Regional anesthesia is part of the curriculum for anesthesia training programs. Although the use of regional anesthesia in children has been limited, the field holds clear promise. The introduction of ultrasound (US) guidance, along with numerous focused workshops at major specialty meetings, have altered the outlook and increased participation and use of regional anesthesia in pediatric practice. This article will review the use of US-guided central neuraxial blocks as they apply to practice in infants, children, and adolescents. In particular, it will focus on 3 US-guided regional techniques—the caudal block, epidural analgesia, and the paravertebral block (PVB)—that are gaining popularity in this patient population.
hernia repairs, urologic procedures, and procedures performed on the lower extremities. A single-shot caudal anesthetic provides relatively brief analgesia, on the order of 4 to 8 hours depending on the agents used, and is appropriate for inpatient and outpatient management strategies.

A successful caudal anesthetic blockade affords the anesthesiologist the opportunity to reduce intraoperative use of volatile anesthetic agents and to use a narcotic-sparing approach that ultimately may benefit the patient while providing a better postoperative course with less nausea and vomiting. Although the block typically is performed with a loss-of-resistance technique using a blunt needle, the use of US not only allows the space to be identified but permits visualization of the spread of the local anesthetic solution.

Ultrasound-guided Caudal Anesthesia

Recent advances in the use of US-guided approaches to regional anesthesia have occurred across the spectrum of adult and pediatric patients. The use of US in neuraxial blockade has had limited success in adult patients because of poor penetration through calcified bony structures. In contrast, potentially promising uses of the imaging technology exist for the pediatric population. Younger children are less likely to have bony ossification, and US may serve as an invaluable tool in the placement of caudal blocks and epidural catheters originating from the caudal space.

ANATOMIC AND TECHNICAL CONSIDERATIONS

Ultrasound imaging of the caudal region is best performed in both the transverse axial and longitudinal paramedian or midline positions (Figure 1a). A higher-frequency (13-6 MHz) “hockey stick” probe is a good choice for the transverse axial view. Placement of the probe at the level of the coccyx, with subsequent scanning toward the sacral canal, will help the clinician localize important landmarks. A larger, lower-frequency probe may be more desirable for the longitudinal paramedian view, which has a large field of interest.

A midline axial transverse scan demonstrates a reasonable representation of the sonoanatomy at the level of the sacral hiatus with the sacral cornu, sacrococcygeal ligament, and dural sac. The sacral hiatus is inferior to the ligament and appears hypoechoic. When the probe is placed in a midline longitudinal position, the sacrococcygeal ligament and dorsal surface of the sacrum can be discerned. The sacral cornua are seen as humps. The sacrococcygeal ligament appears as a hyperechoic membrane between the sacral cornua. The ligament extends as a thick band beyond the end of the dorsal aspect of the sacrum. The image is clearer in neonates and infants but seldom is so distinct in children over the age of 6 years, in whom the sacrococcygeal ligament is likely to have ossified.

Caudal Epidural Anesthesia

Caudal epidural anesthesia is an important tool for pain control and anesthetic management in children undergoing surgical procedures below the umbilicus. Caudal anesthesia is the most frequently used regional anesthetic technique in pediatric patients (Pediatric Regional Anesthesia Network; S. Suresh, personal communication) and is one of the most common blocks taught in anesthesia training programs in the United States.

INDICATIONS

Caudal epidural blocks have numerous indications, including abdominal operations below the umbilicus,
Once the caudal needle has pierced the skin, both transverse and longitudinal views can confirm placement. Case reports detail the use of transverse imaging for visualizing the sacral hiatus anatomy and noting the injection of local anesthetic into the caudal space. Schwartz et al. have described the transverse view of injected local anesthetic as dilation of the caudal space and turbulence (Table).

Color flow or Doppler imaging may enhance viewing the solution. Roberts et al. described their approach to visualization of a saline test bolus in the caudal space under US guidance. They used the longitudinal view cephalad to the catheter insertion site (1 cm) to observe anterior movement of the posterior aspect of the dura.²

Visualization of the needle as it enters the sacral canal may be accomplished with the probe in a longitudinal position similar to an in-plane approach for other peripheral nerve blocks. This view may aid in making adjustments to the needle angle to avoid penetration of surrounding bony structures and help prevent intravascular injection of local anesthetic. As discussed by Tsui and Suresh, initial use of the longitudinal view may aid in assessment of the needle puncture and angle and depth of the needle, and a transition to a transverse view may permit the visualization of the spread of local anesthetic solution.¹

When introducing a catheter into the caudal space, a technique similar to the one described above works well. However, injecting saline into the area as the space is accessed directly with a paramedian view of the spinous process affords the easiest visualization of the spread of the local anesthetic solution. Surrogate markers of the anterior displacement of the dura mater usually are a good sign when placing catheters under US guidance.

