

*David S. Warner, M.D., Editor*

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

## *A Review of Current Literature and Its Application in the Practice of Extremity and Trunk Blocks*

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This article has been selected for the ANESTHESIOLOGY CME Program. Learning objectives and disclosure and ordering information can be found in the CME section at the front of this issue.

### ABSTRACT

The use of ultrasound guidance has provided an opportunity to perform many peripheral nerve blocks that would have been difficult to perform in children based on pure landmark techniques due to the potential for injection into contiguous sensitive vascular areas. This review article provides the readers with techniques on ultrasound-guided peripheral nerve blocks of the extremities and trunk with currently available literature to substantiate the available evidence for the use of these techniques. Ultrasound images of the blocks with corresponding line diagrams to demonstrate the placement of the ultrasound probe have been provided for all the relevant nerve blocks in children. The authors hope that this review will stimulate further research into ultrasound-guided regional anesthesia in infants, children, and adolescents and stimulate more randomized controlled trials to provide a greater understanding of the anatomy and physiology of regional anesthesia in pediatrics.

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Received from Department of Anesthesiology and Pain Medicine, University of Alberta, Edmonton, Alberta, Canada, and the Department of Pediatric Anesthesiology, Northwestern University, Feinberg School of Medicine, Chicago, Illinois. Submitted for publication April 17, 2009. Accepted for publication September 30, 2009. Supported by a Career Scientist Award in Anesthesia (to Dr. Tsui), Canadian Anesthesiologists' Society-Abbott Laboratories Ltd., Toronto, Ontario, Canada, a Clinical Scholar Award (to Dr. Tsui) from the Alberta Heritage Foundation for Medical Research, Edmonton, Alberta, Canada, and Foundation for Anesthesia Education and Research (FAER) Research in Education grant (to Dr. Suresh).

Mark A. Warner, M.D., served as Handling Editor for this article.

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ONE of the most exciting recent advances in technology in pediatric regional anesthesia has been the introduction of anatomically based ultrasound imaging for facilitating nerve localization. This is because regional anesthesia techniques in children have been considered challenging due to (1) targeting neural structures that often course very close to critical structures (e.g., nerves of the brachial plexus run close to the pleura as they traverse the supraclavicular region), and particularly during central neuraxial blocks where the safety margin is narrow for needle placement particularly close to the spinal cord, (2) the prerequisite for sedation or general anesthesia masking potential warning signs (paresthesia), and (3) the need for limiting the volume of local anesthetic solution below toxic levels. With the possibility of visualizing the target structures, ultrasound technology may encourage many anesthesiologists who had previously abandoned regional techniques to resume or increase their use of regional anesthesia in children.

Although literature evaluating the evidence for success and safety of ultrasound in regional anesthesia has begun to emerge, a comprehensive narrative review of the literature pertaining to techniques described and outcomes evaluating ultrasound guidance in pediatric regional anesthesia was not available at the time of writing this article. This review aims to provide the pediatric anesthesiologist with an overall summary of the techniques used and of the outcomes found (based on controlled or comparative studies) as described in the literature on ultrasound guidance of peripheral nerve blocks of the extremities and trunk in pediatrics. A companion article with similar objectives related to neuraxial blocks will be published in the next issue of ANESTHESIOLOGY.<sup>1</sup> In addition to case series and clinical studies, descriptions from

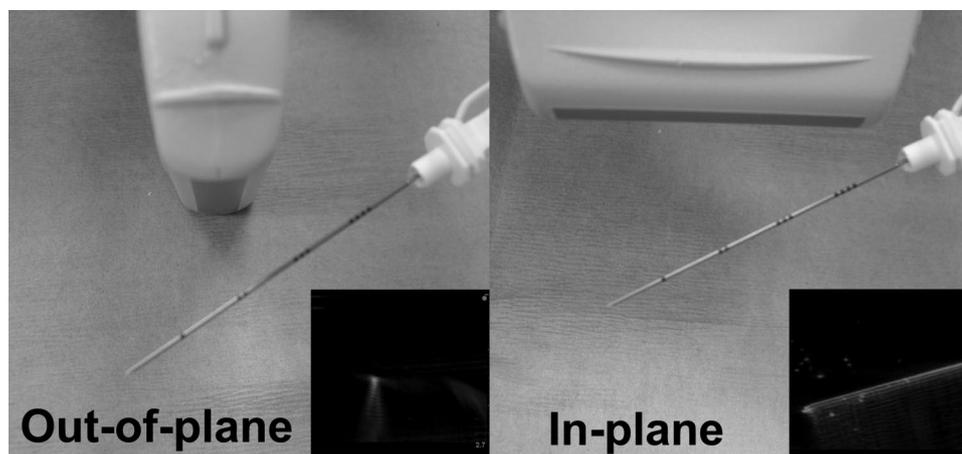


Fig. 1. Needle-probe alignment. In out-of-plane alignment, only a cross-section of one point of the needle is viewed; in an in-plane alignment, the entire needle shaft and tip can be seen.

