Ultrasound Imaging for Regional Anesthesia in Infants, Children, and Adolescents

A Review of Current Literature and Its Application in the Practice of Neuraxial Blocks

Ban C. H. Tsui, M.D., F.R.C.P.C.,* Santhanam Suresh, M.D., F.A.A.P.†

ABSTRACT
Complementary to a previous publication related to pediatric extremity and trunk blockade, the authors present a comprehensive narrative review of the literature pertaining to techniques described and outcomes evaluated for ultrasound imaging in pediatric neuraxial anesthesia. The sonoanatomy related to each block is also described and illustrated to serve as a foundation for better understanding the block techniques described. For neuraxial blockade, ultrasound may fairly reliably predict the depth to loss of resistance and can enable a dynamic view of the needle and catheter after entry into the spinal canal. Particularly, in young infants, direct visualization of the needle and catheter tip may be possible, whereas in older children surrogate markers including the displacement of dura mater by the injection of fluid may be necessary for confirming needle and catheter placement. More outcome-based, prospective, randomized, controlled trials are required to prove the benefits of ultrasound when compared with conventional methods.

The benefits of pediatric regional anesthesia are many, although nerve blocks, especially at the neuraxis, can be challenging. The safety margin for needle placement is narrow within the spinal canal; the anatomical structures are tightly positioned and the epidural space can be as narrow as 2 mm for epidural blocks. Because of the large variation of each patient’s body habitus due to age, it can be difficult to predict the puncture depth to reach either the epidural or intrathecal spaces. Furthermore, loss-of-resistance technique to identify the epidural space can be further challenged in neonates by the less fibrous tissue planes limiting tactile feedback. Finally, although it is generally agreed to be safe to perform regional anesthesia in anesthetized children, there is some inherent risk associated with performing blocks in cases when there is a limited ability to receive subjective warning signs (e.g., paresthesia) of neural damage.

In recent years, anatomically based ultrasound is one of the most exciting advances in technology in relation to pediatric regional anesthesia. The use of ultrasound in neuraxial anesthesia in adults is somewhat limited because of the reduced visibility of the spinal canal resulting from poor ultrasound beam penetration through the ossified bony vertebral column. In theory, ultrasound could be of much greater value in the young pediatric population where there is limited ossification, thus allowing good visual resolution of the anatomy and block-related equipment or solutions.

Reports have begun to emerge with respect to evaluating evidence for the success and safety of ultrasound guidance in regional anesthesia, although a comprehensive narrative review of the literature pertaining to techniques described and outcomes evaluated relating to ultrasound guidance in pediatric neuraxial blockade was not available at the time of writing this article. This review follows another published review article in this journal relating to ultrasound-guided extremity and trunk blockade. Our aim is to provide the pediatric anaesthesiologist with an overall summary of the techniques used and of the outcomes reported (based on controlled or comparative studies) as described in the literature on ultrasound guidance of neuraxial blockade in pediatrics. Moreover, an in-depth understanding of the regional anatomy of the spinal column and canal cannot be overemphasized when performing neuraxial blockade. This review therefore in-
cludes descriptions and illustrations of the relevant sonoanatomy of the spinal regions. We hope that the sonoanatomy sections will assist the reader with a better understanding of the block techniques as described in the literature.

Materials and Methods

A literature search for this review was performed using MEDLINE and EMBASE for the period from 1980 to May 28, 2009. The keywords “ultrasound and children” and “ultrasound and pediatric” were combined with “regional anesthesia,” “epidural analgesia,” “epidural anesthesia,” and “spinal anesthesia.” The medical subject heading term “ultrasonography” was also combined with epidural analgesia, epidural anesthesia, and spinal anesthesia, using the limit of 0–18 yr of age. The searches were limited to literature in humans, and although there was no limit to the English language, only those articles with English text or abstracts were described or discussed if relevant. Relevant literature was printed in full and their reference lists were checked manually. We included clinical studies, case series and reports, as well as relevant correspondence pieces where Institutional Review Board approval and patient–parent consents were obtained. Expert reviews and descriptions as well as correspondence pieces specific to ultrasound in pediatric regional anesthesia were reviewed for references and additional comments on technique, but were not used for outcome evaluation data.

A portable ultrasound unit (Sonosite M-turbo®; Bothell, WA), which is commonly used in the authors’ institutions for performance of pediatric ultrasound-guided regional anesthesia, was used to obtain the images highlighting the sonoanatomy for each block. Ethics committee or institutional review board approval was obtained for the ultrasound imaging and informed consent was provided by the patient’s parents for all the images. Two different high-resolution linear probes were used (SLA 6–13 MHz 25-mm footprint and HFL38 6–13 MHz 38-mm footprint, both from Sonosite), although the former “hockey stick” probe is highly suitable for infants because of its small footprint. The figure legends include a description of the probe and a schematic line drawing depicting the location of its placement.

