid dose will result in a gross overdose of propofol. When intralipid is available for the treatment of local anesthetic systemic toxicity, it is recommended that treatment be initiated at the first signs toxicity.

Unfortunately, the use of local anesthetics can occasionally cause toxicity, even when they are injected appropriately *(see nerve injury discussion above.)* Most of the reports of nerve dysfunction after plexus blockade have occurred in adults, and implicate bupivacaine most commonly. However, since bupivacaine is the most commonly used drug for plexus blockade, we would expect complications to be more commonly reported following its use. The true incidence of nerve dysfunction does not, however, appear to favor any particular local anesthetic. One exception, though, may be lidocaine and its use in spinal anesthesia. Lidocaine is no longer used for spinal anesthesia in most developed countries, due to a number of case reports of the drug causing transient neurologic symptoms after its use. No equivalent cases have been reported in children. However, minor transient neurologic sequelae are not likely to be discovered in infants and preverbal children, so the incidence of injury may be higher than reported in these age groups. Despite these concerns, it is important to recognize that very large surveys of regional anesthesia in pediatric patients reveal startlingly low rates of either temporary or permanent nerve injury.

Since intravascular drug injection can easily lead to systemic toxicity, it is always prudent to aspirate through needles and catheters prior to any injection of local anesthetic and then to slowly give incremental injections of the total dose. The first increment should serve as the "test" dose to detect signs of an intravascular drug injection. However, negative aspiration tests *never* guarantee that the needle or catheter is not intravascular. In children it is recommended that test doses contain epinephrine at 5 mcg/ml (1:200,000). Test doses with only local anesthetic are not interpretable in an anesthetized patient, or in preverbal/immature children who cannot give feedback on subtle neurologic prodromal symptoms (See above). Even frank seizure activity may not be detectable during general anesthesia. Heart rate and blood pressure responses to an epinephrine test dose can be quite variable in anesthetized pediatric patients, especially when a halogenated vapor anesthetic is the primary agent used to produce general anesthesia. Pretreatment with atropine may make heart rate and blood pressure responses more reliable. A more sensitive indicator, however, is an increase in the T wave amplitude on a continuous electrocardiogram (with a 25% increase in amplitude considered a positive test). If continuous ECG monitoring is not available, then an increase of 10 beats per minute in heart rate or a 15mmHg increase in systolic or mean blood pressure is also considered a positive test. Lack of capability for ECG monitoring is a relative contraindication to the use of doses of local anesthetics that approach toxic levels. That risk-benefit analysis should be made on a case-by-case basis.

NEURAXIAL TECHNIQUES

Spinal Anesthesia (Subarachnoid Block, SAB*)*

Spinal anesthesia is a reasonable means of providing anesthesia for surgery below the umbilicus when general anesthesia is undesirable (i.e. the very high risk premature or ex-premature infant). It is also useful for providing analgesia as high as the thoracic levels. Occasionally, mature pre-teenage and teenage children may undergo SAB as a primary anesthetic, but the incidence of post dural puncture headache is significant in this age group. While small diameter pencil tip needles (e.g. Sprotte, Whitacre) will lessen the incidence post Dural puncture headache in the older age group, these needles are much more expensive and less available than the traditional Quinke type needle. Otherwise equipment needs for SAB are minimal and as such, this technique is a useful way to provide surgical anesthesia and postoperative pain relief in resource-limited environments.

Use of SAB is often used in preterm and former preterm infants to decrease the real risk of apnea after general anesthesia. The risk of post anesthetic apnea is elevated until at least the post gestational age of 60 weeks, especially if the infant was born before 36 weeks of gestation, and/or has a hemoglobin concentration of less than 10g/dl. While using SAB, rather than general anesthesia for these patients, appears to decrease the rate of postoperative apnea, it does not *eliminate* that risk. Since patients who are less than 60 weeks post-gestational age should be strictly monitored for apnea after a spinal anesthetic anyhow, resource utilization is not necessarily improved through the use of SAB. However, the benefits of SAB may extend beyond simple apnea reduction. Some infants with significant lung disease may benefit from avoidance of general anesthesia and endotracheal intubation. In this circumstance the use of regional anesthesia to avoid tracheal intubation often can significantly reduce the level of postoperative care required. While SAB provides very dense sensory and motor blockade, the duration of a spinal anesthetic with bupivacaine or tetracaine is significantly shorter in neonates and infants than in older children and adults (90-120 versus >120 min).

There are some procedural details that need to be considered when performing a SAB in infants. First, SAB (or any neuraxial block) rarely leads to hypotension in infants, and consequently, some anesthesiologists will perform the SAB first and then place an IV in an insensate lower limb. Second, the conus medullaris of the spinal cord in infants ends at L2-3 and not L1, as in older children and adults. It is prudent to use the lowest interspace possible when inserting a needle into the intrathecal space of infants to avoid damaging the spinal cord. Third, while positioning of the patient for a SAB is by preference of the anesthetist, there are significant advantages to performing the block in a seated upright position. The sitting position, with the head/neck slightly flexed, is somewhat easier for an assistant to maintain, especially in the case of a vigorously squirming infant. But it is important that the assistant and anesthetist be cognizant of the infant's ventilation and oxygen saturation throughout the procedure. In a neonate with lung disease, even slight airway obstruction due to neck flexion will cause rapid oxygen desaturation. Whenever possible, the patients oxygen saturation should be measured during performance of a SAB. The sitting position also adds a hydrostatic pressure gradient to the CSF at the lumbar level, facilitating CSF flow through the needle.