case reports and correspondence may shed some light into areas where ultrasound has been especially useful for children. Moreover, acquiring a thorough understanding of related regional anatomy cannot be replaced by new technical skills and approaches when performing regional anesthesia. Consequently, this review and the upcoming review of neuraxial blockade include descriptions and illustrations of the relevant sonoanatomy of the various regions. These sonoanatomy sections will hopefully serve as a foundation for a better understanding of the block techniques as described in literature. This review is not intended to serve as a comprehensive training manual. Readers are encouraged to obtain training through workshops and under supervision of an expert to gain competency with this technology.

## Materials and Methods

A literature search for this review was performed using MEDLINE and EMBASE from 1980 to May 28, 2009. The keywords “ultrasound and children” and “ultrasound and pediatric” were combined with “regional anesthesia” and “nerve block.” The medical subject heading term “ultrasonography” was also combined with “nerve block” and “regional anesthesia,” with the age limit of 0–18 yr. 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. Literature relevant to blocks at the extremity and trunk were printed in full, and their reference lists were checked manually. We included clinical studies, case series, and reports, in addition to relevant correspondence pieces where institutional review board approval and patient–parent consents were obtained. Expert reviews and descriptions specific to ultrasound in pediatric regional anesthesia and other correspondence pieces were reviewed for references and additional comments on technique, although they were not used for outcome evaluation data.

The images highlighting sonoanatomy were obtained using a portable ultrasound unit (Sonosite M-turbo®, Bothell,

WA) commonly used in the institutions of the authors for performance of pediatric ultrasound-guided regional anesthesia. Ethics committee or institutional review board approval was obtained for the ultrasound imaging, and informed consent was provided by the parent(s) of patients prior to acquiring images for this review. Two linear, high-frequency probes were used (L-25, 6–13 MHz, 25-mm footprint and HFL38, 6–13 MHz, 38-mm footprint, both from Sonosite), and the hockey stick (SLA) probe was often useful in infants due to the 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 32 results, with one obtained after a manual review of the reference lists. The search resulted in 26 studies of ultrasound-guided peripheral nerve blockade (5 randomized controlled trials, 2 large prospective studies, 13 case series - reports, and 7 correspondence pieces), although there was a large spectrum of blocks described, with eight reports pertaining to sciatic nerve blockade. Five expert reviews and one technical report with descriptions of technique related to pediatric regional anesthesia were also obtained. In the ensuing sections, we will discuss in depth the use of ultrasound guidance for the extremity and trunk blocks 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 (fig. 1). The probe is typically used to view the nerves in short-axis (cross-sectional, transversely), but occasionally a long-axis (longitudinal) view is helpful.

### Upper Extremity Blocks

Although many approaches to the brachial plexus have been described, the axillary block using conventional methods is still the most commonly performed and reported brachial plexus