Results

The search provided 20 results. Sixteen reports were found, including one randomized controlled trial, 10 mid- to large-sized case series, one small cases series, and four case reports or letter to the editor, of infants and children undergoing central neuraxial blocks. Four expert reviews with descriptions of technique related to pediatric regional anesthesia were also obtained. In the ensuing section, we discuss in depth the use of ultrasound guidance for regional anesthesia in infants, children, and adolescents. Although there are different terms used to describe the relative placement of the needle with respect to the probe, we have used the terms “out-of-plane” and “in-plane” to describe the needle being perpendicular (or sometimes tangential) and parallel to the probe axis, respectively. The probe is typically used to view the nerves in short-axis (cross-sectional, transversely), but occasionally a long-axis (longitudinal) view is helpful.

Intervertebral Epidural Analgesia or Anesthesia

Ultrasound imaging seems promising for use either preprocedurally (before puncture) or during (in real time) block performance, although the latter may be most suitable in infants. The largely cartilaginous posterior vertebral column of neonates and infants enables good beam penetration to view the spinal structures and can in some cases enable a view of the needle tip trajectory and catheter tip. Most practical will be the visibility of the spread of fluid during injection through the needle or cannula and catheter; the extradural location of the fluid in a test dose can confirm that the local anesthetic will be deposited safely and the segmental level of the catheter may be determined with some certainty.

Techniques

Sonoanatomy. A moderate to high frequency probe should be placed in both the transverse and longitudinal planes to capture an overview of the neuraxial structures. A paramedian longitudinal view will often provide a view with the largest “ultrasound window” when compared with transverse and median longitudinal views. This means that the ultrasound beam will penetrate the spinal column to a larger degree and offer a larger representative view of the structures; less of the beam is reflected by the bony structures (e.g., vertebral bodies and lamina). Regardless, in young children, the posterior aspect of the vertebral column is largely cartilaginous and the beam penetration will be greater than that for older patients.

In a transverse view (fig. 1), in the lower lumbar spine (L3/4), the central vertebral body appears as a hyperechoic “V,” and the paravertebral muscles appear relatively hypoechoic with hyperechoic striations. One or more circular hyperechoic lines will be seen deep in the posterior vertebral elements; both the ligamentum flavum and dura mater may be distinguished or the dura mater may predominate. In the figure, an epidural catheter is illustrated and appears as a hyperechoic dot in the epidural space. Deep to the dura mater, the cauda equina fibers are represented by hyperechoic dots placed within an anechoic (black) space occupied by cerebrospinal fluid. In more cephalad regions, the spinal cord will appear as an oval structure with a central hyperechoic region representing the invaginated median sulcus. Of note, the best cross-sectional view at the thoracic region may be obtained by angling the probe to 60–80 degrees, because of the inferior inclination of the spinal processes in this region.

In a paramedian longitudinal view (fig. 2) at the thoracic spine, the spinal processes/laminae are represented by slanted hyperechoic lines beneath the homogeneous-appearing paravertebral muscle mass. Dorsal shadowing will be ap-
parently deep to the spinous processes and other posterior vertebral elements. The highly hyperechogenic ligamentum flavum and dura mater are captured lying in the alternate “windows,” and the underlying spinal cord appears largely hypoechoic with an outer bright covering of the pia and a central line of hyperechogenicity (median sulcus). In the figure, an epidural catheter is illustrated as a hyperechoic line within the epidural space. Of note, identification of the catheter can be challenging because of the similarity in appearance to the ligamentum flavum and dura mater. Hence, one needs to be cautious when interpreting the images presented in publications. When labeling the images in this review, every attempt was made to confirm the anatomical or block-related structure’s identity.

Visibility of Neuraxial Structures and Catheters. A prospective, blinded, pilot study of imaging in 32 infants found that the paramedian longitudinal plane using a linear hockey stick probe allowed the best delineation of the neuraxial structures, with the lumbar spine offering a superior “acoustic window” than the thoracic spine. Visibility was greater in neonates up to 3 months of age, with significant impairments in visibility, especially in the thoracic spine, in the older children (e.g., 7 yr of age). The relative visibility of the dura mater (which is more readily identifiable than the ligamentum flavum) correlated with both age and body weight. The authors commented that besides identifying the dura mater, the epidural space could be confirmed by the clear visibility of the pulsations of the surrounding vessels. They speculated that ultrasound imaging could help confirm epidural catheter placement through visualization of the local anesthetic as well as direct identification of the catheter within the epidural space. However, because of accelerated reductions in visibility in patients weighing greater than 10–12 kg, this technique would be recommended only for small infants.

