Clinical Pediatric Anesthesiology >

Chapter 33: Regional Anesthesia: Neuraxial

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INTRODUCTION

FOCUS POINTS

1. Local anesthetics are the primary medication utilized in regional and neuraxial anesthesia or analgesia, with or without other adjuvants.
2. The local anesthetics most commonly utilized are the amino-amides, bupivacaine, and lidocaine. However, given the decreased metabolism and clearance of amino-amides and resultant increased risk of local anesthetic toxicity in infants less than 6 months, chloroprocaine is preferred particularly for infusions administered for greater than 48 hours.
3. Adjuvant analgesics are used in combination with local anesthetics to improve the quality of neuraxial analgesia and at the same time decrease the concentration of local anesthetic agent needed to achieve adequate analgesia.
4. The single-shot caudal technique is the most commonly utilized neuraxial technique for ambulatory surgeries involving the truncal or lower extremity dermatomes.
5. Spinal anesthesia can be particularly useful when used as the sole anesthetic in ex-premature and term infants in an attempt to avoid intubation and/or exposure to general anesthesia.
6. Continuous epidural anesthesia/analgesia is primarily utilized for surgeries involving bilateral lower extremities, open thoracic surgeries, major intra-abdominal surgeries with visceral dissection, or spinal surgeries.

LOCAL ANESTHETICS AND DEVELOPMENTAL CONSIDERATIONS

Local anesthetics are the primary medication utilized in regional and neuraxial anesthesia or analgesia, with or without other adjuvants. The main mechanism of action regardless of chemical structure is the blockage of sodium channels with resultant blockade of neuronal impulse. As in adults, in order to prevent a neuronal impulse, three nodes of Ranvier must be blocked. The pharmacodynamic and pharmacokinetic differences in neonates and infants are imperative to understanding dosage administration. Local anesthetics largely exist in the ionized form and are therefore distributed to the extracellular body water compartment. In neonates and children, this space is nearly double that in adults and therefore results in lower peak plasma concentrations with initial bolus dosing due to the larger volume of distribution. However, due to synthetic liver function immaturity, infants under 6 months of age have decreased serum levels of both albumin and alpha-1-glycoprotein.[1] The lower concentrations of these serum proteins allow for higher free or unbound local anesthetics, placing these patients at higher risk of local anesthetic systemic toxicity with repeated doses or continuous infusions. Luz et al. reported that free plasma bupivacaine concentrations were significantly higher in infants than in older children receiving continuous epidural anesthesia.[2] Furthermore, the ability of the liver to clear and metabolize local anesthetics is greatly reduced in neonates, infants, and children under the age of 4.[3] The amino-amide local anesthetics rely on the cytochrome p450 system in the liver for metabolism which is also not yet fully developed in the neonate and infant. The ability to conjugate is not reached until approximately 3 to 6 months of age.[3] Due to the impaired hepatic clearance of the amino-amide local anesthetics, the elimination half-lives of these drugs are prolonged and the doses should be decreased for this group of patients.

The local anesthetics most commonly used are bupivacaine and lidocaine, both of which are amino-amides. Other amino-amides include levobupivacaine, ropivacaine, and mepivacaine. Levobupivacaine and ropivacaine offer a similar analgesic profile to racemic bupivacaine with lower affinity for cardiac myocytes and is less likely to cause fatal toxicity.[4] The other group of local anesthetics is of the ester-type local anesthetics including chloroprocaine, tetracaine, and procaine. These are quickly hydrolyzed by plasma cholinesterase. Though the activity of plasma cholinesterase is decreased in infants younger than 6 months of age, studies have not shown increased toxicity with use of chloroprocaine and it should be considered for infusions that will last longer than 48 hours in order to avoid the systemic toxicity associated with the amino-amides such as bupivacaine.[5]