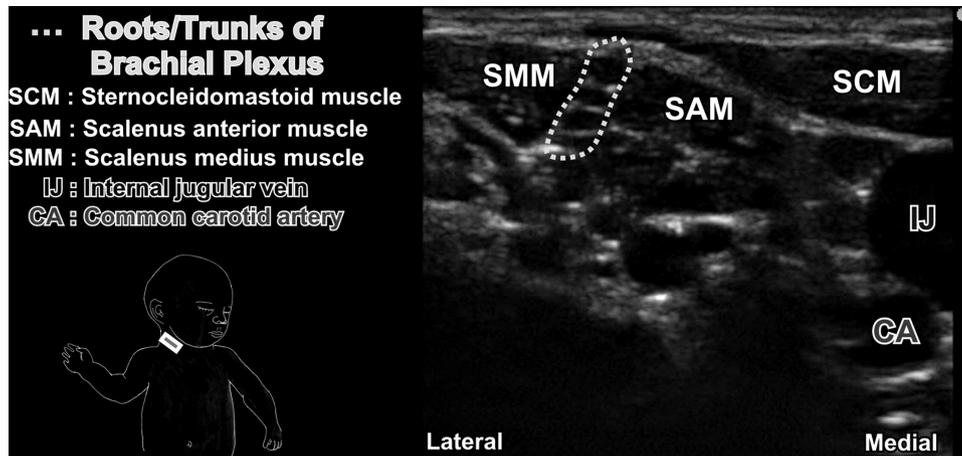


Fig. 2. Sonoanatomy at the interscalene groove using a linear hockey stick probe (SLA, 6–13 MHz, 25-mm footprint). Note that the roots appear to be sitting on top of each other in a “snowman appearance.”

blockade in children. This may be due to the fact that other block sites are situated near critical structures such as the cervical pleura (supraclavicular and infraclavicular) and the spinal cord (interscalene). Although there is a paucity of related literature, the introduction of ultrasound imaging will likely greatly increase the performance of brachial plexus blocks in infants and children at locations besides the commonly described axillary approach.

#### Techniques.

##### **Interscalene Block.**

**Sonoanatomy.** A small footprint hockey stick probe will allow optimal recognition of the superficial structures in this region for infants and younger children. In a transverse oblique plane at the level of the cricoid cartilage and at the posterolateral aspect of the sternocleidomastoid muscle, the superficially located sternocleidomastoid muscle appears triangular in shape and overlies the internal jugular vein and common carotid artery (fig. 2). In small infants, the ultrasound probe footprint is wide enough to capture the great vessels along the brachial plexus in the same image screen. Lateral to the vessels and deep to the sternocleidomastoid muscle lies the anterior scalene muscle, and more posterolaterally, the middle and posterior scalene muscles (the latter two often appearing as a single mass). The hyperechoic (bright)-appearing tissue forming a lining around the muscles and containing the brachial plexus represents the neurovascular (interscalene) sheath composed at this level of the prevertebral fascia and the fascia of the scalene muscles. Brachial plexus trunks and/or roots in this sagittal oblique section are usually visualized as three (or more) round or oval-shaped hypoechoic (gray or dark) structures, lying between the scalenus anterior and medius muscles. They may appear as a “snowman,” with the roots lined up one on top of the other.

**Technique.** To date, one correspondence letter<sup>2</sup> and two case reports<sup>3,4</sup> have been published describing ultrasound-guided interscalene block in children. Fredrickson<sup>2</sup> highlights the use of preoperative marking of the associated landmarks (posterior border of the sternocleidomastoid muscle, external jugular vein, and cricoid cartilage) to assist with subsequent placement of the probe to identify the inter-

scalene groove. Nerve stimulation was used along with ultrasound in the described case to locate the target nerve, but the authors state their preference for using ultrasound-image guidance and that they do not routinely use nerve stimulation in their practice. (Equally, it seems prudent to keep using nerve stimulation during interscalene block to help confirm the identity of the localized nerve root.) With combined ultrasound guided–nerve stimulation techniques, the brachial plexus trunks were viewed in the short-axis using a linear probe, and an insulated needle was initially placed within the middle scalene muscle using out-of-plane alignment at the cranial side of the probe. Tissue displacement within the middle scalene muscle was a primary mode of tracking the needle tip. Redirection of the needle medially placed the needle tip adjacent to the trunks, and the needle was advanced to the point where the motor response (biceps–triceps twitch) was elicited with an appropriate current (0.46 mA in this case). For continuous techniques, a catheter was introduced and advanced 3 cm after injection of 5 ml of 5% dextrose in water to expand the perineural space; this solution was presumably injected both to confirm the nerve localization from the use of nerve stimulation<sup>5</sup> and to observe the spread of the solution with ultrasound imaging. The authors clarify that this length of advancement may be too great for some patients, and that the dextrose solution should be used as needed and within a limit of up to 5 ml to avoid dilution of local anesthetic.