The above-mentioned relative visibility of the dura mater and ligamentum flavum was confirmed by Kil et al. in their study evaluating the depth of the epidural space as measured by prepuncture ultrasound. These authors found that the dura mater had “good” visibility in 170 of 180 infants and small children, although the view of the ligamentum flavum was “good” in only 91 of the 180 patients. This is a common experience that the authors have also encountered in their practice.

Another study investigating sonographic imaging in 60 neonates reported good visibility of structures within the spinal canal, including the dura mater, ligamentum flavum,
Intervertebral Epidurals section.

The concept that ultrasound may enable more rostral puncture points (i.e., L2/3) than those often recommended for this age group, because of the possibility that the spinal cord terminates at higher levels than assumed (L4/5). This could allow higher success with epidural infusions, because of decreased incidence of catheter coiling during cranial advancement.

One specific use of ultrasound imaging before neuraxial blockade is for determining the angle and depth from the skin to the epidural space. This may be particularly helpful in situations where landmarks may be difficult to palpate such as in obese children. Kawaguchi et al.⁹ reported two cases of epidural anesthesia in an obese girl (body mass index, 34.5). Although this report is published in Japanese, the English abstract verifies that the authors found reasonable agreement between the measured depth to the epidural space using ultrasound and during the actual puncture, which could be assumed to be under the control of loss of resistance or some other mechanical technique. Another study formulated a statistical model to help predict the posterior lumbar dura mater as measured by ultrasound.¹⁰ These authors found that the depth to the dura mater from the skin was best correlated with full body weight ($r = 0.79$) and body surface area ($r = 0.76$) in girls. Although this study’s model may be informative to some degree, there is perhaps more value in correlating the ultrasound-measured depth with that obtained when using other clinical tests (e.g., loss of resistance), because the use of the latter will still be mandatory for safety. More discussion of the outcomes related to predictions of the depth of the epidural space is included in the Outcome Evaluation for Intervertebral Epidurals section.

In the first report of ultrasound imaging in central blockade, Chawathe et al.¹¹ performed a pilot study in 12 patients (1 day to 13 months old) to evaluate the possibility of detecting catheters, and verifying their placement, within the epidural space after placement (within 24 h) through the direct lumbar route. Two pediatric radiologists performed the scanning using a high-resolution cart-based ultrasound system (Toshiba SSH 140A; Toshiba, Tokyo, Japan) and a linear high-resolution probe (7.5 MHz). The catheters could be detected as they entered the epidural space in most (9 of the 10) patients younger than 6 months, although they were not detected in patients older than 6 months. The tip of the catheter was not clearly delineated, and the cephalad point of the catheter could be estimated in only seven of the nine viewed catheters. Indeed, the spinal canal was not even clearly viewed in the older patients. These authors do not directly mention the probe placement, although it was depicted as midline (median longitudinal), and a paramedian view (previously found superior in adults for viewing the epidural structures including the dura mater)¹² was discussed as being potentially limited by the space available in this age group. The authors state that the tip visibility may be improved with the injection of a bubble-based fluid. Their findings that the catheter tip was often (seven of the nine detections) placed at the appropriate level of the thoracic region is in contrast to other reports finding much lower rates of catheter advancement from the lumbar epidural space. The important point from this study is that ultrasound imaging (specifically using the midline approach) of static structures such as catheters can be performed, yet only reliably in very young patients where much of the posterior bony elements of the spinal column may exist as cartilage, thus allowing good ultrasound beam penetration. An optimal angle of probe alignment needed to be evaluated in children and surrogate markers for viewing needle, and catheters may be necessary in some cases, thus necessitating a dynamic technique.

Rapp et al.¹³ performed a prospective case series evaluating the visibility of neuraxial structures and the ability to view lumbar and thoracic catheter placement under real-time ultrasound guidance in 23 patients aged between 5 months and 10 yr. The catheters were placed under real-time imaging, using a probe placed in the paramedian longitudinal plane. In 19 of the 23 patients (all with a lumbar approach), the epidural catheter could be viewed during placement, although multiple imaging planes were required in more than half of the patients studied. The injection of medication was visible in 20 of the 23 patients (again using multiple planes in some cases), which could be an important safety measure, by confirming epidural rather than intrathecal placement. Furthermore, after placement and fixation of the catheter, its final position was determined in 12 of the 23 patients. These results are different from those of Chawathe et al., who found it difficult to view the catheter in patients older than 6 months, although this study may have used injection of fluid for their catheter detection and also used multiple planes of viewing. Without the surrogate marking of the injection of fluid, the axial resolution of the machine used may have lead to misinterpretations.¹⁴ Willenschke et al.⁵ placed epidural catheters under real-time ultrasound guidance, using the paramedian longitudinal imaging plane in 35 neonates. Needle tip entry and the injection of local anesthetic within the epidural space were used to confirm epidural placement; these parameters could be viewed in all neonates. Epidural catheters could be identified only by surrogacy through tissue movement and fluid injection. These results are contradictory to those of Chawathe et al. and Rapp et al., who stated that the catheters could be viewed, even after placement. It may be possible that the difference in findings is mainly due to the imaging capabilities of the ultrasound machine, because the previous studies used high-resolution cart-based systems. Despite this, the authors have found it possible to capture a view of the catheter in infants older than 6 months by using a portable ultrasound system (figs. 1 and 2).