NEURAXIAL TECHNIQUES

The choice of neuraxial technique and pharmacological agents utilized is largely dependent on the type of surgery and whether and how long the patient is being admitted to the inpatient setting. For ambulatory surgeries involving the lower extremities or truncal dermatomes, spinal anesthesia or single-shot caudal anesthesia or analgesia is commonly used. Epidural catheters are less commonly used in the ambulatory setting and are typically reserved for surgeries involving bilateral lower extremities, open thoracic surgeries, major intra-abdominal surgeries with visceral dissection, or spinal surgeries.[6]

Spinal

Intrathecal anesthesia has been shown to be beneficial, particularly in the neonatal period. When used as a sole anesthetic, it has been shown to decrease the use of opioids and therefore the attendant respiratory depression, apneic episodes, and bradycardia in the postoperative setting.[3] Regardless, apnea in the infant should be monitored until post 60 weeks' conceptual age.[3] The limitation of spinal anesthesia includes both time constraints (approximately 1 to 2 hours) as well as surgical location. These procedures are largely for incisions below the T10 dermatome, ie, inguinal hernia repair, hypospadias correction, circumcision, or lower extremity surgeries, and can be particularly useful in ex-premature and term infants in an attempt to avoid the risk of prolonged intubation or apnea post general anesthesia.

The physical spinal space differs in adults and infants considerably. Most importantly, the extent to which the spinal cord extends is lower in infants than in adults. Specifically, the conus medullaris extends to L3 in infants and does not move cephalad to the adult level of L1 until after 1 year of age.[3] For this reason, access to the spinal canal is performed at the L5-S1 level in this age group using a midline approach. Typically, a 1.5-inch styletted 22-gauge spinal needle is used, although a variety of pediatric sizes and types of needles are available. Furthermore, the spinal space can be reached at approximately 1.5 cm rather than the average 5 cm in adults. Consideration for dosing on a per kilogram basis for the infant can be 5 to 10 times greater than for adults. This can be explained by the greater percentage of CSF versus body weight in an infant. Additionally, the turnover of CSF is higher in infants than in adults. With this in mind, the duration of surgical anesthesia is also much lower in infants than in adults, thereby limiting the surgical time to approximately 1 to 2 hours.

The typical local anesthetics for spinal anesthesia include tetracaine and bupivacaine. The baricity of either can be altered with the use of dextrose, though the duration of action of either seems to be nearly equivalent.[7] Lidocaine is not commonly used in the spinal space secondary to the potential for transient neurological symptoms that have been documented with its use.

Dosing guidelines can be found in Table 33-1.

Table 33-1

Local Anesthetics for Spinal Anesthesia

Anesthetic Agent	Dose Range (mg/kg)
Bupivacaine 0.5% (isobaric) with epinephrine 1:200,000	0.5–1 mg/kg
Bupivacaine 0.75% in 8.25% dextrose (hyperbaric)	0.5–1 mg/kg
Tetracaine 0.5% in 5% dextrose (hyperbaric)	0.4–0.8 mg/kg

Epidural

Caudal

The caudal epidural technique remains the most popular choice for postoperative analgesia in the infant to achieve opioid sparing in the operative theater. The incomplete fusion of the sacral vertebrae allows for epidural access via the sacral hiatus which is found between the two sacral cornu at the level of the fifth sacral vertebra. The sacrococcygeal ligament covers the sacral hiatus and the dural sac extends down to the level of S3. The proximity of the dural sac, as well as the ease of passing a needle through bone in an infant, poses significant risks for dural puncture and incorrect needle placement. The use of ultrasound to visualize caudal anatomy can increase successful needle placement as well as minimize the risk of dural puncture.

A single-shot technique is indicated for procedures below T10 dermatome, whereas a caudal catheter can be used for higher level dermatomal coverage. A single-shot technique is commonly used for ambulatory procedures in those children who are not yet walking, as leg weakness secondary to motor blockade may be a scary occurrence for those now accustomed to being mobile. That being said, some institutions will routinely place a caudal block for analgesia even in school-aged children, thereby necessitating parental education to avoid unassisted weight-bearing for 6 to 12 hours status post administration.