A small skin wheal with 1% carbonated lidocaine[6] injected through the smallest needle available (30 gauge if possible) and/or the use of a topical local anesthetic (such as EMLA cream)[7] is helpful, especially when a 22 gauge spinal needle must be used for the block. A short (30mm) x 22-to-25 gauge Quinke tip spinal needle is typically used when available. While longer "adult" needles can be used, they are very awkward to use and have a significant amount of dead space, which can affect detection of CSF flow and can allow part of an infant's anesthetic dose to be left in the needle and not be injected into the subarachnoid space. Smaller gauge spinal needles can be used, but CSF flow can be very sluggish in this age group and smaller needles exacerbate this

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[6] *Adding sodium bicarbonate to neutralize the pH of lidocaine significantly decreases the initial sting from infiltration. Typically 1 mEq of NaHCO3 will neutralize the pH of 10cc of 1% lidocaine.*

[7] *EMLA cream is a eutectic mixture of lidocaine and prilocaine, which is effective at producing topical anesthesia through intact skin. In needs to be applied at least 45 minutes before anticipated need in order to be effective.*

problem. If it is felt the intrathecal space has been accessed with the needle but there is no CSF flow, *gentle* aspiration of the needle with a 1cc syringe is suggested. When injecting medication, it is important to be aware of the volume of the needle and either adjust the total dose volume in the syringe to compensate for drug remaining in the needle, or to flush the needle with 0.1-0.2cc of sterile preservative free saline after the local anesthetic is injected. After a SAB, the infant should be kept supine until the extent of cephalad spread of the anesthetic is stable. Placing the baby in a head down position, even transiently, can cause rapid cephalad spread of the hyperbaric local anesthetic solution and result in a very high or total spinal.

Table 21-3: Dosing Guidelines for Neonatal Spinal Anesthesia.

Hyperbaric Local Anesthetic	Dose Range	Duration
0.5% tetracaine	0.8-1.2 mg/kg	90-177 minutes
0.5% bupivacaine	0.8-1.2 mg/kg	90-177 minutes
2.5% lidocaine*	5 mg/kg	60-90 minutes

**There are numerous case reports of transient neurologic symptoms when using lidocaine for spinal anesthesia in adults. While no similar reports exist in infants or children, lidocaine should probably be avoided for SAB.*

The SAB technique in older children does not vary from that in an adult patient, with the exception that, depending on the age and temperament of the child, he/she may need significant sedation or general anesthesia prior to placing the block.

Spinal Analgesia

The use of intrathecal opiates has some utility for postoperative analgesia in ~~major~~ spinal, abdominal, thoracic and cardiac surgery. For example, addition of intrathecal opiates has been shown to be of significant benefit after major spinal surgery (e.g. scoliosis correction). These operations are associated with severe postoperative pain and a single intrathecal dose of morphine (10-25mcg/kg) placed by the surgeon under direct vision near the end of the procedure provides significant postoperative pain relief. *Preservative free* morphine is the most commonly used spinal opiate and doses of 10-30mcg/kg are typically used. Delayed respiratory depression can occur for as long as 24 hours post injection, especially when higher doses of narcotic are used. Respiratory depression is also more likely to occur when parenteral opiates are used in addition to the intrathecal morphine. When postoperative respiratory monitoring is not possible, the use of neuraxial opioids is contraindicated.

Epidural Anesthesia

While the caudal approach is primarily used for epidural analgesia in the pediatric population, there are several uses for caudal epidural anesthesia as the sole anesthetic in high-risk neonates and infants. Whenever one might consider a spinal anesthetic in an infant, a caudal epidural anesthetic is a good alternative, as it is often technically easier to perform and may have less potential for complications. It is reasonable to use a single shot caudal anesthetic for simple, short duration lower extremity or lower abdominal surgery (e.g., inguinal hernia repair, circumcision, rectal biopsy, achilles tenotomy, etc.).

Caudal injection is the simplest and most reliable way to access the epidural space in neonates, infants and children up to about 5-7 years of age. Up to this age, the sacral hiatus is relatively superficial and easy to identify with simple palpation at the apex of an inverted equilateral triangle drawn between the posterior superior iliac spines. Traditionally, the presence of a sacral dimple has been considered a relative contraindication to any caudal injections, due to their association with spinal dysraphism and other cord anomalies. More recent studies, however, have found this association to be quite weak.

Bupivacaine, 0.375%, is most commonly used drug for surgical anesthesia by the caudal route. By using the maximum permissible dose of 2.5-to-3mg/kg, it is possible to achieve approximately 90 minutes of surgical anesthesia up to the L1 level. Lidocaine or chloroprocaine are acceptable alternative drugs to use, but in all but the shortest of procedures (<45 minutes), use of these agents requires placement of a catheter in the sacral hiatus to permit repeated intermittent injection or continuous infusion of drug. Placement of a temporary epidural catheter is easily accomplished by inserting a small IV catheter (22 gauge) into the epidural space via the sacral hiatus, attaching a short extension tubing, and securing the catheter with adhesive dressing. This permits administration of intermittent boluses of local anesthetic during the surgical procedure. One useful dosing regimen, when using 3% chloroprocaine, is to administer 1 ml/kg of the drug initially, followed by 0.3 ml/kg boluses of the drug solution until the desired block level is achieved. Subsequently, approximately 1ml/kg/hour of drug is given, either by intermittent injection or continuous infusion. This dose scheme, while differing from previously described dosing limits for chloroprocaine, was shown in a small study to result in very low plasma levels of local anesthetic and no complications. Onset of caudal epidural anesthesia when bupivacaine is used may take 10-to-15 minutes to attain a dense enough block to perform surgery. The presence of flaccid lower extremities is usually a strong indication that the anesthetic will be adequate to perform the surgery.

