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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.[1] 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.[2] Finally, although it is generally agreed to be safe to perform regional anesthesia in anesthetized children,[3] 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,[4] relating to ultrasound-guided extremity and trunk blockade. Our aim is to provide the pediatric anesthesiologist 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-

* Professor, Department of Anesthesiology and Pain Medicine, University of Alberta, Edmonton, Alberta, Canada. † Professor, Department of Anesthesiology and Pediatrics, Children's Memorial Hospital, Northwestern University, Feinberg School of Medicine, Chicago, Illinois.

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Address correspondence to Dr. Suresh: Department of Pediatric Anesthesiology, Children's Memorial Hospital, 2300 Children's Plaza, Box 19, Chicago, Illinois 60614. ssuresh@childrensmemorial.org. This article may be accessed for personal use at no charge through the Journal Web site, www.anesthesiology.org.

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.[5] Of note, the best cross-sectional view at the thoracic region may be obtained by angling the probe to 60–80 degrees,[6] because of the inferior inclination of the spinous processes in this region.

In a paramedian longitudinal view (fig. 2) at the thoracic spine, the spinous processes/laminae are represented by slanted hyperechoic lines beneath the homogeneous-appearing paravertebral muscle mass. Dorsal shadowing will be ap-

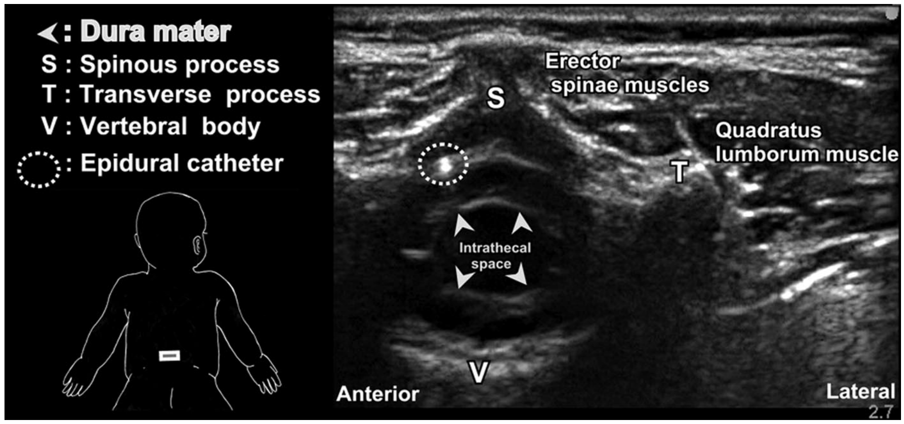

Fig. 1. Sonoanatomy of the spinal column and canal in transverse axis at the L3/L4 level. This image was captured in real time during the advancement of a catheter (viewed), using a linear probe (HFL38, 6–13 MHz, 38 mm footprint) in an 8-month-old child. The *dura mater* is clearly delineated.

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.[7] 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.*[8] 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*,

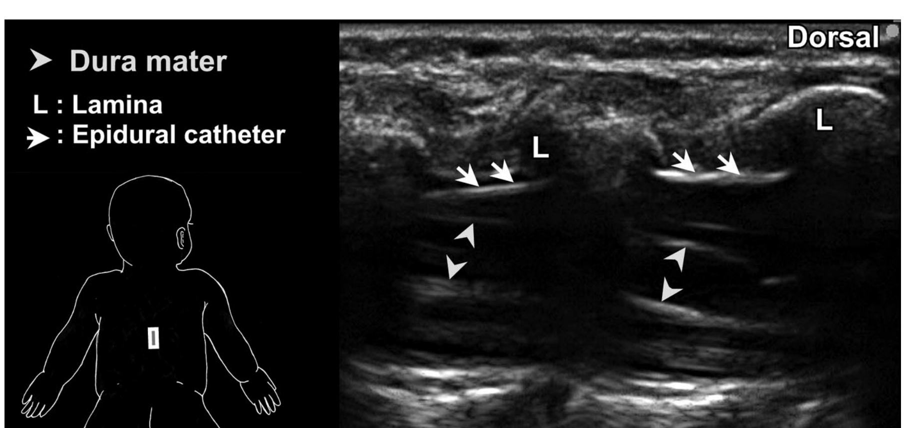

Fig. 2. Sonoanatomy of the spinal column and canal in paramedian longitudinal view at the midthoracic level. This image was captured in real time during the advancement of a catheter (viewed), using a linear probe (HFL38, 6–13 MHz, 38 mm footprint) in an 8-month-old child.

and the termination of the spinal cord (terminating at the mean level of L2 in these patients placed in the left lateral position with the hips flexed).[5] This study introduces 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 finding 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]

Willschke *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 measured 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.*[5] 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 publications[9,10] 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.*[8] 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 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 midthoracic 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.[14] 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. Ultrasound 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.[19] 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