The continuous caudal epidural technique can be used for procedures as high as a T4 dermatomal level. Those catheters intended for a higher dermatomal blockade are inserted at the caudal level with cephalad advancement to the appropriate thoracic dermatome. When advanced blindly, radiographic determination of the catheter is recommended as it is difficult to ascertain the final tip location otherwise.[8] Alternatively, the use of electrical stimulation, otherwise known as the Tsui test, or the use of ultrasound can obviate the need for radiographic confirmation and minimize unnecessary exposure to radiation.[9,10]

Procedurally, a caudal block can be successfully completed quite easily. At our institution, we place the patient in the lateral decubitus position after the monitors, airway, and intravenous line are secured. The knees should be flexed to the chest, as this facilitates palpation of the sacral cornu. Sterile preparation can be achieved using either chlorhexidine, alcohol, or betadine solution. After proper positioning and using a sterile technique, the sacral cornu is usually identified quite easily by palpating for two bony prominences at the sacral hiatus approximately 0.5 to 1 cm apart. Using a 22-gauge angiocatheter, at approximately a 45-degree angle to the skin, the needle is inserted in between the sacral cornu and advanced into the sacral canal. Once the sacrococcygeal ligament is pierced, which is indicated by a very slight “pop” with the catheter tip, the catheter angle is dropped to about 15 degrees to the skin and the catheter and needle advanced approximately 3 mm together, after which the catheter alone is advanced over the needle into the caudal space. The needle is then removed and the catheter examined for cerebrospinal fluid (CSF) or blood leakage. A syringe with the caudal medication can be connected directly to the catheter. Gentle aspiration should be negative for blood or CSF prior to injection. Injection should be performed with fingers over the skin to detect unintentional extravasation into the subcutaneous tissue. If this is the case, a palpable wheal will be felt with injection. Injection should occur without encountering resistance and should be done in a slow, incremental manner, carefully watching the EKG monitor for changes, most specifically, for QRS changes or peaking of T waves.

The dosage of drug varies depending on the dermatomal level and density of the block desired. Higher volumes of local anesthetic are necessary to achieve a higher level of blockade. Higher concentrations of local anesthetic are needed to achieve anesthesia versus analgesia. In general bupivacaine 0.25% or lower concentrations is used for caudal analgesia. Two commonly used formulas to determine volume are those described by Armitage and Takasaki and colleagues. Armitage recommends using 0.5 mL/kg for procedures involving lumbosacral dermatomes, 1 mL/kg for procedures involving thoracolumbar dermatomes, and 1.25 mL/kg for procedures involving mid-thoracic dermatomes.[11] Takasaki and colleagues suggest a volume of 0.05 mL/kg dermatome to be blocked.[12] Preservative-free formulations should always be utilized when delivering drug to the neuraxial space.

Lumbar/Thoracic

Placement of epidural catheters in infants and children is distinctly different than in adults, largely because the placement of the catheter is done after the child is anesthetized. Though there is a level of safety concern regarding the placement of epidurals under general anesthesia, a large case-series by Krane et al. has reported that the risk of performing these procedures in the anesthetized child is not increased.[13]

In addition to caudal epidural placement, placement in lumbar or thoracic locations may be utilized for procedures involving higher dermatomal levels.[3] Examples include major abdominal surgery, open thoracic surgery, spinal surgery, and chronic pain management in life-limiting diseases.[6] Potential benefits of epidural catheter placement in the lumbar or thoracic levels include a lower risk of fecal contamination, catheter placement closer to the desired level of analgesia, and a smaller volume of drug for a more cephalad dermatomal level.[3]

Suggested dosing for the epidural local anesthetics is as follows:

Epidural infusions:

Neonates:

Term neonates: Bupivacaine ≤0.2 mg/kg/h for no more than 48 hours, then change to choloroprocaine 1.5% at a rate of 0.2 to 0.8 mL/kg/h

Infants:

1–6 months: Bupivacaine 0.2 mg/kg/h

>6 months: Bupivacaine 0.4 mg/kg/h

Pediatric patient-controlled epidural analgesia (PCEA)—thoracic:

Bupivacaine 0.125% + Fentanyl 2 mcg/mL or Bupivacaine 0.1% + Fentanyl 2 mcg/mL

Continuous rate: 0.2 mg/kg/h

Demand dose: 0.04mL/kg

Lockout 20 minutes

Pediatric patient-controlled epidural analgesia (PCEA)—lumbar:

Bupivacaine 0.1% + Fentanyl 2 mcg/mL

Continuous rate: 0.25 mL/kg/h

Demand dose: 0.05 mL/kg

Lockout 20 minutes

ADJUVANT ANALGESICS

Adjuvant analgesics are used in combination with local anesthetics to improve the quality of neuraxial analgesia and at the same time decrease the concentration of local anesthetic agent needed to achieve adequate analgesia. In addition to improving onset of neural blockade they also improve the quality and duration of the blockade while limiting the density of motor blockade, which would be likely to occur if local anesthetics were used alone.

The most commonly utilized adjuvants for neuraxial analgesia are opioids (ie fentanyl, sufentanil, morphine, and hydromorphone). Opioids act primarily on pre- and post-synaptic mu-opioid receptors in the substantia gelatinosa of the dorsal horn of the spinal cord. The most important determinant of onset and duration of analgesia is lipid solubility. Lipophilic opioids (ie fentanyl, sufentanil) produce rapid onset of analgesia with limited cephalad spread, whereas hydrophilic opioids (ie morphine, hydromorphone) have a much slower onset with prolonged duration of analgesic effects and greater cephalad spread. Accordingly, there is an increased risk of delayed respiratory depression with hydrophilic opioids as compared to lipophilic opioids. However, given the narrow therapeutic index of amino-amide local anesthetics, it is often necessary to rely on hydrophilic opioids to improve dermatomal coverage for epidural analgesia when the tip of the epidural catheter is not optimally positioned to cover the distribution of pain.

The other common adjuvant drug utilized in neuraxial analgesia is the centrally acting partial alpha-2 adrenergic agonist, clonidine. A recent meta-analysis by Schnabel et al. suggested its efficacy in increasing the duration of analgesia when given with local anesthetics and improved safety profile given the low incidence of adverse effects including respiratory depression.[14] This makes clonidine an ideal adjuvant agent for neonatal and infant neuraxial analgesia.

Ketamine has also been successfully used as an adjuvant in caudal analgesia,[15] but a preservative-free formulation is not available in the United States, which limits its application in this circumstance. Furthermore, given the expression of neuronal toxicity in translational animal models, ketamine's safety profile has been controversial particularly when considering its use in developing organisms.

PLACEMENT TECHNIQUES

Thoracic and lumbar epidural catheters may be placed safely in anesthetized infants and children. Despite concern in the adult literature about risk of neural injury in the deeply sedated or anesthetized patients, no studies have validated this to be the case in clinical practice. The vast majority of regional and neuraxial anesthetic techniques in infants and children are performed under general anesthesia and large-scale prospective studies in the United States and Europe have found the risk of complications to be very low.[16–19]

Direct Injection

The technique for placement of lumbar or thoracic epidural catheters is similar to that in adults, but with several important exceptions. Most commonly, a midline approach is utilized. However, it is important to note that the ligamentum flavum is thinner and less dense in infants when compared to older children and adults and perception of engagement in ligament may be more difficult. This necessitates slower and more careful passage of the needle to prevent inadvertent subarachnoid puncture. It may take experience to perceive the more subtle differences in the characteristics of the tissue planes in small children. Additionally, the angle of approach may be more perpendicular in infants and children due to the angle of the spinous processes in this age group. Another important consideration is the use of saline with loss of resistance technique as the use of loss of resistance with air has been associated with venous air embolism in infants and children.[20] Similar to the concept of a hanging drop technique, an IV infusion may be connected to the epidural Tuohy needle, and when the epidural space is entered the IV infusion begins to drip.[3]