The report of Van Geffen *et al.*<sup>4</sup> on interscalene block in a 7-yr-old child with femur fibula ulna syndrome (presenting with hypoplasia of the humerus) highlights that ultrasound can be an important modality in those patients in whom the use of other nerve localization (*i.e.*, nerve stimulation) techniques is impossible. With the patient’s head turned to the contralateral side, a linear ultrasound probe was first placed on the lateral side of the larynx to capture the thyroid gland, carotid artery, and internal jugular vein, and then moved laterally to the edge of the sternocleidomastoid muscle. The roots (or likely trunks) of the brachial plexus were viewed at a depth of 0.4 cm as oval hypoechoic nodules within the interscalene groove. An out-of-plane needle alignment (similar to the technique of Fredrickson) was

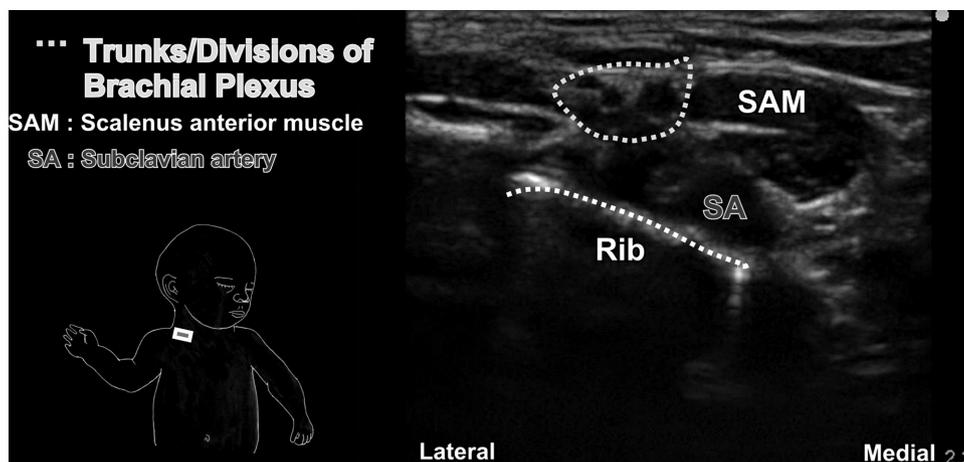


Fig. 3. Sonoanatomy at the supraclavicular block location using a linear hockey stick probe (SLA, 6–13 MHz, 25-mm footprint) placed in the coronal oblique plane. Note the subclavian artery and that the surrounding hyperechoic plexus appears like a “cluster of grapes.”

used, directing the needle slightly caudal. The injection of local anesthetic (8 ml of ropivacaine 0.75%) was noted to surround the plexus roots or trunks. Analgesia was effective in this patient for 20 h after the block was performed. The authors of this review prefer to use a lower concentration of local anesthetic, such as 0.2–0.5% ropivacaine or bupivacaine.

Ultrasound-guided continuous interscalene blockade was performed for a 10-yr-old girl in the Philippines during a plastic surgery medical mission.<sup>3</sup> Without the availability of perineural catheters and stimulating needles, a 22-gauge angiocatheter was used for the block, which used an in-plane alignment to the posterior edge of the probe. An ultrasound unit was fortunately available (brought by a pediatrician to perform transthoracic echocardiography) to enable the performance of this higher risk block in a case where there would otherwise be limited choice for providing postoperative analgesia.

**Comment.** Blockade of the brachial plexus at locations above the clavicle is necessary for shoulder girdle surgery. The interscalene block provides adequate analgesia that can last for a period of up to 6–12 h. A catheter can be left in place for continuous analgesia. Identification of the interscalene groove by palpation can be challenging in anesthetized patients (as is common in pediatrics), and this in addition to the short distance of the plexus to vital structures may make it difficult for some to justify performance of this block in children under general anesthesia. Indeed, one recent report recommends that these blocks are not to be performed in any heavily sedated or anesthetized patient.<sup>6</sup> This recommendation may be criticized though, due to a lack of support from more than a few (albeit serious) case reports and because the authors cite more neurologic complications, resulting from large-scale studies of awake patients than anesthetized. By allowing visualization of vital structures and improving nerve localization, ultrasound guidance may increase the use of this block.

#### Clinical pearls—interscalene block.

- Use a high-frequency linear or hockey stick probe.
- The needle is placed using an in-plane approach from posterior to anterior.

- Once the needle is close to the plexus, a volume of local anesthetic solution should be injected, using slight needle redirections, until it is seen to surround the brachial plexus roots or trunks. This may be accomplished with a dose as little as 0.1–0.2 ml/kg or approximately 5 ml in children, when there is precise needle placement.
- Aspirate intermittently to make sure that the injectate is not placed intravascular.