There are numerous formulas for determining the drug volume required for a desired spread of a drug in the epidural space. The easiest and most consistent formula to use, in this author's opinion, is 0.05-ml/kg per spinal segment. This works well when discussing spread from the tip of an epidural catheter. However, practically speaking, 1.2-ml/kg of drug administered by caudal injection should reach up to mid thoracic dermatomes. One ml of drug per kg of body weight is usually sufficient to provide a block up to the high lumbar/low thoracic levels. This applies for both anesthesia as well as analgesia.

Other approaches to epidural anesthesia, such as lumbar and thoracic, are rarely used for surgical anesthesia in children. They can, however, be used to provide epidural analgesia.

Epidural Analgesia

Single shot caudal blocks for postoperative analgesia are the most common regional anesthetics utilized in children. It is a relatively simple procedure, has few equipment requirements and has an extensive safety record. It is indicated for lower extremity, genital, perineal, anal, and lower abdominal procedures. While it can be used for procedures above the umbilicus, its duration of analgesia at those dermatomes is limited. Single shot caudal blockade with 0.125-0.25% bupivacaine can be expected to provide about 4-8 hours of analgesia. Urinary retention and lower extremity motor weakness are potential complications that are rarely issues in infants, but could present problems for an ambulatory toddler.

If analgesia is desired for longer than 4-8 hours, one option is to add preservative free morphine (30-100-mcg/kg) or the α-2 agonist clonidine (1-2-mcg/kg) to the local anesthetic; both of these adjuvants are given as a single dose and not repeated. The result is a synergistic improvement in pain control and a longer duration of pain relief. However, complications such as sedation, nausea, pruritus, urinary retention, and respiratory depression can occur and may limit the use of these adjuvants, especially if medications and staffing to treat those problems are not available. Additionally, adding any opiate to the local anesthetic requires that postoperative respiratory monitoring is available and used. When morphine is added to the local anesthetic, respiratory monitoring is required for up to 24 hours after the final dose of morphine is administered.

Placing an indwelling epidural catheter is perhaps the best option for prolonged neuraxial analgesia. Since infusion pumps (either electronic or elastomeric) are often not available in settings with limited resources, intermittent manually administered boluses of drug may be given through these catheters. It is very important to maintain good sterile technique when catheters are repeatedly accessed for bolus drug injections. Depending on the surgery type, the final position of the catheter tip, and the drugs chosen, dosing schedules could be as frequent as every 3-4 hours or as infrequent as every 12 - 24 hours. When repeated bolus dosing of local anesthetics is used, motor blockade is a more likely than when the drugs are continuously infused. The patient must be prevented from falling if he/she is ambulatory, as some degree of motor weakness is common with epidural administration of local anesthetic. While the use of epidural catheters is very effective for pain control, they have relatively high resource requirements, including the catheter and infusion equipment itself, the staffing needed for both intermittent bolus administration of drugs and for respiratory monitoring when opiates are used. As a result epidural analgesia is less often used when resources are scarce.

However, if sufficient equipment and staffing are available, continuous epidural analgesia is a good option for postoperative pain relief. When this is the case, the following details should be considered. Caudal, lumbar, or thoracic catheters can be used, but caudal catheters are the most widely used in this author's experience. In fact, catheters can be successfully threaded blindly from the sacral hiatus to the thoracic dermatomes with modest success rates in children under 5 years of age. The epidural fat is very loosely packed in such patients, which permits catheters to be advanced from the sacral hiatus up to thoracic levels with little resistance. This is especially true in infants, and when a styletted catheter is used. Methods for determining the level of the resultant catheter tip include ECG monitoring (via the catheter), electrical stimulation, ultrasound, and epidurogram, all of which require significant additional equipment and resources. They do, however improve ones ability to place the tip of the catheter in the desired location for the block. Lumbar placement of catheters is also a reasonable choice in most infants and children, but placement of thoracic epidurals is best left to those with significant experience, as the potential for spinal cord injury can be much higher. If a loss of resistance technique is used for epidural access in a pediatric patient, the syringe should be filled with saline rather than with air, as inadvertent intravenous injection of significant amounts of air is possible. Such a venous air embolism can have catastrophic consequences in patients with right-to-left shunting lesions, and is significant even in otherwise normal infants. Placement of the epidural catheter tip near the dermatomal level of the expected surgical pain reduces the amount of local anesthetic required and/or allows one to successfully use lipophilic opiates, such as fentanyl or sufentanil, for pain relief. If the catheter tip cannot be placed at the correct dermatome, or many dermatomes must be covered, the only viable option is the use of more hydrophilic opiates (e.g., morphine, hydromorphone.) If it is available, the addition of clonidine to the anesthetic solution can be very useful for covering dermatomes distant from the catheter tip.

