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

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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 “ultrasoundography” 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 anesthesiaology journals. Meta-analyses/systematic reviews, randomized controlled studies, 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.

METHODS

Search Strategy

The 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 anesthesiaology 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. 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 and 6 case series, whereas the neuraxial set contained 1 RCT, 1 comparative study, and 10 case series. 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, 3 scores of 3, 1 score of 4, and 2 scores of 5. 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.
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 Ia–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 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 primarily evaluated block quality and distribution, but the success of surgical anesthesia was reported

<table>
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<th>Evaluated Outcomes</th>
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<tr>
<td>Reduces block performance time</td>
<td>No evidence found.</td>
<td>N/A</td>
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<tr>
<td>Hastens block onset</td>
<td>Ultrasound guidance reduces onset of sensory block for upper extremity PNBs.</td>
<td>Ib</td>
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<tr>
<td>Improves block success</td>
<td>Ultrasound guidance does not improve block success rates in upper extremity PNBs when compared with nerve stimulation guidance.</td>
<td>Ib</td>
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<td></td>
<td>Ultrasound guidance improves the intraoperative block success for PNBs at the trunk.</td>
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<td>Improves block quality</td>
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<td></td>
<td>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.</td>
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<td>Ultrasound guidance can directly detect catheters during advancement in some young infants.</td>
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</tr>
<tr>
<td>Reduces bone contact</td>
<td>Bone contact can be reduced in most cases in infants and children using real-time ultrasound guidance.</td>
<td>Ib</td>
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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 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 \( r = 0.441 \) 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 obtained very similar results (comparing ultrasound and fascial click; 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 rates5,26,27 or use of other (primary) variables5 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, \( P < 0.001 \)) and sciatic and/or femoral (508 ± 178 versus 335 ± 169 mins, \( P < 0.05 \)) 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 periproductive 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 precision28 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/femoral3 and ilioinguinal/iliohypogastric2 blocks. These blocks also resulted in similar in 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 al13 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 periproductive period (no additional analgesia required to 4 hrs postoperatively) for 20 children undergoing umbilical hernia repair.5 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 al7 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 orchietomy).

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 al12 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 al13 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 al14 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 r² of 0.8 at L1/L2) between epidural depth and weight in 50 term and preterm neonates.25 Similarly, Ozer et al26 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 planes19 and has been successfully used by several authors in children 12 years or older.16,18–20 In 23 elective surgical patients (5 months to 10 years old) and using 7- to 11-MHz frequencies, Rapp et al22 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 al18 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,3,5,21 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 variables16,20 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 al22 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 r² = 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 al25 found a moderate correlation between skin-to-epidural depth and the depth to LOR (adjusted r² = 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 al18 incorporating this methodology in their future study design.

Using linear regression analysis (confirmed with the Bland-Altman method), a high correlation (r² = 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.25 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.22

What is interesting is that the addition of ultrasonographic measurements lowered the predictive value (ie, reduced the r²
and increasing the mean squared error) of a model using weight and postconceptual age to predict subarachnoid space depth (with final adjusted \( r^2 = 0.72 \)). 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\(^{29} \) 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 intravascular 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 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 misinterpretation.\(^{14} \) 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

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

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<th>Peripheral nerve blockade</th>
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<td>• Evaluation and methods for improvement of catheter visibility for continuous upper and lower extremity blockade.</td>
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<td>• Comparison of efficacy with ultrasound versus nerve stimulation guidance of catheter placement for postoperative analgesia after various surgical procedures.</td>
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<td>• 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.</td>
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<td>• Further evaluation of block success (including surgical anesthesia) of different blocks, using patients in whom surgery is viable without general anesthesia.</td>
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<tr>
<td>• Comparison of ultrasound and nerve stimulation guidance for interscalene, lower extremity, and lumbar plexus blockade.</td>
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<tr>
<td>• Evaluation of whether ultrasonography can lower complication rates including hematoma, hemidiaphragmatic paralysis, peripheral neuropathy.</td>
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<th>Neuromaxial anesthesia</th>
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<td>• 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).</td>
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<tr>
<td>• Evaluation of whether ultrasound guidance can lower complications associated with epidural and caudal placement.</td>
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<tr>
<td>• Enhance direct visibility of epidural catheters to enable confirmation of epidural and segmental location of tip to improve safety and success.</td>
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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 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). Neuromuscular anaesthesia 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).

**REFERENCES**


skin to the subarachnoid space can be predicted in premature and former-premature infants. Can J Anesth. 2004;51:160–162.