Compared with the “swoosh test”—an audible spread of local anesthetic up the epidural space—US guidance can better capture the spread of local anesthetic solution.³ The difference is even more marked with the use of Doppler ultrasound.

**COMPLICATIONS**

There is a chance, albeit small, that these blocks may fail after improper needle placement or alteration of needle position once initial loss of resistance has been obtained. The implications of failure are magnified in neonates or young infants, for whom the margin of error in dosing is minimal. In addition, bloody punctures and intravascular events have been reported and must be carefully monitored⁴; test dosing prior to injection should be performed.

In general, major complications of caudal anesthesia in pediatric patients are uncommon. The risk of greatest concern to the anesthesiologist is the inadvertent injection of local anesthetic into a vascular space, which may lead to central nervous system dysfunction and cardiovascular compromise. Electrocardiographic changes involving an increase in T-wave amplitude of more than 25% are highly predictive of intravascular injection.⁵

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**Figure 2a.** A high-frequency ultrasound scan using the paramedian view generates the best views for epidural analgesia. However, a transverse axial scan also can enable adequate measurement of the epidural space.

**Figure 2b.** A paramedian scan using a linear high-frequency ultrasound probe demonstrates the spinous process (saw-tooth appearance) and the dura mater as a hyperechoic shadow between the bony spinous process. Correct placement of the local anesthetic solution in the epidural space is demonstrated by anterior displacement of the dura mater.
Efforts should be made to avoid the test dose during periods of light anesthesia or when other stimulation is occurring. Inadvertent dural entry is unusual, provided close attention is paid to the depth of the needle. Other rare complications include epidural abscess, epidural hematoma, dural puncture, subdural injection, air embolism, total spinal, and other adverse events associated with epidural anesthesia. The incidence of systemic toxicity is higher with caudal blocks than with epidural blockade at other levels.

**Epidural Analgesia**

Epidural analgesia has been an important dimension of pediatric practice for nearly 2 decades. Many studies have assessed the efficacy as well as the pharmacokinetics of local anesthetic solutions in infants and children. Detecting the epidural space through US guidance initially was part of a preprocedure scan and delivered excellent results, particularly in obese parturients. The technique can be applied in neonates and infants with ease, as the posterior vertebral column in infants is cartilaginous and thus effectively transparent to the US beam.

The advantages of US guidance are manifold in this population: The epidural space is superficial and errors are likely to be made with access; dosing parameters can easily be exaggerated with the use of loss of resistance; loss of resistance with air may lead to a potential for air embolism, raising the risk for further complications.

**SONOANATOMY**

A high-frequency probe (13-6 MHz) typically works best for US-guided epidural analgesia. With the paramedian view, structures are identified more readily, although a transverse axial scan can adequately measure the epidural space (Figures 2a-b). With the paramedian scan, a large acoustic window enables visualization of several vertebral spaces, and also the intervertebral spaces. Clinicians may choose the transverse axial view, but the decreasing depth of the epidural space limits the utility of the image.

A prospective study in infants found a linear hockey stick probe provided easy visualization of neuraxial structures, the lumbar spine being more acoustic than the thoracic spine. The dura mater is often more readily visible than the ligamentum flavum. The study also found the visibility of the epidural space to be greater in infants under 3 months of age, which is similar to our own experience. Kil et al. corroborated these findings, and a subsequent study from Austria demonstrated the ability to differentiate the dura mater as well as the ligamentum flavum in infants who were placed lateral with caudal hip flexion. It is crucial to remember that loss of resistance must be carried out with saline, as air will obliterate the image that is obtained.

US guidance has been shown to provide better visualization for catheter placement in infants under 6 months of age than in older infants. A study by Rapp...
et al. found that US imaging of the catheter was possible in 19 of 23 patients studied; however, multiple planes were required to visualize the catheter placement. The Austrian group noted that with the patient flexed at the hip and in the lateral position with a paramedian scan of the spine, placement of the epidural catheter was not obvious. However, anterior displacement of the dura mater was clear, again similar to our own experience of catheter placement.