Drug choice for epidural analgesia depends highly on the location of the catheter tip. If the catheter is sited at or near the relevant dermatome, a dilute bupivacaine solution with fentanyl is an excellent combination of drugs for pain relief. If the catheter tip is far from the surgical dermatome (e.g., when using a lumbar catheter for thoracic surgery) there is little reason to use local anesthetic, as it is unlikely to reach the appropriate dermatome. In this circumstance, a hydrophilic opiate, such as morphine or hydromorphone, is a better choice of drug, as these opiates tend to spread significantly better than the lipophilic opiates fentanyl and sufentanil. Epidural hydromorphone and fentanyl appear to be associated with lower rates of nausea, urinary retention, and pruritus than morphine. Morphine, however, is universally available, inexpensive, and has a longer duration of action. As discussed before, all drugs used epidurally should be preservative free preparations.

Dosing of epidural drugs is complex and depends on a number of factors, including catheter location, intermittent versus continuous infusion of drugs, drug combination, number of dermatomes to cover, and of course the patient's age and size. Continuous infusion of drugs is usually the better approach, as it avoids large variations in the concentration of drug at the effect site and may result in fewer side effects. However, infusion pumps are quite expensive and are not universally available, so intermittent dosing of an epidural block may be the only choice. Notice the wide range of doses and the intervals between doses in the table below (**Table 4**). It is appropriate to adjust subsequent drug doses and intervals on the patient's response to the previous dose. Combining a local anesthetic and an opiate allows lower doses of either drug to be used than if they were used alone.

Table 21-4: Intermittent Epidural Dosing Guidelines

Drug	Dose	Interval
morphine	30-100 mcg/kg/dose	12-24 hours
hydromorphone	5-10 mcg/kg/dose	6-12 hours
bupivacaine 0.1-0.25%	0.2-0.5 ml/kg/dose	2-6 hours

Continuous epidural drug infusions can contain either single or multiple agents. It is typical to calculate the amount of local anesthetic to be infused and then to mix in an opiate to achieve the desired final dose of both agents (**Table 5**). For example, a 1 year old, 10kg child for whom we would like to infuse 0.4mg/kg/hr. of 0.1% bupivacaine would require an infusion of 4 ml/hour. By then adding fentanyl 2mcg/ml to the anesthetic solution, the child would also receive 0.8mcg/kg/hour of fentanyl.

Table 21-5: Continuous Epidural Dosing Guidelines

Drug	Concentration	Dose
morphine	20-50 mcg/ml	5-15 mcg/kg/hour
hydromorphone	3-20 mcg/ml	1-5 mcg/kg/hour
fentanyl	1-5 mcg/ml	0.5-2 mcg/kg/hour
bupivacaine	0.0625-0.2 %	0.1-0.5 mg/kg/hour*
lidocaine	0.5-1%	0.5-1.6 mg/kg/hour*

**Age dependent maximum doses should always be observed when calculating epidural dosing regimens.*

PLEXUS AND PERIPHERAL NERVE BLOCKS (PNB's)

As pointed out previously, most PNB's are usually placed for the management of postoperative pain. There may also be the circumstance where a PNB can be used as the primary anesthetic in a mature teen or pre-teenage patient. Postoperative pain is usually best managed by using a multimodal approach[8] with regional blockade at the cornerstone. Single shot drug injections are the most common form of PNB, but they only provide anesthesia/analgesia for a limited period of time. Single shot blocks are usually relatively simple to perform and require relatively little equipment. Unfortunately, most single injection PNB's last for 24 hours at best, and often for significantly less time. Anecdotally, this author has noted that even blocks performed with 2.5-3mg/kg doses of 0.5% bupivacaine usually last less than 12 hours when used for brachial plexus blocks in school age children or toddlers. Infants and adults experience somewhat longer duration of pain relief with most blocks. There is growing evidence that adding dexamethasone to local anesthetics for peripheral nerve blocks extends the duration of analgesia approximately 30%, although there are few data in pediatric patients, and safety data for adding this adjunct drug is still lacking. Epinephrine does increase the duration of blocks performed with lidocaine, but only modestly so when bupivicaine is used. There is no convincing evidence that any other adjunct drug consistently improves the quality or duration of PNB's.

Placing plexus catheters, if equipment and staffing are available for doing so, allows postoperative pain relief until the drug infusion is stopped and the catheter is removed, typically for up to five days. While the use of this technique extends the duration of blocks, it also adds significant complexity and cost to the procedure, and as such, is rarely used in environments with limited resources.

Dosing of PNB's is somewhat dependent on the location of the block and the desired effect. If the PNB is used solely for postoperative analgesia, lesser concentrations of local anesthetic can be used, usually in the 0.125%-to-0.25% range for bupivacaine. If, however, the goal is to minimize the surgical stress response or to guarantee muscle relaxation, a surgical anesthetic dose of 0.375-0.5% bupivacaine is required. It should be noted that the duration of drug action is directly correlated with the amount of drug injected, so in order to maximize the duration of analgesia from a single shot PNB, it is appropriate to administer the largest recommended safe dose.