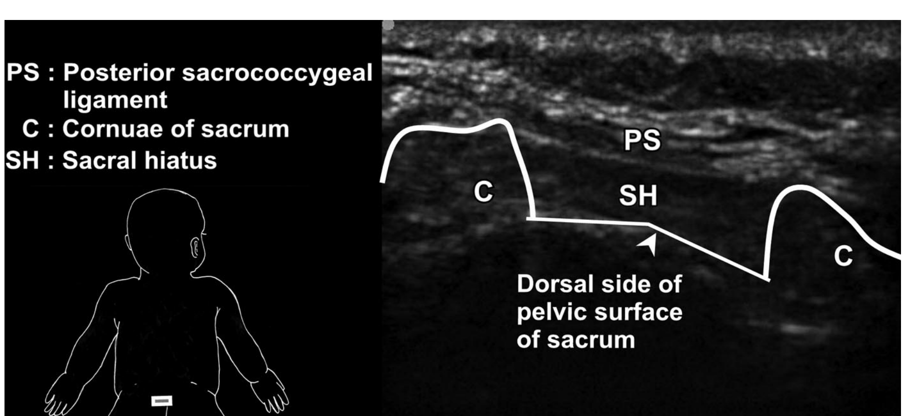

Fig. 3. Sonoanatomy of the caudal epidural space at the level of the sacral hiatus using a linear hockey stick probe (SLA, 6–13 MHz, 25 mm footprint) placed in the transverse plane. Note the anechoic sacral hiatus between the hyperechoic lines of the sacrococcygeal membrane and the dorsal side of the pelvic surface of the sacrum. The sacral cornua appear as "humps" bilaterally.

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.[20] 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[21,22] and longitudinal[20,23] sonographic planes can be used for confirming caudal epidural needle placement. Schwartz *et al.*[21,22] 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,[19] 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.[19] In addition, either color flow or power Doppler imaging can be used to view the solution.[19,21]

Roberts *et al.*[24] 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.*[23] 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[20] and in a letter to the editor.[25]

Roberts and Galvez[20] 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[25] 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,[26] 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.[27] Although promising, the clinical value of electrical stimulation in caudal needle placement has not been extensively studied.[28] 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 epidural 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.[29] 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.[30,31]

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 dilation 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.[21] 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.[1] 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.[32] 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 from 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,[9] 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),[33] one review summarized localization of nerves in pediatric anesthesia,[34] and only the last was directly related to ultrasound in pediatric regional anesthesia.[35] The review by Marhofer and Kapral[35] 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[36] and the currently relied on technique of nerve stimulation is showing to have less than optimal sensitivity.[37] 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

Table 1. Useful Landmarks for Use with Ultrasound in Neuraxial Blocks

Block	Useful Ultrasound Landmark	Comments
Central neuraxial		
Epidural	Distinct bony structures (spinous processes mark midline in transverse plane and laminae border intervertebral space using paramedian longitudinal plane) and *ligamentum flavum/dura mater*	*Dura mater* becomes harder to visualize in children older than 6 months
Caudal	Two cornua with hyperechoic lines of sacrococcygeal membrane and dorsum of pelvic surface of sacrum	Injectate can be observed, especially when using color Doppler

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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Evidence-Based Medicine: Assessment of Ultrasound Imaging for Regional Anesthesia in Infants, Children, and Adolescents

Ban C.H. Tsui, MSc, MD, FRCPC and Jennifer J. Pillay, BSc

Abstract: This review was performed to evaluate and discuss the quality and outcomes of studies assessing ultrasound imaging in pediatric regional anesthesia. Literature searches were conducted using MEDLINE and EMBASE, combining the search term "ultrasonography" with "regional anesthesia," "nerve block," "epidural anesthesia," and "spinal anesthesia," with the limit of 0 to 18 years. Additional literature was sought from departmental files and recent issues of several major anesthesiology journals. Meta-analyses/systematic reviews, randomized controlled trials, clinical studies without either randomization or control (eg, comparative studies), and case series (n > 10) were collected, reviewed, and graded for their quality (Jadad scores) and level of evidence (Grades of Recommendation). The search resulted in 211 total publications in pediatric literature, of which 12 were included in the evaluation of peripheral nerve blocks and 12 in the evaluation of neuraxial anesthesia. Although there is some evidence to support ultrasound for various outcomes in pediatric regional anesthesia, more randomized controlled studies with sufficient power are required to further support these findings and to evaluate the potential for ultrasound to reduce complications for regional anesthesia in children.

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Ultrasound imaging may be of particular use in pediatric regional anesthesia owing to the close anatomical relation of their nerves to critical structures, the concomitant use of general anesthesia in most cases precluding the use of potential subjective warning signs, and the possibility of local anesthetic toxicity with above-threshold doses of local anesthetics. To assess whether there is a sufficient evidence base for any benefit of ultrasound imaging, relevant literature was reviewed to evaluate and discuss the quality and outcomes of related studies assessing ultrasound imaging in pediatric regional anesthesia.

From the Department of Anesthesiology and Pain Medicine, University of Alberta, Edmonton, Alberta, Canada.
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Address correspondence to: Ban C.H. Tsui, MSc, MD, FRCPC, Department of Anesthesiology and Pain Medicine, 8-120 Clinical Sciences Bldg, University of Alberta, Edmonton, Alberta, Canada T6G 2G3 (e-mail: btsui@ualberta.ca).
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METHODS

Search Strategy

Literature searches using MEDLINE (through Entrez PubMed) and EMBASE for the period from 1994 to present were performed during the third week of August 2009. The MEDLINE search initially used a combination of the medical subject headings "ultrasonography" and "anesthesia, conduction," with the limits of publication date (as previously mentioned), humans, and all children aged 0 to 18 years. Subsequent searches combined the key word "ultrasound" with one of "regional anesthesia," "nerve block," "epidural anesthesia," or "spinal anesthesia"; 4 of these searches were limited to humans and children (0–18 years) and 2 ("ultrasound" and each of "regional anesthesia" and "nerve block") were combined with the key word "children" (7 searches in total). For the EMBASE search, we combined "ultras'*' title" (* denotes truncated form) with the key word "children" and each of "nerve block" and "regional anesthesia." Additional literature was sought from within our departmental files as well as the recent (6 months previously) table of contents to several major anesthesiology journals.