Technique. Rapp et al.¹³ studied ultrasound-guided epidural catheter insertion in 23 children scheduled for elective major surgery. Ultrasound was used preoperatively to view the sacral, lumbar, and thoracic regions; the distance between the skin and the ventral side of the ligamentum flavum was mea-
sured and presumed as the depth to loss of resistance. Although an anesthesiologist performed the epidural puncture (presumably using a midline approach) using loss of resistance to saline, another operator positioned the probe (frequencies between 7 and 11 MHz were used) in the paramedian longitudinal position at the level of the catheter insertion. Loss of resistance could be seen as widening of the epidural space followed by ventral displacement of the dura mater. These authors claim that the catheter placement was controlled through one or more planes of view of the catheter tip and position and that the final catheter position could be viewed in some patients. This is the preferred technique used by one of the authors in their institution (S.S.).

In their randomized, controlled study comparing ultrasound with loss-of-resistance technique for epidural placement, Willschke et al.14 placed epidural catheters under ultrasound guidance in 31 children. The child was placed laterally with the knees flexed with an assistant performing the imaging by placing a hockey stick probe in a paramedian longitudinal plane at the level of epidural puncture. The anesthesiologist performed the epidural puncture using an epidural catheter set with a 19-gauge Tuohy 50-mm needle and 24-gauge catheter. A midline puncture was performed after identification of the dura mater on ultrasound imaging. The needle was noted to penetrate the ligamentum flavum and its epidural placement was confirmed through viewing the spread of an initial volume of local anesthetic and ventral movement of the dura mater. After introducing and advancing the catheter 2–3 cm, the catheter’s tip was localized by monitoring the movement of the remainder of the local anesthetic solution.

During their three-part study of sonoanatomy and feasibility of ultrasound guidance in neonates, Willschke et al.15 performed ultrasonographic guidance of epidural catheter placement in 35 neonates using a similar procedure as that described earlier. With the probe placed in the longitudinal paramedian plane and using a midline needle puncture, the needle (21-gauge nanoline-coated Tuohy epidural needle) tip could be viewed clearly within the epidural space. Viewing the spread of local anesthetic solution on two separate injections confirmed both epidural needle placement and catheter position.

Comment. Ultrasound imaging in neonates and infants has shown that the epidural space (specifically the space between ligamentum flavum and dura mater) is less than 2 mm wide. Because of this tiny size, one group of anesthesiologists has found that a specially designed catheter kit containing a 21-gauge Tuohy cannula and a 25-gauge catheter is suitable for epidural catheter placement for this age group.15 Rigorous training in observing the relationship of the structures may be needed before this can be routinely used in pediatric patients.

Clinical Pearls—Intervertebral Epidurals.

- Ultrasound imaging may be used to estimate the depth to the epidural space and to view the spread of local anesthetic.
- At present, ultrasound-guided technique would certainly not preclude continuous testing for loss of resistance.
- The main limitation of the technique is that the needle shaft and tip may be hard to localize with the tangential relationship of the needle (midline) and the probe (paramedian longitudinal).
- An assistant is generally required during catheter placement to perform the imaging in real time.

Outcome Evaluation for Intervertebral Epidurals

Predicting the Depth of the Epidural Space. Several investigators have determined that preprocedural use of ultrasound may fairly reliably determine the depth required to reach the epidural space. In the preceding sections, there is discussion of two publications9,10 that describe the use of ultrasound to predict/determine epidural depth, although their noncomparative design prevents them from being included in this discussion. Correlations have been calculated between the skin-to-epidural space distance (the distance to the ventral surface of the ligamentum flavum), as measured by the built-in calipers of the ultrasound system, and the depth of needle penetration during clinical practice using the loss-of-resistance technique.

Rapp et al.13 found an estimated correlation of 0.88 and a high conformity (using Bland–Altman precision analysis) between ultrasound-measured epidural space depth and depth to loss of resistance in a prospective case series including 23 children aged between 5 months and 10 yr. Various probe positions were used, although the authors do not state which positions were used for their correlation data. They also fail to describe whether they accounted for the angles of needle and probe placement when calculating the correlation of their distances.