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[8] *Multimodal analgesia refers to the use of several different drugs and techniques targeting different parts of the pain perception pathway. For example, by combining a regional anesthetic, a systemic opiate receptor agonist, a non-steroidal anti inflammatory (e.g. ibuprofen), and acetaminophen, a profoundly effective pain management strategy results. In combination each individual component can be minimized in order to lessen side effects.*

Plexus and Peripheral Nerve Localization

Nerve localization for PNB's relies on a thorough understanding of nervous system anatomy, motor and sensory innervation patterns, and surface landmarks. Injection of local anesthetic based solely on surface landmarks, however, has mediocre success rates at best, and is routinely found to be lacking in efficacy when compared to the use of ultrasound or electrical stimulation methods. A reproducible, reliable, safe, and inexpensive method for localizing the appropriate nerve and injecting medication as near to it as possible is the holy grail of peripheral and plexus regional anesthesia. The technique of seeking paresthesias in patients who are awake is not generally applicable to pediatric practice.

The present state of the art in nerve localization is to use real time ultrasound imaging to visualize the target nerve and the needle and/or catheter used to deliver the medication. Small stand-alone systems, however, can cost upwards of $70,000 USD. It is possible, however, to adapt a typical hospital owned ultrasound machine that is used for echocardiography or obstetrical imaging by acquiring a single high-resolution linear ultrasound probe. These linear array probes are usually 25-50 mm long, and operate at frequencies of 5-15 MHz. They cost a fraction of what a total system would cost. Even when the equipment is available, ultrasound guided regional anesthesia still requires a long and involved training period before any degree of proficiency with the technique can be attained. Medical missions often take portable ultrasound machines to do PNB's for postoperative pain. This is a great opportunity for local anesthetists to get exposure and training in the use of these techniques for PNB's. Ultrasound imaging is also an invaluable tool for teaching anatomy and other nuances of regional anesthesia to practitioners using alternative methods of nerve localization.

Since most practitioners trained in the last 20 years are familiar with motor *nerve stimulation* for localization of nerves, and the equipment needs are modest, this is probably the most viable option for doing blocks in resource-limited environments. The basic principle behind electrical nerve stimulation is that delivery of a small intermittent current through the block needle (i.e. the cathode) will usually depolarize the intended target nerve and elicit a motor response in that nerve's motor distribution. All other variables being equal, the amplitude of the motor response is inversely proportional to the distance of the needle tip from the nerve (i.e., the closer the needle tip is to the nerve, the greater the response). When a motor twitch is still present at a very low current, the needle tip should be near to the nerve, and injection of local anesthetic can proceed. Using surface mapping to locate nerves can also be helpful, and is particularly effective in pediatric patients due to the relatively small distance between nerves and the skin surface.[9] The use of surface mapping for this purpose requires a somewhat higher current setting on the

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[9] *Surface mapping is a noninvasive nerve localization technique accomplished by application of electrical current on the skin overlying a nerve plexus or peripheral nerve.*

stimulator (1-5 mA). The cathode must be applied directly to moistened skin above the anticipated injection site. Again, muscle response (twitching) is most prominent when the cathode-to-nerve distance is smallest. Microprocessor controlled peripheral nerve stimulators are commercially available throughout the world and are far less costly than an ultrasound system. Finally, while any needle can be used for electrical stimulation of nerves, the best results occur when specifically designed block needles with blunt tips, insulated shafts, and a simple connector designed for use with the particular brand of nerve stimulator are used.

While many blocks rely on specific localization of the nerve with a nerve stimulator or ultrasound, field blocks or infiltration blocks using anatomic landmarks are also used. Anatomic landmarks and tactile feedback during needle advancement are used to get the needle tip close to the target nerves. Blocks that rely on sensing "fascial clicks"[10] with advancement of the needle are best achieved with a blunt needle (known as a B-bevel needle), as sharp needles tend to pass through tissue with little observable resistance. A possible secondary benefit of short bevel needles is that there is potentially less nerve damage if the needle makes direct contact with a nerve. This theoretic advantage has never been proven, however. Short bevel needles of many differing lengths and gauges are manufactured specifically for performing nerve blocks, but may or may not be available depending on resources. Needles designed specifically for use with a nerve stimulator are usually insulated along the shaft of the needle to concentrate the highest current density near the tip of the needle. A Tuohy needle can be used if a blunt needle is not available. Tuohy needles give very obvious sensory feedback to the operator as the needle passes through fascial planes, and these needles are particularly useful for deeper blocks as they tend to track better due to their rigidity. They are, however, usually much larger in diameter and may be inappropriate due to their size. Unfortunately, electrical stimulation and landmark localization blocks have higher failure rates than ultrasound-guided blocks, even in the most experienced of hands. Consequently, they should always be carried out with a good backup plan for providing anesthesia or analgesia should the block fail.

Step by step performance of most routine peripheral and plexus blocks is well documented elsewhere, so the following sections will simply address the indications, contraindications, and a few caveats specific to each block. An excellent free source of information is the New York School of Regional Anesthesia website (http://www.nysora.com).