Literature Selection

Our aim was to review, as systematically as possible, the evidence for ultrasound imaging in pediatric patients, therefore we chose to select only meta-analyses/systematic reviews, randomized controlled trials (RCTs), nonrandomized clinical studies with control, and case series including at least 10 patients. We assumed that 10 patients would be an absolute minimum that could potentially provide an estimate of any outcome; these small case series would likely not have been included if the literature base was estimated as being sufficient to provide evidence as based on clinical studies. Case series (n < 10), case reports, and letter to editors were all excluded, as well as both narrative/expert reviews and those publications where adults and children were jointly studied (ie, the latter including no outcome data specific to the pediatric patient). There was no limit to the English language, although only those articles with English abstracts were to be described or discussed if relevant. We considered that blocks for treatment of chronic pain were out of the scope of this review because the techniques used and outcome assessments would likely not be comparative. With some of the potential advantages of ultrasonography for analgesia/anesthesia, mainly neuraxial, being related to preprocedural landmark identification (ie, not real-time guidance), publications where there was no clinical block performed were included to fully assess the value of ultrasound imaging. Conversely, those publications that evaluated or demonstrated ultrasound use in children yet were not related to anesthesia were excluded because the scanning technique would likely be different (including the ultrasound system) and the patients may often have anatomical abnormalities not influenced by, or amenable to, anesthesia. Dural punctures as related to anesthesia practice were included.

Evidence Evaluation

The retrieved literature was divided into 2 sets to separately evaluate peripheral and neuraxial anesthesia. Thereafter, data related to specific outcomes (see below) were extracted from the publications and entered into a database (Microsoft Excel, Microsoft Corp., Redmond, Wash) to enable the assigning of a Grade of Recommendation to each outcome, as defined by the Statements of Evidence. Furthermore, because the Grade of Recommendation does not incorporate a measure of the scientific quality of each study design (defined as the likelihood of the design generating unbiased results and approach the "therapeutic truth"), Jadad scores were given for each RCT.[1] The questions we attempted to answer in this review include the following:

1. For peripheral nerve blocks (PNBs), is there evidence that ultrasound (*a*) reduces block performance time, (*b*) hastens block onset (time to onset of sensory anesthesia in all related nerves), (*c*) improves block success (surgical anesthesia via complete sensory block and without conversion to general anesthesia, or intraoperative analgesia without need for rescue analgesia [via vital signs monitoring]), (*d*) improves block quality (either time from block placement to first analgesic [block duration] or number of patients requiring rescue analgesia over the study period [improved pain relief]), and (*e*) reduces local anesthetic dose?
2. For neuraxial anesthesia, does ultrasound enable (*a*) clear visibility of the dura mater or ligamentum flavum as landmarks (defined as necessary to measure/estimate depth of epidural space and spinal cord and to help prevent intrathecal placement, especially if real-time imaging is used), (*b*) accurate measurements for good prediction (correlation coefficient, $r^2 \geq 0.7$) of the depth to epidural space compared with mechanical means (eg, loss-of-resistance [LOR]), (*c*) identification of the needle's epidural placement (needle puncture or LOR via displacement of tissue), and (*d*) identification of the catheter within the epidural space (directly or indirectly via surrogacy of tissue movement and injection of fluid)?

Additional outcomes were also evaluated if they were related to the primary or secondary objective(s) of an RCT if the study was assumed to have corresponding statistical power to enable sufficient evidence to provide a Grade A or B recommendation. Those studies that could not provide appropriate evidence, and those non-RCTs that did not relate to our predetermined outcome measurements, are discussed briefly as "other comments."

RESULTS

The search resulted in 211 total publications in pediatric literature, of which 12 were included in the evaluation of PNB and 12 in the evaluation of neuraxial anesthesia. The PNB set contained 6 RCTs[2–7] and 6 case series,[8–13] whereas the neuraxial set contained 1 RCT,[14] 1 comparative study,[15] and 10 case series.[16–25] A modified PRISMA flow diagram (designed for reporting of systematic reviews) is included in Figure 1 (www.prisma-statement.org). There was no exclusion of publications that did not have English text because all relevant studies were published in English. Papers related to regional anesthesia, which were not written in English, were all excluded based on small sample size or being an expert/narrative review.

Quality of Studies

Using the Jadad scale, a numerical score between 0 and 5 was assigned to each RCT included in this review. The results of this assessment are as follows: 1 score of 2,[14] 3 scores of 3,[3,5,7] 1 score of 4,[4] and 2 scores of 5.[2,6] We considered the patient and assessor/anesthesiologist blinded despite failure to directly mention this procedure, if they were under general anesthesia or mentioned as not being involved in the study, respectively.