#### Supraclavicular.

**Sonoanatomy.** The probe is first placed in a coronal oblique plane at the lateral end of and just above the upper border of the clavicle. It is then moved medially until an image of the subclavian artery appears on the middle of the screen (fig. 3). At this location, the plexus is located superior and lateral to the artery, and the neurovascular structures are noted to be above the first rib. The subclavian artery is generally anechoic, hypodense, pulsatile, and often round; its identity can be further confirmed by the use of color Doppler. The trunks and divisions of the brachial plexus appear as a cluster of hypoechoic grape-like structures consisting of usually three clustered (more visualized as one moves distally) nodules, all surrounded by a hyperechoic lining. Medial and deep to the artery, the rib may be seen as a hyperechoic line with dorsal shadowing. The subclavian vein, inferomedial to the artery, is often not visualized.

**Technique.** Although ultrasound-guided supraclavicular block in adults has been described in several articles, only one report is available in the pediatric literature.<sup>7</sup> By using a similar technique as described in adults, the block can be performed using a needle (short-beveled, 22–25 gauge, 35–50 mm) aligned in-plane to a high-frequency probe placed in the coronal-oblique plane once the brachial plexus trunks or divisions (forming a cluster of hypoechoic nodules) can be visualized lateral to the subclavian artery (hypoechoic and pulsatile) and close to the underlying first rib (hyperechoic and curvilinear).<sup>7</sup> These authors directed the needle from lateral to medial, to approach the plexus lateral to the artery, preventing direct contact of the plexus. A linear probe with a 35-mm foot-

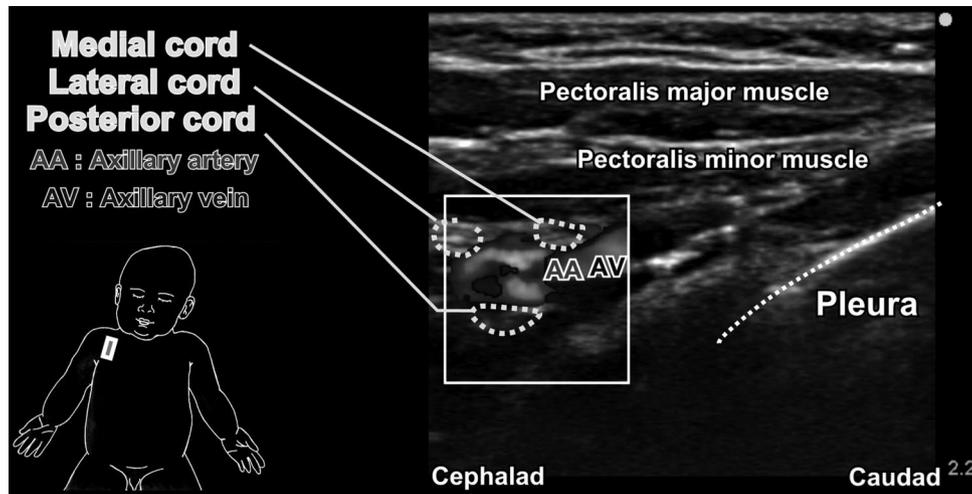


Fig. 4. Sonoanatomy at the infraclavicular block location using a linear hockey stick probe (SLA, 6–13 MHz, 25-mm footprint) placed below the clavicle in a parasagittal plane. Note the pectoralis major and minor muscles and that the axillary artery is surrounded by the cords of the brachial plexus. The pleura can be seen medially.

print was used, although a smaller footprint linear or curvilinear probe may be more suitable in some cases due to the reduced contact area and array characteristics.<sup>8</sup>

**Comment.** When performing a supraclavicular block, there is a greater risk of pneumothorax as the cupola of the lung lies just medial to the first rib, not far from the plexus; the distance of the plexus from the lung being especially short in children. It is critical to ensure that clear visibility of the needle shaft and tip is obtained by aligning the needle in-plane to the ultrasound probe at all times. Single injection techniques generally suffice for the block; however, multiple injections of local anesthetic can be performed if needed with the needle redirected to ensure sufficient circumferential spread around the plexus. However, care should be taken to avoid intravascular injection of the surrounding vessels (including the transverse colli artery located cephalad to the plexus). Auscultation of the lungs should be performed before and after performance of the block and before discharge to detect the clinical signs of pneumothorax, and a chest x-ray should be obtained when suspicion arises.

Intuitively, visualization of the needle tip and its relation to the plexus should reduce associated complications and increase the use of this block significantly. Indeed, this block offers the most reliable blockade of the brachial plexus, with rapid onset, for analgesia and anesthesia of the entire upper extremity, such that it may be referred to it as a “spinal for the upper extremity.”