Brachial Plexus/Upper Extremity Blocks

The brachial plexus is a complex neurologic structure originating at the C4 through T1 nerve roots

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[10] *A fascial click is a sensation noted by the practitioner as the block needle is advanced through tissue. It is best described as an increase in resistance followed by a sudden "give" as the needle punctures a relatively dense fascial structure.*

and enervating the upper extremity, shoulder, and a portion of the neck and chest. Techniques for localizing the brachial plexus in pediatric patients include landmark, infiltration, nerve stimulation, and ultrasound. This discussion will assume the practitioner has a basic understanding of the sensory and motor innervation patterns of the brachial plexus. Proximal plexus blocks described in this section will require at least a nerve stimulator be used for plexus localization. Some more distal blocks can be accomplished with only a needle and local anesthetic. Ultrasound guidance, if available, will always yield the best overall success rates with the least risk.

The choice of block should be very specific to the sensory coverage needed for the surgery proposed. For surgery of the distal clavicle, shoulder and proximal humerus, the *interscalene* approach is most useful technique and is well-described using both nerve stimulation and ultrasound. Deltoid, or more distal muscle twitches, are acceptable endpoints when using a nerve stimulator. This approach frequently spares the lower roots of the brachial plexus (C8-T1) and as such, blockade in the distribution of the ulnar nerve will be unreliable. Nearly 100% of the time, the ipsilateral phrenic nerve will be blocked with the interscalene brachial plexus block. Additionally, the cervical sympathetic blockade that usually occurs produces an ipsilateral Horner’s syndrome (ptosis, hyperemia of the conjunctiva, nasal congestion). Neither of these side effects is of much consequence except for in patients with significant pulmonary disease. In these patients, loss of unilateral diaphragm strength can cause acute respiratory failure, and consequently, interscalene block should be used very cautiously in patients with pulmonary issues. Since morbidly obese individuals frequently have reduced pulmonary reserve, caution is also advised when using this block in these patients. It should be noted that the American Society of Regional Anesthesia recommends against using interscalene brachial plexus blockade in anesthetized adults or pediatric patients, due to several case reports of spinal cord injury. These case reports occurred before routine use of ultrasound guidance for blocks and may not reflect the risk when using an ultrasound-based technique. Nevertheless, except for the occasional mature preteen or teenager in whom the block can be performed under mild or no sedation, this block should be used with great care, and perhaps avoided completely in anesthetized pediatric patients.

For surgery from the mid humerus to the hand, *supraclavicular* or *infraclavicular blocks* are both reasonable choices. Both approaches can be done using either nerve stimulation or ultrasound. When a stimulator is used for localization of the brachial plexus, success rates are greatest when twitches of the hand are achieved. The block is usually of lower quality when only more proximal twitches are used as an endpoint. A supraclavicular block occurs at the level of distal roots and divisions of the brachial plexus, while the infraclavicular block occurs at the level of the cords. Both levels are proximal to the take off of the musculocutaneous nerve and reliably block this nerve. When a nerve stimulator is used to localize the brachial plexus during supraclavicular block, the reported incidence of pneumothorax as high as 6%. Proper use of ultrasound almost completely eliminates this risk. Additionally, while the incidence of phrenic nerve block is significantly reduced with a supraclavicular block compared to that with an interscalene block, it is not completely eliminated. Because of the significant risk of pneumothorax (with a nerve stimulator technique) and small but present risk of phrenic nerve block, the supraclavicular approach may not be the best choice of block for patients with limited pulmonary reserve. Additionally, if the resources to perform chest tube drainage for a pneumothorax are not available, alternative block methods should be seriously considered. Infraclavicular block also caries some risk of pneumothorax, albeit much less so than with a supraclavicular block, especially when the lateral (sub coracoid) approach is used. This is a relatively "deep" block and can be difficult to accomplish in larger patients (even with ultrasound). The success rate is good, however, when ultrasound is used, or if stimulation of the posterior cord of the brachial plexus is achieved (i.e. radial nerve mediated wrist extension) when using electrical stimulation.

*Axillary block*ade can be used for surgery that will be done distal to the elbow and is the one brachial plexus block technique that can be accomplished with nothing more than a needle and some local anesthetic. While a nerve stimulator or ultrasound technique can be used, the trans arterial approach (injecting an adequate volume of local anesthetic deep to and superficial to the axillary artery) is simple and relatively effective. Some practitioners simply use a "field block" technique by depositing drug below, above, and superficial to the axillary artery. Both of these techniques rely on the close proximity of the radial, median and ulnar nerves to the easily palpable artery. An additional injection of local anesthetic into the body of the coracobrachialis muscle can be done to anesthetize the musculocutaneous nerve, but the success rate with this block is inconsistent. Unfortunately, not blocking the musculocutaneous nerve during an axillary block is common and often negates the efficacy of this block. Since purposeful or inadvertent arterial puncture often occurs with axillary block, formation of an axillary hematoma is a common, but easily managed complication.

Simple field injections near terminal branches of the brachial plexus may sometimes be useful, especially to rescue an otherwise incomplete brachial plexus block. The median nerve can be blocked in the antecubital fossa, just medial to the brachial artery, or more distally between the flexor carpi radialis and the palmaris longus tendons. The ulnar nerve is best blocked by infiltrating local anesthetic under the flexor carpi ulnaris tendon and on the medial side of the ulnar artery. Performing a field block lateral to the radial artery near the anatomic snuffbox can sometimes be used to blindly block the radial nerve. Ultrasound guidance to block the median, ulnar and radial nerves in the forearm results in near 100% success rates, as these are very easy nerves to image. *Digital blocks* of the fingers are easy and safe with the caveat that epinephrine should never be added to the local anesthetic due to the risk of digital ischemia from this adjunct.