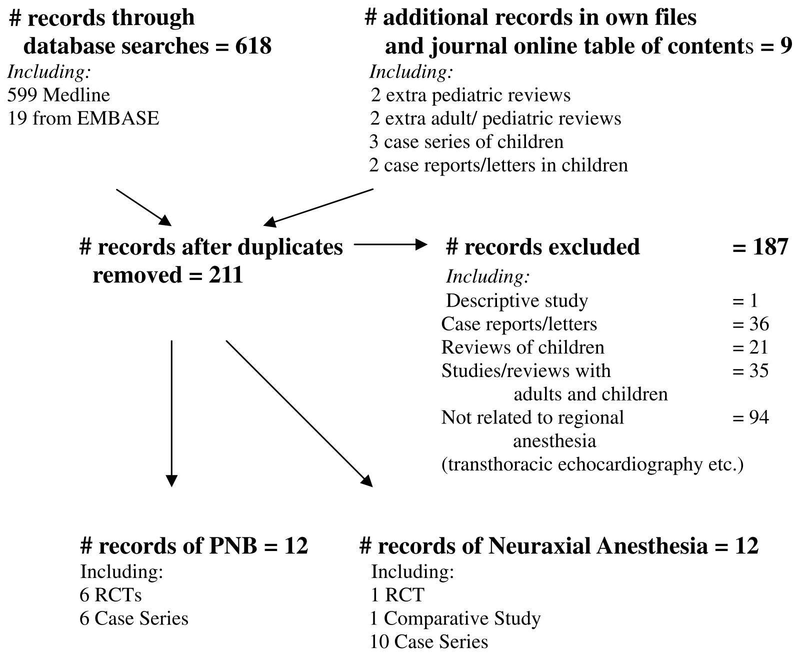

FIGURE 1. PRISMA flow diagram illustrating results of search strategy and literature selection. This diagram is modified from that designed for systematic reviews, since we did not actually screen any studies for inclusion, i.e. all RCTs, case series > 10, and clinical studies were included.

Evidence and Grades of Recommendation

A structured summary of the outcomes, Statements of Evidence and Grades of Recommendation are presented in Table 1. There were no meta-analyses published in relation to ultrasound guidance in pediatric regional anesthesia, thus a Statement of Evidence of Ib (ie, RCT) was the highest score given. Statements of Evidence IIa–b were not applicable for the studies, a grade of 3 was assigned for the descriptive (comparative) study and for the case series. No IV Statements were assigned because we did not consider expert reviews or opinions or clinical experiences reported without specified protocol and ethical review.

DISCUSSION

Peripheral Nerve Blocks

There is no evidence to support that ultrasound-guided block placement is faster than when using conventional localization techniques. No RCT, controlled clinical study, or case series addressed the outcome of reduced block performance time.

Ultrasound guidance reduces onset of sensory block for upper extremity PNBs. **Statement of Evidence Ib, Grade of Recommendation B (No body of literature).** Because regional anesthesia is often performed in anesthetized children, limited studies existed to evaluate sensory onset time. Marhofer et al[3] compared ultrasound guidance with nerve stimulation for infraclavicular blocks used for surgical anesthesia in 40 children and found that ultrasound imaging hastened onset of the block (9 versus 15 mins; $P < 0.001$) as measured between the time of local anesthetic injection to the first recording of VAS = 1 (no pain as measured in 5-min intervals). It is not clear whether this onset was in all the related nerves, but with the block sufficiency in part determined through analgesia in 2 nerves' distributions, it may be assumed this is similar for block onset.

Ultrasound guidance does not improve block success rates in upper extremity PNBs when compared with nerve stimulation guidance. **Statement of Evidence Ib, Grade of Recommendation B (No body of literature).** The comparison of ultrasound and nerve stimulation-guided lateral infraclavicular block by Marhofer et al[3] primarily evaluated block quality and distribution, but the success of surgical anesthesia was reported

TABLE 1. Statements of Evidence and Grades of Recommendation for the Outcomes Evaluated in This Review

Evaluated Outcomes	Statements of Evidence	Grade of Recommendation
Peripheral nerve blockade		
Reduces block performance time		
No evidence found.	N/A	N/A
Hastens block onset		
Ultrasound guidance reduces onset of sensory block for upper extremity PNBs.	Ib	B
Improves block success		
Ultrasound guidance does not improve block success rates in upper extremity PNB*s when compared with nerve stimulation guidance.*	Ib	B
Ultrasound guidance improves the intraoperative block success for PNBs at the trunk.	Ib	A
Improves block quality		
Ultrasound guidance prolongs analgesia for upper and lower extremity blocks.	Ib	A
Ultrasound-guided blocks at the anterior trunk improve early postoperative pain relief for inguinal and umbilical procedures.	Ib	B
Reduces local anesthetic dose		
Ultrasound guidance reduces the volume of local anesthetic required for successful perioperative analgesia in PNBs.	Ib	A
Ultrasound guidance achieves sufficient intraoperative analgesia using minimal volumes (0.1 mL/kg) of local anesthetic for blocks of the nerves in the anterior trunk.	Ib	B
Neuraxial anesthesia		
Clear visibility of landmarks		
Ultrasound enables sufficient visibility of the dura mater and ligamentum flavum in neonates, infants and children.	Ib	A
Good prediction of depth to LOR		
Preprocedural ultrasound imaging offers a moderate prediction of the depth to LOR.	III	B
Visibility of needle puncture or LOR		
Ultrasound offers visibility of a needle within the epidural space in neonates.	III	B
Visibility of catheter (directly or indirectly)		
Ultrasound guidance can directly detect catheters during advancement in some young infants.	III	B
Ultrasound guidance can confirm epidural catheter placement via surrogacy during injection of fluid.	III	B
Reduces bone contact		
Bone contact can be reduced in most cases in infants and children using real-time ultrasound guidance.	Ib	B

as 100% for both groups. Successful anesthesia was defined by those blocks meeting Vester-Andersen criteria (effectively blocking 2 of 4 nerves [ulnar, radial, median, and musculocutaneous] at 30 mins), in addition to the lack of any pain response to surgical stimulation. In patients with radial club hands where musculoskeletal abnormalities prevent or modify elicitation of motor responses to nerve stimulation, Ponde et al[5] found that ultrasound improved block success (96% versus 64% intraoperative analgesia, $P = 0.0053$). These findings do not extend to all children, especially because 100% block success occurred in those patients where correct responses to nerve stimulation (wrist movements) occurred.