The study by Rapp et al. also found a significant correlation between the measured epidural depth and the depth at which loss of resistance was obtained. The US-guided technique led to less bone-needle contact (17% vs 71%) and shortened the procedure time (162 vs 234 sec). Although the study did not demonstrate greater success in the US group, the added safety of knowing the depth of the epidural space and the ability to determine proper placement outweighs the extra effort required to use US guidance. Indeed, US guidance soon may prove to be the only method for successful cannulation of the epidural space, providing greater comfort for patients and a teaching tool for residents and fellows in anesthesia.

Paravertebral Blocks

PVBs produce ipsilateral analgesia by injection of local anesthetic solution alongside the body of the vertebra. They have been used for pain control in patients undergoing thoracotomies, chest wall trauma, breast reconstructive surgery, cholecystectomy, herniorrhaphy, and renal surgery. Bilateral PVBs may be needed in some cases to provide adequate analgesia.

Paravertebral blockade may be administered either as a single injection or by a catheter that can provide continuous or bolus administration of a local anesthetic. PVBs provide nerve blockade to the roots of nerve plexus or spinal nerves soon after their emergence from the spinal canal. However, often they are not categorized as a peripheral nerve block as they share characteristics of neuraxial blocks. They have been described as “paraneuraxial” epidural blocks, because the nerves they affect are enclosed by dura mater extending from dura lining the spinal cord. It is important to understand that PVBs are performed in close proximity to nerve roots surrounded by dura mater and their complications may be similar to those associated with central neuraxial blocks.

PVBs may be classified as a family of 4 related blocks. Baumgarten et al. subdivides PVBs by their location into these regions: cervical, thoracic (T1-10), thoraco-lumbar or hernia region (T11-L2), and lumbar or psoas compartment (L2-5).

History

Sellheim is credited with performing the first PVB in 1905, while searching for an alternative to spinal anesthesia and its associated dangers of hemodynamic and respiratory complications. In the early part of the century, PVB was used for relief of surgical pain, angina pectoris, intractable pain of malignancy, ischemic limb pain (including causalgia), and reflex sympathetic dystrophy. The technique experienced a brief popularity in the 1920s and 1930s but almost completely disappeared from the literature in the 1950s and 1960s. In 1979, Eason et al. reestablished the safety and efficacy of thoracic PVBs in cadaver studies, and since then numerous authors have refined the technique.

Boezaart discussed the use of continuous cervical PVB and PV approaches to the brachial plexus. In 1997, Weltz et al. demonstrated enhanced patient satisfaction and the safety of thoracic PVBs in surgery for breast malignancy, which has become a leading indication for the block.

Applied Anatomy

The PV space is located on either side of the vertebral column anterior to the transverse process and posterior to the parietal pleura. In the thorax, it is wedge-shaped.
The thoracic PV space contains the spinal (intercostal) and bounded posteriorly by the superior costotransverse ligament, which connects the corresponding upper and lower borders of the transverse process, and anterolaterally by the parietal pleura. The base is formed by posterolateral aspect of the vertebral body, intervertebral disk, and intervertebral foramina.3,20 The PV has no lateral limit, and depending on the level of injectate, local anesthetic can provide cervical, stellate, brachial plexus, intercostal, and lumbar plexus blockade. The PV communicates medially with the epidural space through the intervertebral foramina and can connect with the contralateral PV space through the prevertebral or epidural space. It can track along the PV gutter to the ipsilateral PV spaces above and below. The endotheracic fascia is interposed between the parietal pleura in front and costotransverse ligament behind and divides the PV space into the anterior extrapleural and posterior subendothoracic PV compartments. The thoracic PV space contains the spinal (intercostal) nerve, dorsal ramus, intercostal vessels, rami communicantes, and the sympathetic chain.21

Lonnqvist et al. studied the caudal limit of thoracic PV space in cadavers and observed that it was limited by the origin of the psoas limiting spread below the 12th thoracic vertebra.22 However, cadaver studies by Saito et al. revealed the presence of a communication between the thoracic and lumbar PV regions.24 Local anesthetic spread through the medial and lateral arcuate ligaments to the anterior surface of the psoas major and quadratus lumborum muscles, where it contacted the peripheral nerves originating from the lumbar plexus.