Lumbar and Sacral Plexus/Lower Extremity

Approaches to blockade of a lower extremity are essentially divided into two major groups*:* *lumbar plexus blocks* (T12-L4) and *sacral plexus blocks* (L4-S3). Lumbar plexus innervation of the lower extremity is comprised of the femoral nerve and its terminal saphenous branch, obturator nerve (anterior and posterior division), and the lateral femoral cutaneous nerve. These nerves are responsible for sensory innervation of the inguinal area, the anterior and lateral thigh, some portions of the medial thigh, a portion of the knee, and a strip of skin down the medial leg to approximately the medial malleolus. The sacral plexus innervation is comprised of the sciatic nerve and its terminal peroneal and tibial nerves, which supply the rest of the lower extremity. All these nerves can be blocked either individually or in groups.

A posterior lumbar plexus block ideally provides anesthesia and analgesia for hip surgery. The traditional posterior lumbar plexus block is a deep block in which local anesthetic is deposited within the body of the psoas muscle where the lumbar nerve roots travel. This is one of the few blocks where nerve stimulation is the preferred localization technique with quadriceps contraction being the desired endpoint prior to injection. This block is also the only reliable way, other than neuraxial techniques, to block all three major terminal branches of the lumbar plexus with one injection. Retroperitoneal hematoma, renal injuries, and injuries to the great vessels are high morbidity complications that make the risk-benefit ratio of this block somewhat questionable in this authors opinion. Consequently, experienced practitioners should only perform it. The lumbar plexus can also be approached anteriorly (e.g. 3-in-1 block, fascia iliaca block), but success with these anterior approaches is inconsistent. For the *3-in-1 block*[11], the needle is the same as if one were doing a *femoral nerve block*, but a larger volume of local anesthetic (typically 20-to-50ml in adults) is injected while pressure is applied to the tissues just distal to the needle. The *fascia iliaca block* is similar, but the needle is place more laterally, with the best success achieved with ultrasound guidance. For a landmark guided fascia iliaca block, a blunt needle is advanced while feeling for fascial “clicks”, since no specific nerve is targeted. The second click occurs when the needle pierces the fascia iliaca and a large volume of anesthetic is then injected. Theoretically, both these anterior approaches rely on local anesthetic tracking into the pelvis under the fascia iliaca, and into the psoas compartment, to block the lumbar plexus. Neither, however, reliably achieves full lumbar plexus blockade, and the obturator nerve commonly remains unanesthetized. As such, these anterior lumbar plexus blocks are not terribly reliable for surgical anesthesia, but can be useful as part of a multimodal analgesic plan in hip surgery.

For procedures on the mid/distal femur, thigh and knee, an isolated *femoral nerve block* can be done using electrical stimulation or ultrasound. Innervation of the knee is quite variable and

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[11] *The 3-in-1 block was originally named as such because it is an attempt to anesthetize the femoral, obturator, and lateral femoral cutaneous nerves with one anterior injection.*

includes contributions from the sciatic, femoral, and obturator nerves. For analgesia purposes, femoral nerve block alone is quite effective for reducing both pain and opiate consumption. When using the nerve stimulator to perform this block, it is important to achieve contraction of the quadriceps muscle as an endpoint and not accept a sartorius muscle twitch. Seeing the patella move up and down is the most reliable way to identifying quadriceps contraction. Injecting drug when only sartorius muscle twitch is present usually results in an incomplete or failed femoral nerve block. The most significant side effect of any femoral nerve block (including those achieved with lumbar plexus blocks) is quadriceps weakness, which lasts for the duration of the block. Falls have been reported when a patient who feels very comfortable after surgery (no pain), tries to bear weight on the partially paralyzed limb. A more distal variant of the femoral nerve block is the *adductor canal block*. This block produces modest analgesia of the knee while minimizing quadriceps weakness. The use of a knee immobilizer, or enforced non-weight bearing, for the duration of these blocks is crucial to prevent injuries. This may limit the usefulness of this block, depending on the circumstances.

It should be noted that heavy sedation plus a femoral nerve block, and/or lateral femoral cutaneous nerve block is a reasonably good option as an anesthetic for quadriceps muscle biopsy in patients who are potentially susceptible to malignant hyperthermia. The susceptibility to malignant hyperthermia is perhaps one of the few indications for “awake” regional anesthesia during childhood and may be the most cost effective option when resources are scarce. Infusions of non-triggering general anesthetic agents (i.e. propofol) may be very costly or completely unavailable. And while a ketamine/narcotic/barbiturate-based general anesthetic is certainly possible and inexpensive, it is a less than elegant alternative.