Ultrasound guidance improves the intraoperative block success for PNBs at the trunk. *Statement of Evidence Ib, Grade of Recommendation A.* For some trunk blocks, intraoperative analgesia can often be achieved using "blind" landmark techniques without precise nerve localization. However, several targets of PNBs within the anterior aspect of the abdomen or groin ("anterior trunk blocks") are closely situated outside the peritoneum (ilioinguinal nerve 3.3 mm [1–4.6 mm] from peritoneum), and the poor predictability of their depth (eg, correlation of weight to depth of rectus sheath [$r^2 = 0.175$] and to depth of ilioinguinal nerve [$r = 0.44$]) strongly supports the use of ultrasound imaging for directing the needle safely toward the nerve.[7,12] Accordingly, ilioinguinal/iliohypogastric blocks have shown to benefit from ultrasound visualization of the nerves, of the needle tip (outside the peritoneum and muscles and in the fascial plane of the nerves), and of the circumferential local anesthetic spread. Weintraud et al obtained success rates of 94% and 74% ($P < 0.05$) for ultrasound compared with a single-pop technique in an RCT evaluating the plasma levels of 0.5% ropivacaine (1.25 mg/kg) in 66 children.[6] Willschke et al[7] obtained very similar results (comparing ultrasound and fascial click for localization; 96% versus 74%, $P = 0.004$) using levobupivacaine 0.25% in volumes either usual for the landmark technique (0.3 mL/kg) or sufficient to spread around the nerves (0.19 ± 0.05 mL/kg). The statistical significance of the findings of Willschke et al may be overestimated owing to either their use of an overconservative expected difference (50% success rate) as relates to other work showing 22% to 26% failure rates[26,27] or use of other (primary) variables[6] in their sample size calculation.

Ultrasound guidance prolongs analgesia for upper and lower extremity blocks. **Statement of Evidence Ib, Grade of Recommendation A. In addition,** ***ultrasound-guided blocks at the anterior trunk improve early postoperative pain relief for inguinal and umbilical procedures. Statement of Evidence Ib, Grade of Recommendation B.*** Improving block quality, generally via increased block duration or reducing pain scores, with effective regional anesthesia may be especially valuable in children because this could limit or eliminate their risk of developing respiratory depression, to which they can be particularly prone, from large-dose opioid consumption. Time to first rescue analgesic was prolonged in patients receiving ultrasound compared with nerve stimulation–guided infraclavicular (384 [280–480] versus 310 [210–420] mins, $P < 0.001$)[3] and sciatic and/or femoral (508 ± 178 versus 335 ± 169 mins, $P < 0.05$)[4] nerve blocks. The addition of an ilioinguinal block to a caudal block for postoperative analgesia failed to result in prolonged analgesia for all patients except those who underwent inguinal hernia repair (285 ± 16 versus 118 ± 102 mins, $P = 0.059$).[2] Overall, for the various groin surgical procedures, there was no difference in time to rescue analgesia or number of patients requiring rescue analgesia at the hospital or at home (24% versus 32%, $P = 0.76$). In many instances, the study period limits a reliable evaluation of the duration of analgesia, and the investigators often then report on the number of patients requiring rescue analgesia during the study period. In 1 RCT, ultrasonography reduced the number of patients (6% versus 40%, $P < 0.0001$) receiving rectal acetaminophen before discharge at either 163 (ultrasound) or 171 mins (fascial click) after ilioinguinal/iliohypogastric nerve blockade.[7] Two children (20%) received intravenous acetaminophen within 90 postoperative mins (discharge time) after receiving an ultrasound-guided umbilical nerve block (0.1 mL/kg bupivacaine 0.25%) for umbilical hernia repair, with no patient requiring more than 2 doses of ibuprofen at home.[8] Rectus sheath blocks lasted for at least 4 hrs (discharge time) in all 20 patients studied by Willschke et al.[12] Finally, 36% (nerve stimulation) and 4% (ultrasound) of patients undergoing repair of radial club hand received tramadol during the study period continuing to 10 postoperative hrs.[5] No patient in which nerve stimulation was successful required tramadol.

Ultrasound guidance reduces the volume of local anesthetic required for successful perioperative analgesia in PNBs. **Statement of Evidence Ib, Grade of Recommendation A. In addition,** ***ultrasound guidance achieves sufficient intraoperative analgesia using minimal volumes (0.1 mL/kg) of local anesthetic for blocks of the nerves in the anterior trunk.*** **Statement of Evidence Ib, Grade of Recommendation B.** Although there may be benefit for minimizing the dose of local anesthetic for some blocks, the ultrasonographer requires advanced skills for placing the needle and local anesthetic with such exact precision[28] and one must also weigh the value of reducing the volume to such an extent (below that which is thought to lead to toxicity) with that of possibly reducing the quality of the block for some patients.