Most pediatric epidural kits available in the United States contain 17- to 18-gauge, 4.5- to 6-cm Tuohy needles. Authors report better control with the use of a short 5-cm needle in infants and children in comparison to an adult sized 9- to 10-cm needle. Additionally, most kits contain 20- to 21-gauge catheters as there is a higher incidence of kinking and high resistance with smaller catheters, ie, 24 gauge.[3]

Fluoroscopy/Epidurograms

Ease of epidural catheter advancement is not a reliable indicator of successful placement in the epidural space, and successful advancement from caudal to thoracic or lumbar to thoracic levels is variable. For this reason, fluoroscopic confirmation via an epidurogram was recommended to ascertain tip position of epidural catheters advanced to the thoracic level in order to avoid the potential for respiratory compromise if a catheter is inadvertently advanced too cephalad and to avoid the potential for inadequate analgesia in the event of catheter coiling or malposition.[8] Alternative methods to limit radiation exposure, including the Tsui test and the use of ultrasound technology, have been developed and are more commonly used in current clinical practice.

Tsui Test

The Tsui test consists of using a nerve stimulator on epidural nerve roots at low voltages in order to confirm epidural placement via visual confirmation of muscle twitch.[9] Generally speaking, this direct method of epidural catheter placement (ie, at the dermatomal level of the surgical intervention) is favored for children greater than 10 kg. Goobie et al. prospectively looked at 30 pediatric patients to assess the direct placement of epidural catheters via Tsui test and found that though the positive predictive value of the test was 82%, it was not clinically advantageous over the "blind stick" method via landmarks and test dosing.[9] Despite this, the educational utility of this method still persists.

The method of the Tsui test/stimulation catheter placement is like that of the direct stick with the additional use of a nerve stimulator that has a grounding anode and a stimulating cathode. Normal saline serves as the conducting fluid. Muscle twitch should typically be elicited between 1 and 10 mA and any muscle twitch less than 1mA should raise suspicion of intravascular or intrathecal location. Greater than 10 mA should also be considered a misplaced epidural.

The technical aspect of placing the epidural with the use of Tsui epidural stimulation is like that of standard epidural placement with a Tuohy needle. The epidural catheter itself is more successfully advanced with the use of a metal stylette that is within the catheter. This metal stylette allows for passing of the catheter over long distances in the pediatric patient, as the stiffness circumvents the troublesome kinking or coiling of the soft tip catheters.[9]

Ultrasound

It is becoming increasingly common to use ultrasound during preprocedural assessment of the spinal anatomy prior to performing neuraxial procedures in infants and children. The advent of ultrasound technology has allowed clinicians to visualize anatomical structure with clarity, as well as perform guided procedures with greater precision. Rapp et al described the use of ultrasound for lumbar and thoracic epidurals as a valuable tool in those greater than one year of age.[21] This can be useful to predict skin-to-dura distance, improve first-pass success rate, and decrease the risk of complications.[22,23] The detailed images are possible in infants less than 9 months of age due to absence of vertebral ossification; therefore, the application of ultrasound is particularly useful in this high-risk population. In older infants and children, vertebral ossification impedes transmission resulting in more limited acoustic windows.[24]

CONCLUSIONS

Regional neuraxial anesthesia/analgesia is a well-established and safe practice that is being routinely applied in the pediatric perioperative setting with the accessibility of appropriate equipment, instrumentation, well-established guidelines for administration of neuraxial analgesics, and the availability of ultrasound guidance. The addition of regional techniques to the clinical armamentarium of pediatric anesthesia not only limits opioid usage, which permits the restoration of the child’s pre-anesthetic emotional and intellectual awareness, but also affords parents the opportunity to resume their role in providing the emotional safety in an environment of comfort, which is effectively accomplished by guiding parental expectation through education. These skills are unique to the pursuit of our subspecialty, and well worth the extra time and effort.

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