**Clinical pearls—supraclavicular block.**

- Recognize the structure lateral to the carotid artery and lateral to the pulsation of the subclavian artery.
- Use a linear probe or a hockey stick probe to visualize the plexus, which appears as a bunch of grapes around the artery.
- By using an in-plane technique, advance needle into the plexus, and after aspiration, inject local anesthetic until circumferential spread around the plexus trunks or divi-

sions is seen (0.2 ml/kg may suffice depending on the age of the patient and accuracy of needle tip placement).

**Infraclavicular Block.**

**Sonoanatomy.** Although a lower frequency probe is often used in adults due to the depth of the plexus, the plexus is superficial enough in most children to use a higher frequency probe. In a parasagittal plane immediately medial and inferior to the coracoid process, a short-axis view of the brachial plexus cords and axillary vessels can be visualized (fig. 4). The pectoralis major and minor muscles are separated by a hyperechoic lining (perimysium); the pectoralis major muscle lies superficial and lateral to the pectoralis minor muscle. The axillary neurovascular bundle lies deeper, with the large axillary vein lying medial and caudad to the artery. The lateral cord of the plexus is readily visualized as a hyperechoic oval structure; the medial and posterior cords can be difficult to identify because the medial cord lies between the axillary artery and vein, whereas the posterior cord is often hidden deep to an axillary artery acoustic artifact. In addition, the medial cord can be posterior or even slightly cephalad to the axillary artery.

**Technique.** Shortly after an initial case report describing ultrasound-guided peripheral nerve blockade in children (of the sciatic nerve),<sup>9</sup> Marhofer *et al.*<sup>10</sup> described their use of ultrasound-guided lateral infraclavicular block for surgical anesthesia in children. The children were placed supine with their arm adducted, elbow flexed, and forearm placed on their abdomen. A linear probe was placed transversely below the clavicle (the relative orientation to the coracoid process was not stated) to capture an image of the brachial plexus (presumably the cords surrounding the subclavian artery). These authors report successful visualization of the plexus in all 40 patients studied. The needle was inserted out-of-plane, 1 cm from the inferior aspect of the probe, and directed slightly cranially (thus at an angle approximately 60°–70° to the skin) to

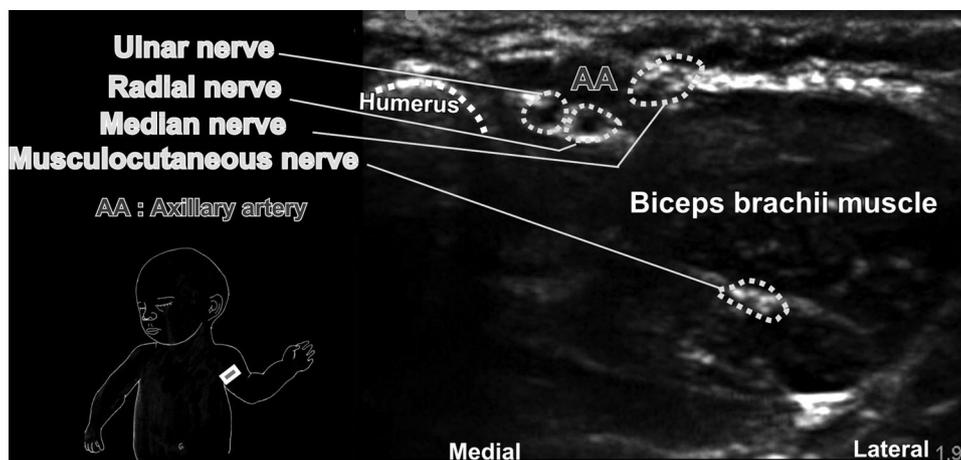


Fig. 5. Sonoanatomy at the axillary block location using a linear hockey stick probe (SLA, 6–13 MHz, 25-mm footprint) placed transversely to the humerus.

direct it toward the lateral border of the plexus. The local anesthetic spread was viewed surrounding the plexus.