Similar correlation data using the longitudinal median view ($r^2 = 0.848$) and a transverse view ($r^2 = 0.788$ at L4–5) were calculated by Kil et al.16 in 180 infants and small children. These authors specifically state their methodology with respect to needle and probe alignment and calculations to compare the perpendicular depths for both needle and ultrasound beam. Although the correlation calculations may have been more rigorous than previous work, the ultrasound measured skin-to-ligamentum flavum distance was referred to in this study during the blind procedure, and the technique used for needle entry to the epidural space (drip infusion method) is not widely practiced.

Willschke et al.5 correlated the epidural space depth (depth of the ligamentum flavum from the skin) to body weight as well as to the clinical depth of loss of resistance in 50 neonates, using a paramedian longitudinal plane. The depth of the dura mater and ligamentum flavum from the skin was measured at mid-thoracic and lumbar levels, and the correlation between skin-ligamentum flavum depth and body weight at the L1/2 level was good ($r^2 = 0.8$; similar values were obtained for other levels). The correlation between ultrasound-measured epidural depth and depth to loss of resistance was moderate at 0.64. The anesthesiologist performing the epidural was blinded to the measured depth of the ligamentum flavum.
Comparison of Block Characteristics between Ultrasound Guidance and Standard Loss-of-resistance Technique. A randomized study was performed to compare ultrasound guidance with loss-of-resistance technique for placing epidural catheters at the lumbar and thoracic levels. Th14 The epidural placement procedures were analyzed primarily for bone contacts (17 vs. 71%) and speed of execution (162 vs. 234 s) in the ultrasound and loss-of-resistance groups, respectively. However, the merit of these outcomes is questionable. The key benefit of ultrasound guidance is the ability to visualize and monitor the needle tip advancement. In their study, there were several bone contacts (17% overall, but 21% in infants younger than 6 months), which raises a major concern of the possibility that approximately 20% of the needle tips were not seen. On the other hand, it is difficult to judge the significance of bone contact when using loss-of-resistance technique because there is an inherent use of contacting bone particularly when using a paramedian approach. In terms of the speed of execution, the authors did not include the start-up time for their system and this may be highly variable with respect to the ultrasound systems used. Despite the above comments and the fact that no difference was found between groups for placement success or perioperative analgesia, it is intuitive that ultrasound should improve the success and safety of epidurals at least by providing a good estimate of the depth to the epidural space and possibly by allowing a direct view of the injection of local anesthetic within the epidural space. The catheter tip can be tracked during placement by viewing either the injection of the local anesthetic solution or the ventral movement of the dura mater.

Caudal Needle Placement
Caudal blocks, including both single-shot caudal and lumbar or thoracic epidural catheters advanced from the caudal epidural space (thus avoiding the spinal cord), have been by far the most commonly practiced regional anesthesia techniques in children. Neuraxial blockade is suitable for lower extremity perioperative analgesia in children and may be preferable to peripheral nerve blocks in some cases because multiple peripheral nerve blocks are often required to anesthetize the involved sensory regions, and the volumes of local anesthetic solution required may reach toxic levels in combined blocks of the lumbar and sacral plexuses. Despite this, continuous peripheral nerve blocks of the lower extremity may allow equal block efficacy with reduced adverse effects (i.e., less urinary retention, nausea, and vomiting)16 when compared with epidural analgesia. In addition, it has been found that caudal blocks can be associated with higher rates of complications than peripheral blocks, with their potential for bloody punctures and intravascular injections.3,17 Current literature recommends that the use of caudal blocks should be performed only when indicated by major surgery and that peripheral blocks should be used when possible.18

Techniques.
Sonoanatomy. Ultrasonic imaging at the midline using both transverse and longitudinal alignment of the probe should be performed before needle placement, to appreciate the patient’s anatomy and identify the sacrococcygeal ligament, dural sac, and cauda equina. A linear high-frequency small footprint or hockey stick probe is a suitable choice, although a larger footprint may be used when viewing the longitudinal axis to allow an adequate field of view.

Placing the probe initially in a transverse plane at the coccyx and scanning in a cephalad direction can help with landmark identification particularly during training in sonoanatomy. This view allows a good delineation of the sacral hiatus (fig. 3); the sacral cornua are viewed laterally (as “humps”)19 and the sacral hiatus is located between an upper hyperechoic line, representing the sacrococcygeal membrane or ligament and an inferior hyperechoic line representing the dorsum of the pelvic surface (base) of the sacrum. Placing the probe longitudinally between the sacral cornua will capture the dorsal surface of the sacrum, the dorsal aspect of the pelvic surface of the sacrum, and the sacrococcygeal ligament. The sacrococcygeal ligament covers the sacral base beyond the end of the dorsum of the sacrum. It appears as a relatively thick linear hyperechoic band sloping caudally. The sacral hiatus is identified as the hypoechoic space located