Without attempting to use minimal volumes of local anesthetic, approximately two-thirds of a conventional volume (0.3 mL/kg levobupivacaine 0.25%) of local anesthetic was required to spread local anesthetic circumferentially around the sciatic/femoral[4] and ilioinguinal/ iliohypogastric[7] nerves. These blocks also resulted in similar or superior success and quality of analgesia compared with the control technique (nerve stimulation or fascial click, respectively).

Lower volumes have been evaluated and used for anterior trunk blocks. Willschke et al[13] determined that 0.075 mL/kg provided 100% success for intraoperative and postoperative analgesia, although they admitted that analgesia beyond their 4-hr study period was unknown. Bilateral placement of levobupivacaine 0.25% 0.1 mL/kg enabled sufficient analgesia in the perioperative period (no additional analgesia required to 4 hrs postoperatively) for 20 children undergoing umbilical hernia repair.[12] In contrast, a similar protocol (bupivacaine 0.25%) resulted in 2 of 10 patients requiring intravenous analgesia during the 90-min study period.[8] Further contradiction of the value in minimal volume of local anesthetic stems from the study of Jagannathan et al,[2] which determined whether the addition of an ilioinguinal nerve block adds benefit to a caudal block for unilateral groin surgery. Although there showed to be improvement in recovery room pain scores and reduction in time to postoperative rescue analgesic requirement, these findings were only statistically significant (pain scores, 0.91 versus 1.95 [CHIPS scale of 0–10], $P < 0.05$; time to first rescue analgesic, 285 ± 16 versus 118 ± 102 mins, $P = 0.059$) for the group who underwent inguinal hernia repair (versus hydrocelectomy, orchidopexy, and orchiectomy).

Other Comments

In a prospective case series of 10 continuous subgluteal sciatic nerve blocks, a mean ± SD of 9 ± 2 mins was required to use ultrasound imaging to both confirm needle placement and to later visualize local anesthetic spread through the stimulating catheter.[11] No study has compared performance time with respect to ultrasound-guided versus blind techniques for continuous blocks.

Two imaging studies support the use of sonographic identification of block-related anatomical structures to improve on the success of deep blocks of the lower extremity and posterior trunk. The success and quality of sciatic nerve blocks placed at the popliteal fossa may be related to placement of local anesthetic at or above the sciatic nerve bifurcation, thus near both components of this large nerve. Schwemmer et al[10] scanned the posterior thigh in 12 children weighing less than 45 kg and determined that there was wide variation in both the depth of the sciatic nerve (7–18 mm) and the distance of the nerve's division (32–76 mm). Kirchmair et al[9] illustrated the ability of ultrasound to delineate the lumbar plexus, especially in those children younger than 9 years and found that the depth of the plexus from the skin was moderately correlated ($R = 0.64$ [L4–L5] to 0.68 [L3–L4]) to weight. The remaining bony and muscular paravertebral structures could be identified in all cases and, together with the finding that the plexus was located in the posterior aspect of the psoas major muscle, implies that identification of the plexus is not critical for ultrasound imaging to assist with performance of this block.

Neuraxial Anesthesia

Ultrasound enables sufficient visibility of the dura mater and ligamentum flavum in neonates, infants, and children. *Statement of Evidence Ib, Grade of Recommendation A.* Any potential improvement in the success and safety of neuraxial blockade may likely depend on the ability of ultrasound to clearly identify the ligamentum flavum or dura mater. Therefore, although the overall visibility is significantly higher in children younger than 3 months,[19] good visibility of the ligamentum flavum and dura mater has been reported for much older patients and thus imaging may be useful in a range of ages. However, the visualization of such structures is often limited to the area, "acoustic window," of the intervertebral space owing to the calcification of the vertebrae on aging. In the sole RCT of ultrasound imaging for neuraxial anesthesia in children, Willschke et al[14] were able to clearly delineate the dura mater and view its downward movement during injection in all patients thus confirming the epidural injection. Using the measured depth to the ligamentum flavum as the skin-to-epidural depth, they found good correlation to the weight of 32 neonates younger than 6 months ($R = 0.9$). The same group later found a similar degree of agreement (adjusted r^2 of 0.8 at L1/L2) between epidural depth and weight in 50 term and preterm neonates.[25] Similarly, Ozer et al[20] also reported clear visibility of the dura mater when using the measured skin-to-dura mater depth to predict the posterior lumbar dural depth using demographic variables in 137 children aged 7 to 12 years. The dura mater has been reported as being easier to identify than the ligamentum flavum,[18,19] with its visibility being superior using a paramedian longitudinal approach at the lumbar spine level (compared with 5 other perspectives, $P < 0.0001$) and its depth correlating well to both weight and age (−0.8 and −0.7, $P < 0.0001$).[19] It is important to note here that a linear probe has been shown to offer better neuraxial images in all scanning planes[19] and has been successfully used by several authors in children 12 years or older.[18–20] In 23 elective surgical patients (5 months to 10 years old) and using 7- to 11-MHz frequencies, Rapp et al[22] could clearly distinguish the dura mater at all levels and could see LOR, as a "widening of the epidural space followed by a ventral movement of the dural cover and compression of the dural sac." Conversely, Kil et al[18] reported "good" visibility of the dura mater and ligamentum flavum in 170 and 91 of 180 children aged 2 to 84 months, although these authors did use a median longitudinal viewing plane and report "sufficient" (as relates to measurement of the epidural space depth) visibility of these structures in all children.