The question of whether a single- or multiple-level PV injection should be used is controversial. Multiple-level thoracic injection avoids large doses of anesthetic and therefore may prevent intravascular or intrathecal injections.17 However, multilevel injections may provide a more reliable distribution of drug.24 Single-level injection may be more desirable for both patients and clinicians as it reduces procedure time, patient discomfort, and the incidence of needle-related complications.25 For these reasons, among others, Ben-David et al. have advocated the placement of a single PV catheter instead of multiple blocks.15

Paravertebral Blocks in Children

PVBs in children are effective and safe, and provide prolonged blockade. Splinter et al. studied 36 children undergoing appendectomy under general anesthesia with or without a PVB (right PVB at T11, 12, and L1 level with 0.2% ropivacaine at a dose of 0.25 mg/kg). They found no difference in side effects between the 2 groups of patients, but those who received a PVB reported superior pain relief.26

Contraindications and Complications

Contraindications to PVBs are similar to those relating to central neuraxial blocks. They include injection at the site of needle insertion, empyema, and a history of local anesthetic toxicity. The presence of coagulopathy is a relative contraindication, as a paravertebral hematoma may have milder neurologic consequences than extradural hematoma.32 Caution to avoid pleural puncture should be exercised in patients with kyphoscoliosis or who have had a previous thoracotomy.

The overall failure rate reported by Lonnqvist et al. is 10% in adults and 6% in children.30 Complications include hypotension (4.6%), vascular puncture (3.8%), pleural puncture (1.1%), and pneumothorax (0.5%). These rates compare favorably with other regional techniques. A bilateral PVB can double the incidence of vascular puncture and raise the risk for pneumothorax 8-fold compared with a unilateral block.31 The high incidence of vascular puncture and pneumothorax was associated with bilateral, multiple-level injections, however, and would not apply to bilateral single-level blocks.

Transient ipsilateral Horner syndrome can result from the cephalad spread of local anesthetic to the cervical segment and is not a cause for concern in patients undergoing PVBs. Bilateral Horner syndrome can result from spread anterior to vertebra or from crossover sympathetic fibers. It may be associated with bilateral phrenic or recurrent nerve blocks.30

Ultrasound-guided Paravertebral Blocks

The introduction of US guidance has increased the potential for PVBs to be placed in younger children with fewer complications.32 This technique is the preferred approach in our institution for infants, children, and adolescents undergoing major surgical procedures including pyeloplasty, thoracotomy, breast augmentation, and

Case Studies

1. A 10-year-old girl undergoing forequarter amputation for osteosarcoma of the humerus received a high continuous PVB at C5 and T2. Brachial plexus block was divided and resected during surgery and was not an option. The patient experienced excellent postoperative analgesia with no need for opioids in the immediate postoperative period.27

2. Single-injection PVBs were used as an adjunct to general anesthesia in 24 children undergoing major renal surgery. Low thoracic PVB was employed with levobupivacaine (0.5 mg/kg) and epinephrine (5 mcg/mL). The blocks were successful in 23 of 24 children, providing a median duration of analgesia of 600 minutes. The incidence of vascular puncture (8.3%) was high.28

3. Continuous PVBs were used for post-thoracotomy pain in 15 children. Excellent analgesia was obtained without pulmonary complications or complications related to the continuous infusion of bupivacaine.29
video-assisted thoracoscopic surgery. Initial work done by Lonnqvist et al. in the area of PVBs using the loss-of-
resistance technique has now been complemented with the use of US guidance by Karmarkar et al.

There are 2 ways of recognizing the PV space—a midline paramedian or an oblique transverse view (Figures 3a-c). Our preference is the paramedian view, as it can provide the easiest way to access the PV space in a child. Injection of local anesthetic in the correct area leads to a downward movement of the pleura. An M-mode is applied to the US machine to determine if the pleura has been rent, as demonstrated by the maintenance of the “sea shore” sign.

Conclusions
Recent anesthetic literature has shown that caudal anesthesia and PVBs are effective and safe for use in children, with complication rates comparable to other regional techniques. They have relatively few contraindications, are easy to perform, and can be used in a wide variety of clinical situations. They have a low side-effect profile and are becoming more acceptable to the anesthetic community with a resurgence of interest and research in this technique. The use of US for determining the epidural space may become the standard of care as more anesthesiologists receive training in the art of reading US imaging. The result likely will be safer practice in pediatric patients.

References
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