![Fig. 3. Sonoanatomy of the caudal epidural space at the level of the sacral hiatus using a linear hockey stick probe (SLA, 6–13 MHz, 25 mm footprint) placed in the transverse plane. Note the anechoic sacral hiatus between the hyperechoic lines of the sacrococcygeal membrane and the dorsal side of the pelvic surface of the sacrum. The sacral cornua appear as “humps” bilaterally.](image-url)
between the dorsum of the sacrum and the dorsal side of the pelvic surface of the sacrum. In older patients where ossification has advanced at the midline, the paramedian longitudinal view may be necessary because it will allow the ultrasound beam to penetrate the spaces on either side of the spinous processes. This paramedian view would allow appreciation of the ventral movement of the dura mater during fluid injection but would not allow a real-time view of the needle along its axis. **Technique.** During or after skin puncture with the needle, both transverse and longitudinal sonographic planes can be used for confirming caudal epidural needle placement. Schwartz et al. published a case report and a retrospective observational study where transverse ultrasound imaging was used for viewing the sacral anatomy and confirming the local anesthetic spread within the caudal epidural space. In an 8-month-old infant, ultrasound imaging was helpful to locate the sacral hiatus because a previous failed block attempt produced significant edema, thus hindering anatomical palpation. The transverse plane allowed clear identification of the sacral anatomy (sacral cornua and hiatus) and the authors marked the skin at the location of the sacrococcygeal ligament midway between the cornua. For both this single case and the 83 pediatric patients reviewed, transverse imaging was performed after cannula placement with the probe placed cephalad to the injection point. This imaging plane enabled recognition of the injection of local anesthetic within the caudal epidural space, as dilation of the caudal space and localized turbulence, thus confirming correct placement and avoidance of intravascular or intrathecal puncture. These authors commented that the best view of the turbulence may be found when the ultrasound depth (focus) is adjusted to 2 cm. In addition, either color flow or power Doppler imaging can be used to view the solution. 

Roberts et al. published a prospective observational study of 60 children in whom they determined whether a saline test bolus could be reliably imaged with ultrasound to confirm cannula placement in the caudal epidural space. Although transverse imaging was performed in the prepuncture scan to help visualize the neuraxial structures (there was no mention of measurements or skin markings), longitudinal imaging (~1 cm above the cannula insertion site) was used during the saline test bolus of 0.2–0.3 ml/kg to view the anterior displacement of the posterior dura mater. The longitudinal plane may allow a view of the long axis of the needle as it penetrates the sacrococcygeal ligament. This technique may be particularly beneficial to allow adjustments in needle angle to ensure adequate length of advancement and depth of penetration without intraosseous placement. The optimal angle for needle insertion during caudal block has been evaluated using ultrasound because many of the previous recommendations include multiple angles, necessitating needle manipulations, including a steep initial angle that may increase the incidence of bony puncture. It does seem ideal to find a single angle that could be maintained during puncture, especially in the case of real-time observation under ultrasound imaging. Performing caudal punctures in 130 children, 2–84 months of age, Park et al. found that aligning the needle to the angle of the caudal canal (specifically the posterior surface of the sacrum), thus using a 21-degree angle to the skin surface, leads to successful needle placement in 92.3% of patients.

When introducing a catheter into the caudal space to reach the lumbar or thoracic spine, a technique similar to the above is used for cannula placement, and the catheter is viewed during advancement using ultrasound imaging at the level of the spine above the sacrum. The earlier discussion of intervertebral epidural catheter placement can be referred to for imaging techniques when viewing the spinal column. Ultrasound assessment of epidural catheter position through a caudal route has been described in a small case series and in a letter to the editor. Roberts and Galvez found that sagittal placement of the probe was sufficient to view lumbar and thoracic catheter advancement in two patients of 1 and 8 months of age, whereas paramedian placement was required for the 10-month-old because of poor imaging at the thoracic spine. Surrogate marking of the 20-gauge catheter was seen through anterior displacement of the posterior dura mater during the saline test injection and caudal and cephalad spread of the local anesthetic injection. The tip of the catheter could be viewed in the 1-month-old, enabling exact placement at the desired level of T6.

Rapp and Grau placed an epidural catheter through the caudal route using ultrasound imaging in a 6-month-old infant. They did not specify whether the catheter was placed under real-time guidance or whether the catheter was viewed at all, nor did they state which position (paramedian or midline) they placed the probe while obtaining the longitudinal views. Nevertheless, the images obtained from both the longitudinal and transverse views of the sacral region in this infant show fairly good clarity with respect to the cauda equina, epidural space, and dural sac.