The dural sac and cauda equina were visible in all patients during a study evaluating the ability of ultrasound visibility of a saline test bolus to reliably indicate correct caudal cannula position in 60 patients aged 2 days to 10 years.[23] The relative clarity of the images, although illustrated as high, was not reported except for that of the sacrococcygeal membrane (which was not easily seen in 1 patient). Without comment on the visibility of the dural sac in other reports of ultrasound use for caudal blocks in children,[15,21] it is not possible to make any recommendation at this time.

Preprocedural ultrasound imaging offers a moderate prediction of the depth to LOR. *Statement of Evidence III, Grade of Recommendation B.* Several studies have used ultrasound imaging to predict the depth to the epidural space or spinal cord as either a standard for correlation of the depth to demographic variables[16,20] or as related to actual epidural or spinal depth measured clinically through some other means (eg, LOR or free flow of cerebrospinal fluid).[18,22,24,25] Using Bland-Altman analysis, Rapp et al[22] found that epidural space depth was in high concordance (with an accuracy of 2.02 ± 2.03 mm although only using 21 of the 23 patients) with depth to LOR in a prospective case series of children between 5 months and 10 years. A correlation coefficient was estimated (without significance stated) at 0.88 (approximately $r^2 = 0.77$). In view of the authors using various probe positions, this analysis may be confounded and the results may be hard to reproduce. Using a standard paramedian longitudinal scanning plane, Willschke et al[25] found a moderate correlation between skin-to-epidural depth and the depth to LOR (adjusted $r^2 = 0.64$). These previously discussed studies failed to describe whether they accounted for the different angles of needle and probe placement when calculating the correlation of their distances, which lead to Kil et al[18] incorporating this methodology in their future study design.

Using linear regression analysis (confirmed with the Bland-Altman method), a high correlation ($R^2 = 0.848$ and 0.788 for longitudinal median and transverse views) was calculated between the ultrasound-measured distance of skin-to-ligamentum flavum and the perpendicular skin-to-epidural depth, with the latter being a calculation using trigonometry incorporating the clinical puncture angle and depth of LOR.[18] Although these authors' degrees of agreement analyses may have been more rigorous than others owing to their adjustment for different probe and needle angles, the preprocedural measurement of the skin-to-ligamentum flavum distance was referred to during the subsequent "blind" procedure, and the technique used for entry to the epidural space (drip infusion method) is not widely practiced. Potential bias would have been eliminated if the anesthesiologist performing the epidural were to have been blinded to the ultrasound measurements as in the other work.[25] Moreover, their use of the longitudinal median plane for ultrasound imaging has been shown to provide inferior images of the neuraxial structures.[19] Finally, others have claimed that the diagonal distance is proportional to the perpendicular depth of the subarachnoid space, thus discounting any substantial effect of the scan direction.[24]

What is interesting is that the addition of ultrasonographic measurements lowered the predictive value (ie, reduced the r^2

and increasing the mean squared error) of a model using weight and postconceptual age to predict subarachnoid space depth (with final adjusted $r^2 = 0.72$).[24] These authors suggest many disadvantages of using ultrasound for assisting with spinal anesthesia.

Ultrasound offers visibility of a needle within the epidural space in neonates. *Statement of Evidence III, Grade of Recommendation B.* Willschke et al[14] have twice reported seeing the needle tip, both penetrating the ligamentum flavum (as per protocol) and within the epidural space of 35 (100%) term or preterm neonates.[25] In contrast, Rapp et al[22] failed to view the needle in older patients (only 1 was <6 months) and therefore identified LOR via surrogate markers including the consecutive movements of the epidural space and dural cover and sac. Park et al[21] viewed caudal needles using a longitudinal scanning plane, when evaluating the optimal puncture angle (21 degrees; range, 10–38 degrees) for caudal blocks by aligning the needle with the caudal canal. Although illustrating clear visibility of the dural sac and reporting good identification of structures (sacrococcygeal membrane, dural sac and cauda equina) and observation of dural displacement after a saline test bolus, Roberts et al[23] comment that they failed to view the 22-gauge intravenous cannula in most (55/57) patients. These authors report higher success when using 20-gauge and larger cannulas.

Ultrasound guidance can directly detect catheters during advancement in some young infants. **Statement of Evidence III, Grade of Recommendation B.** ***Ultrasound guidance can confirm epidural catheter placement via surrogacy during injection of fluid.*** **Statement of Evidence III (not evaluated in RCT), Grade of Recommendation B.** In 2003, Chawathe et al[17] were the first to report of ultrasound imaging of catheters in pediatric central blockade, using a pilot study in 12 patients (aged 1 day to 13 months) to evaluate the possibility of detecting and verifying the position of catheters after placement (within 24 hrs) via the direct lumbar route. Two pediatric radiologists scanned the patients' spines (using a high-resolution cart-based ultrasound system [Toshiba SSH 140A; Toshiba, Tokyo, Japan] with a linear high-resolution 7.5-MHz probe) and detected catheters as they entered the epidural space in most (9/10) patients younger than 6 months. The tip of the catheter was not clearly delineated in any patient, with the cephalad portion of the catheter only estimated in 7 of these 9 patients. Although the probe placement was not directly mentioned, it was depicted as being midline (median longitudinal) with a paramedian view (previously [2001] found superior in adults for viewing the epidural structures including the dura mater)[29] discussed as being potentially limited by the space available in this age group. The finding of Chawathe et al that the catheter tip was often (7/9 detections) placed at the appropriate level of the thoracic region is in contrast to other reports finding much lower rates of successful catheter advancement from the lumbar epidural space. Nevertheless, ultrasound imaging seemed to detect static block-related equipment such as catheters in at least the very young.