Anesthesia and analgesia of the posterior thigh, lower leg or foot can be accomplished with *sciatic nerve blockade*. This block can be accomplished via the classic posterior gluteal and sub gluteal approaches, or it can be done more distally in the popliteal fossa, where the nerve is relatively more superficial and easier to localize. Either ultrasound or nerve stimulation is appropriate for localization of the nerve. While selective blockade of the peroneal or tibial nerve is possible, it is rarely necessary. When using a nerve stimulator to localize the sciatic nerve in the popliteal fossa, it is typical to see either a plantar flexion-inversion (of the foot) response (tibial component) or dorsiflexion-eversion response (peroneal component). If, for example, surgery on the lateral aspect of the foot is planned it can be beneficial to look specifically for a peroneal muscle twitch, as this will ensure appropriate sensory block and have a quicker onset of blockade in that sensory area. Additionally, since the location of the split of the sciatic nerve into its peroneal and tibial components varies in person to person, and can be as proximal as mid thigh, it is prudent to do popliteal sciatic blocks as high up as possible if one wishes to anesthetize the entire nerve. It needs to be pointed out that the terminal sensory branch of the femoral nerve, the saphenous nerve, does supply some innervation of the medial aspect of the lower leg, the skin over the medial ankle and a variable amount of the medial foot. When ankle or foot surgery is planned within these areas, *saphenous nerve block* is also required for complete analgesia/anesthesia. Either a field block at the knee, near the saphenous vein, or a low dose femoral nerve or adductor canal block is typically done. The femoral nerve/adductor canal block is significantly more effective and reliable than the field block, but will often result in quadriceps weakness (as described above.) The sciatic nerve is large and consequently it is not uncommon for full onset of sciatic nerve blockade to take 30+ minutes when using long acting local anesthetic. Sciatic nerve blocks can last for upward of 36 hours. Again, partial lower extremity weakness or paralysis is likely and must be accounted for during postoperative care to prevent injury if patients try to walk.

For isolated foot surgery, the *ankle block* is simple and nearly risk free. Isolated nerves can be blocked individually to suit the particular need. The target nerves at the level of the ankle are the saphenous, sural, superficial peroneal, deep peroneal, and the tibial nerves. These blocks are usually performed by using specific landmarks for each nerve, or by performing field blocks, and require no equipment other than a needle and some local anesthetic.

Truncal Blocks

Thoracic paravertebral blocks rely on the existence of a paravertebral space bordered anteriorly by the parietal pleura, and posteriorly by the bony transverse processes of the spinal column. This block is useful for reducing/preventing post thoracotomy pain and for breast surgery in adults. This block is probably as effective as a thoracic epidural for pain management, with the added benefit of fewer side effects. "Walking" a needle off the transverse process of the appropriate vertebra and advancing it slightly while seeking a loss of resistance has traditionally been used to localize the paravertebral space. Since the risk of pneumothorax is significant when using this blind technique, the block should not be performed in environments incapable of managing a pneumothorax. Even with the use of ultrasound, which is the localization method of choice, there still is a modest risk of pneumothorax. If thoracotomy is planned, then the resources to manage this complication are available and this block is a reasonable choice. Additionally, the anesthetist can place catheters in the paravertebral space preoperatively, or the surgeon can place it under direct vision intraoperatively.

The *transversus abdominus plane block, or TAP block*, is an excellent block for abdominal surgery when neuraxial analgesia is otherwise contraindicated or impossible to perform. The terminal branches of the low thoracic (T8 - 12) and lumbar nerve roots consistently lie in the plane between the transverses abdominus muscle and the internal oblique muscle. Depositing local anesthetic in this plane reliably blocks abdominal wall sensation. The use of ultrasound for identification of this space is easy and reproducible, but performing the block using landmarks has met with variable success rates. The *rectus sheath block* is the most distal variant of the TAP block and covers only midline abdominal wall structures. As in the TAP block, ultrasound is the localization method of choice for this block, though landmark approaches are also well described. A very specific version of the TAP block, *the ilioinguinal nerve block,* is often used for surgery in the inguinal area. The ilioinguinal and iliohypogastric nerves are the terminal branches of the T12 and L1 nerve roots, respectively, and supply the skin over the inguinal area. Blockade of these nerves is especially useful for inguinal hernia surgery, inguinal orchipexy, hydrocele surgery, etc. Since these nerves run in the plane between the internal oblique and transversus abdominus muscles, the method typically described for identifying this plane is feeling for fascial "clicks" as the needle is advanced through the fascial layers. The efficacy of the block is significantly better when ultrasound is used for localization of the nerves. If an ultrasound machine is not available, it is still reasonable to attempt this block, as the rare complications are injection of drug into the peritoneal space or bowel, and an occasional femoral nerve block, both of which are of little consequence. Alternatively, the surgeon can place this block under direct vision during the surgical procedure.

Penile nerve block is often used for circumcision or other penile surgery in male infants and children. The traditional block relies on insertion of a needle below Scarpa's fascia and injection of local anesthetic. Since there is midline septation of this space, it is important to do this block bilaterally. Alternatively, subcutaneous injection of local anesthetic around the base of the penis, otherwise known as a *ring block*, is simple, but not quite as effective as a penile nerve block. Hematomas are a common complication of these blocks. As in digital blocks, it is important to avoid epinephrine-containing solutions because epinephrine has been implicated in causing vascular compromise of the penis after penile nerve block.

Conclusions

Regional anesthesia is one the most satisfying and elegant approaches to anesthesia and analgesia in pediatric surgical patients and there are numerous benefits to its skillful application. The challenges in the pediatric patient, while significant, should not be a barrier to its use by anesthetists accustomed to caring for infants and children. And while many of the most modern approaches to regional anesthesia in the developed world revolve around advanced and expensive technology, it is important to recognize that a good portion of the field was developed before many of these technologies were available and, as such, can be used by any practitioner willing to learn and use them. Your patients will thank you!

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