**Comment.** It is of critical importance during caudal blocks to place the needle or cannula in the correct position, to both avoid complications from intravascular or intrathecal placement and ensure effective analgesia. Most current techniques aiming to help confirm whether the needle is placed appropriately within the caudal epidural space cannot distinguish epidural from intrathecal placement or warn of intravascular placement. When using an epidural electrical stimulation test, elicitation of a motor response to very low current (<1 mA) in the caudal space may warn of needle placement intrathecally or against a nerve, and injection of a test dose (or repeated doses) of local anesthetic solution into the intravascular space will not obliterate the motor response. Although promising, the clinical value of electrical stimulation in caudal needle placement has not been extensively studied. This technique may assist ultrasound guidance if the age or body weight of the patient precludes direct viewing of the caudal needle and local anesthetic spread within the epi...
dural space. Electrical stimulation may be more valuable to assist ultrasound-assisted or guided technique in cases where the catheter is poorly viewed during its advancement from the caudal to lumbar or thoracic space, because the test can both confirm the epidural location of the catheter (via current requirement of motor responses) as well as determine the segmental location reached (by observing the specific motor responses).

Depending on the plane of view, ultrasound guidance, or the aid of ultrasound imaging may allow the anesthesiologist to (1) appreciate the sacrococcygeal anatomy, including the position of the sacral cornua/hiatus and the position of the dural sac; (2) view in real time the cannula as it enters the sacrococcygeal membrane (in longitudinal viewing); and (3) view the spread of a test dose of fluid (saline or local anesthetic) either directly or as displacement of the posterior dura mater in an anterior direction (mainly using an axial view).

Although the pediatric literature includes descriptions of block technique, which seem to favor one plane of viewing during needle placement and injection, using both planes may be suitable especially during initial experience with ultrasound imaging. A technique using first longitudinal (to view the needle puncture) and then transverse (to view the spread of solution) may be ideal. This is similar to that described in the adult literature. As with conventional technique, the injection of local anesthetic should be performed in small aliquots with additional monitoring of heart rate changes and electrocardiography morphology to detect T-wave changes.

Clinical Pearls—Caudal Needle Placement

- Initially, use a transverse plane of imaging to identify the sacral hiatus located between the cornua. The hiatus is located between an upper hyperechoic line representing the sacrococcygeal membrane or ligament and an inferior hyperechoic line representing the dorsum of the pelvic surface (base) of the sacrum.
- Rotate the probe to the longitudinal plane (a paramedian plane may be required in older children) to capture the sacrococcygeal membrane, a relatively thick linear hyperechoic band, sloping caudally.
- Insert the needle under either plane of view, although a longitudinal view may allow for optimal viewing along the needle. A transverse view can be used after needle placement within the epidural space, to view the spread of local anesthetic (as dilution of the caudal space and localized turbulence).
- Using a single-needle direction may lead to successful placement during ultrasound guidance; aligning the needle to the angle of the caudal canal (specifically the posterior surface of the sacrum), thus using a 21-degree angle to the skin surface, has been shown to be reliable.

Outcome Evaluation for Caudal Needle Placement. Ultrasound imaging has been evaluated in comparison with the swoosh test for confirming caudal epidural placement. This retrospective observational study evaluated the predictive values of the swoosh test and ultrasonography in 83 patients, all of which received both tests in sequence. The swoosh test was performed by listening over the lower lumbar spine with a standard stethoscope during injection of small aliquots of local anesthetic. Subsequent real-time ultrasound scanning (incorporating color flow Doppler) incorporated use of a transverse view slightly above the injection point to capture turbulence of the fluid within the epidural caudal space. Both tests were considered negative, positive, or equivocal, although negative and equivocal tests were combined for analysis. The sensitivity and negative predictive value (96.3 and 40%) of ultrasound were significantly higher than those using the swoosh test (57.5 and 5.6%). The low negative-predictive value of ultrasound may have been partly due to the older age (5–8 yr) of these patients or the imaging technique of the authors. The negative-predictive value of the swoosh test was lower than that previously reported, with contributory factors attributed to the larger bore catheter used (improving ultrasound visibility yet reducing the turbulence required for the auscultation during the swoosh test) and the relatively high level of ambient noise in their operating room.

Spinal Anesthesia

To our knowledge, there is no published literature directly related to ultrasound imaging for spinal anesthesia in pediatrics. Theoretically, ultrasound could be used to help predict or determine (if using in real-time) the depth to reach either the subarachnoid space or some depth within the spinal canal. This would be especially relevant to help ensure that the needle does not advance toward the posterior aspect of the vertebral body and the associated venous plexus. Ultrasound imaging has helped determine that the sitting position may enable higher success when performing a lumbar puncture in newborns, because the subarachnoid space is wider in this position when compared with the lateral decubitus position. Some of the above-mentioned work, describing how ultrasound may be used to predict the depth to the dura mater, would be relevant to spinal anesthesia, as would the experience of using ultrasound to guide needle placement (in this case, beyond the dura mater) after penetration of the ligamentum flavum.