Rapp et al[22] 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 between 5 months and 10 years. The catheters were placed under real-time imaging using a probe placed in the paramedian longitudinal plane. In 19 of 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. The injection of medication was visible in 20 of 23 patients, which these authors claim 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 23 patients. These latter results are different than those of Chawathe et al, although Rapp et al used multiple planes of viewing and may have used injection of fluid for detecting the catheters. Without the surrogate marking of the injection of fluid, the axial resolution of the machine used may have lead to misinterpretations.[14] In more agreement with the work of Chawathe et al, Willschke et al[25] could not see catheters with confidence during advancement even in neonates.

In contrast to directly detecting catheters either during or after placement, their position may be confirmed through surrogate markers such as viewing tissue movement or injection of solution. Specifically, "the actual position of the tip can be confirmed by sonographically monitoring the movement of the liquid (or a puff of air) within the epidural space or the movement of the dura as the epidural space is expanded by the injection of local anesthetic."[14] Willschke et al achieved this in both groups of young (up to 6 years) children[14] and neonates.[25]

Additional Outcome Evaluation

Bone contact can be reduced in most cases in infants and children using real-time ultrasound guidance. **Statement of Evidence Ib, Grade of Recommendation B (No body of literature).** In the RCT by Willschke et al[14] evaluating real-time ultrasound guidance for direct epidural placement at the lumbar or thoracic spine in children, the authors found that ultrasound resulted in fewer bone contacts (17% versus 71%, $P < 0.0001$) and swifter placement (162 ± 75 versus 234 ± 138 secs, $P < 0.01$) of epidurals than did standard LOR technique. The authors do not state whether there was any attempt to reduce bone contacts in the LOR group, during which there may be intentional bone

TABLE 2. Some Areas for Additional Research in Ultrasound-Guided Pediatric Regional Anesthesia

Peripheral nerve blockade

- Evaluation and methods for improvement of catheter visibility for continuous upper and lower extremity blockade.
- Comparison of efficacy with ultrasound versus nerve stimulation guidance of catheter placement for postoperative analgesia after various surgical procedures.
- Evaluation of the block quality (duration and analgesic potency) of ultrasound-guided blocks using minimal volumes of local anesthetic compared with using larger/conventional volumes.
- Further evaluation of block success (including surgical anesthesia) of different blocks, using patients in whom surgery is viable without general anesthesia.
- Comparison of ultrasound and nerve stimulation guidance for interscalene, lower extremity, and lumbar plexus blockade.
- Evaluation of whether ultrasonography can lower complication rates including hematoma, hemidiaphragmatic paralysis, peripheral neuropathy.

Neuraxial anesthesia

- Develop an effective way to perform epidural needle placement to allow a single clinician to perform both LOR and ultrasound technique simultaneously (one-operator ultrasound guidance technique).
- Evaluation of whether ultrasound guidance can lower complications associated with epidural and caudal placement.
- Enhance direct visibility of epidural catheters to enable confirmation of epidural and segmental location of tip to improve safety and success.

contact for some anesthesiologists. In addition, the rate of bone contacts was relatively higher than expected for the group younger than 6 months (21%), which the authors state is owing to poor delineation of the exact dimension of the (highly cartilaginous) vertebrae. Nevertheless, there seems to be the possibility to avoid bone contact, if one so desires, especially in older patients. The length of time required for the ultrasound-guided technique (up to approximately 4 mins) seems impressive and would likely not be achievable for those without extensive experience. Whether this difference is clinically relevant is questionable. There were no significant differences in this study with respect to perioperative analgesia, time to extubation, or adverse events including blood aspiration (once in the LOR group) or dural punctures (none in either group).

Other Comments

Raghunathan et al[15] performed a retrospective observational and comparative study of 83 patients who received both ultrasound and "swoosh" tests in sequence. After the performance of the swoosh test, real-time ultrasound scanning incorporating color flow Doppler was performed via a transverse view, at a location slightly above the injection point, to capture turbulence of the fluid within the epidural caudal space. The sensitivity (96.3% versus 57.5%, $P < 0.001$) and negative predictive values (40% versus 5.6%, $P < 0.05$) of ultrasound (using turbulence or color flow Doppler) were significantly higher than those using the swoosh test. The older age (5–8 years) of these patients and/or the imaging technique of the authors may have contributed to the low negative predictive value of ultrasound.

CONCLUSIONS

Ultrasound guidance during PNBs seems to hasten onset of upper extremity blocks, improve intraoperative and early postoperative analgesia for surgery at the anterior trunk, prolong analgesia after extremity blockade, and lower anesthetic requirements (Table 1). Neuraxial anesthesia may benefit from ultrasound imaging with respect to its ability to sufficiently view the dura mater and ligamentum flavum, predict (moderately) the depth to LOR, clearly view the epidural needle in neonates, confirm catheter position either directly (in some young infants) or indirectly after injection of fluid or air, and limit contact to the bone during placement, if desirable. More randomized controlled studies with sufficient power are required to further support these findings (ie, raise their Grade of Recommendation, especially for alternative block sites) and further evaluate the potential for ultrasound to reduce complications of regional anesthesia in children (Table 2).

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