Discussion

There is an increasing amount of literature being published describing ultrasound-guidance techniques for neuraxial blocks in children. Although the outcomes documented suggest that there may be benefits, there is insufficient evidence to make such claims based on relatively small studies. However, it is reasonable to postulate that ultrasound imaging, during or before performing neuraxial blockade, may reliably predict the depth of loss of resistance and can enable a dynamic view of the needle and catheter after entry into the spinal canal. In some patients particularly young infants, direct visualization of the needle and catheter tip may be
possible, whereas in older children surrogate markers including the spread of local anesthetic and displacement of the dura mater will be prerequisites for confirming needle and catheter placement. With improved technology, such as developing a method to improve the echogenicity of catheters, one may have more confidence and ability to place epidural catheters at the optimal segmental location without the coiling and bending associated with catheters advanced cephalad from the caudal space.

Despite an increasing amount of literature supporting the use of ultrasound imaging for neuraxial blocks, it has not been established that ultrasound imaging will improve the performance or outcome of neuraxial blocks for all patients. The use of ultrasound may thus be reserved for certain cases where blind technique may be challenging. For example, even though the use of ultrasound imaging for caudal blockade may be somewhat cumbersome, and considering that these blocks are relatively simple to perform in a blind manner, identification of the anatomical landmarks may be facilitated in some patients by direct visualization, such as when palpation of the cornua is limited by the presence of significant presacral adipose tissue.

Prerequisite to a safe and successful ultrasound-guided block is an accurate identification of the target neural structures and their surrounding milieu. Sonoanatomy can be highly dependent on the available ultrasound system and the plane of view. For this reason, this review includes representative images obtained from a portable ultrasound unit (using the scanning planes commonly described) to serve as examples of typical sonograms used to facilitate neuraxial blockade. Bony or soft tissue landmarks are often essential to help visually identify the various structures related to the successful and safe performance of epidural and spinal blockade. Although more impressive during dynamic viewing, the pulsatile nature of arteries is commonly evident; alternatively color or power Doppler can be used and will help with future reference to a static image. The bony vertebral column will provide an outline for identifying the dura mater and other spinal canal structures. Table 1 provides some examples of landmarks commonly used by the authors and others for identifying the various structures related to peripheral and neuraxial blocks.

The authors limited their discussion to those articles that were either published in English or contained English abstracts. Apart from the one Japanese case report discussed, three expert reviews were obtained, although they are not included in the discussion. One of the reviews, although containing an English abstract, focused on risks and dangers in pediatric regional anesthesia (with ultrasound as a key word), one review summarized localization of nerves in pediatric anesthesia, and only the last was directly related to ultrasound in pediatric regional anesthesia. The review by Marhofer and Kapral may have been valuable to interpret, although it is highly likely that this review discusses many of the same techniques described in their work already included in this review.

Another limitation of the search was that the authors only included reviews that were specific to ultrasound guidance in pediatrics. While this could also have limited the amount of technique description, upon brief review of several general review articles, there is often brief sections devoted to the pediatric population, with descriptions of techniques as performed in the studies included in this review.

**Conclusion: Ultrasound in Pediatric Regional Anesthesia**

There is increasing use of regional anesthesia in infants, children, and adolescents. Marked improvement in postoperative outcomes and excellent pain relief, with the absence of adverse side effects including postoperative nausea and vomiting, have increased their use in this age group. For peripheral nerve blocks, direct visualization of the block needle tip and proximal anatomic structures, including the nerves and their closely associated vascular structures, may provide pediatric anesthesiologists with a tool to help accurately place the local anesthetic solution while avoiding potential complications such as intraneural and intravascular injections. An avoidance of mechanical nerve injury is particularly relevant to children, because the ability to use (potentially reliable) subjective warning signs is not possible in the anesthetized and the currently relied on technique of nerve stimulation is showing to have less than optimal sensitivity.

Many techniques have been described, many of which are those that can benefit from the use of preprocedural or real-time imaging because of their inherent risks. Perhaps most suitable for ultrasound imaging are those blocks situated at the trunk, where the nerves lie in close proximity to the abdominal viscera and for which conventional techniques relying on palpation have often failed. In addition, obesity and anatomical malformations are particular scenarios where
ultrasound may be of the greatest value. The most exciting potential is the possibility for performing pharmacodynamic studies that can potentially decrease the volume of local anesthetic solutions that can be administered for those blocks or situations where there is an increased risk of toxicity in children. More outcome-based, prospective, randomized controlled trials are required to prove many of the benefits of this technology when compared with conventional methods used for nerve blocks, but there has certainly been a trend in some centers favoring its use in infants, children, and adolescents. One more very important aspect of this endeavor is to ensure proper resident education for the performance of ultrasound-guided regional anesthesia on a consistent basis in infants, children, and adolescents.

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