De Jose Maria *et al.*<sup>7</sup> recently compared the efficacy of ultrasound-guided infraclavicular and supraclavicular blocks. For the infraclavicular block, these authors also placed the probe below the clavicle, either parallel to the clavicle or using a slightly parasagittal plane depending on the visibility of the plexus. A medium frequency probe (thus allowing greater visualization of deeper structures) was used in some of the older children to improve the visibility of the pleura and vessels. In contrast to Marhofer *et al.*, the needle was placed immediately cephalad to the probe; both groups use a fairly steep angle of needle insertion. The needle was redirected when necessary to ensure the targets of the block, *i.e.*, the cords were adequately surrounded by local anesthetic solution. The spread of local anesthetic was seen around the axillary artery and brachial plexus. The authors of this review routinely use the paracoracoid approach with a probe that is placed perpendicular to the clavicle. The needle is inserted from the superior and lateral aspect of the probe and aimed toward the posterior cord. A total volume of 0.2 ml/kg may suffice for providing an adequate blockade in most children if the needle is positioned close to the posterior cord. It is most critical to envision adequate spread of local anesthetic rather than try to inject the lowest potentially effective volume.

**Comment.** It is important to note that there is a great deal of individual anatomical variation in the location of the cords around the artery. At this location, the nerve structures now appear hyperechoic, rather than hypoechoic as seen more cephalad, probably due to an increase in the number of fascicles and amount of (hyperechoic-appearing) connective tissue. The cervical pleura is situated closest to the brachial plexus cords at medial locations within the infraclavicular fossa, thus it may be most prudent to use a more lateral puncture site to perform an infraclavicular blockade in children.<sup>11</sup> Ultrasound imaging will offer visualization of the related anatomy and the approaching needle, which may be particularly useful for avoiding multiple punctures in children,<sup>10</sup> and some anatomical landmarks (*i.e.*, the coracoid

process) may be underdeveloped to enable ease of palpation using “blind” techniques.<sup>12</sup> Similar to the supraclavicular approach, an in-plane needle alignment may provide superior outcomes with this block, because viewing the needle tip and shaft at all times may ensure that the vessels and cervical pleura are not punctured.<sup>13</sup>

#### Clinical pearls—infraclavicular block.

- Place the linear probe medial to the coracoid process and inferior to the clavicle.
- After recognizing the axillary artery, look for the cords of the brachial plexus surrounding the artery.
- Place a needle with an in-plane approach with the tip of the needle aimed toward the posterior cord.
- After aspiration, inject local anesthetic solution.
- Stay away from using a medially positioned needle due to close proximity to the pleura.

#### Axillary Block.

**Sonoanatomy.** With the probe placed perpendicular to the anterior axillary fold, a short-axis view of the neurovascular bundle can be obtained (fig. 5). In this view, the biceps brachii and coracobrachialis muscles are seen laterally; the triceps brachii muscle is medial and deep to the biceps brachii muscle. The anechoic and circular axillary artery lies centrally, adjacent to both the biceps brachii and coracobrachialis muscles, and is surrounded by the nerves. Although there can be many variations, the median nerve is typically located superficial and between the artery and biceps brachii muscle, the ulnar nerve is commonly located medial and superficial to the artery, and the radial nerve often lies deep to the artery at the midline. At this level, the musculocutaneous nerve is located between the biceps brachii and coracobrachialis muscles. This nerve may be undetectable in children.<sup>14</sup> It is common to perform a distal scan to identify the nerves along their paths in the upper extremity. The median nerve will continue to be viewed adjacent to the artery; the ulnar nerve will remain located near the surface on its path to the ulnar nerve sulcus; and the radial nerve travels posterior toward the spiral groove of the humerus.<sup>15</sup> Of note, the radial, median, and

ulnar nerves may appear the same size as the axillary artery on ultrasound, which contradicts anatomical descriptions in textbooks.<sup>14</sup>

**Technique.** The literature search for this review did not result in any original report of ultrasound-guided axillary block in children. Three expert reviews were found, which described the technique as performed by the respective author.<sup>14–16</sup> Intuitively, this block could be performed with similar techniques used in adults, using out-of-plane needle alignment to a high-frequency probe placed transversely to the humerus and using multiple injections to surround all the terminal nerves of the plexus. Multiple punctures will be necessary to anesthetize all the relevant nerves for many surgical procedures (*i.e.*, brachial cutaneous, medial antebrachial, and possibly musculocutaneous nerves will require separate blockade).

**Comment.** Multiple injections and needle redirections are commonly required to ensure circumferential spread of the local anesthetic around each of the individual nerves. Because there is an abundance of vessels in this region, complete avoidance of vessel puncture can be a challenge even when using ultrasound imaging. It is important to understand that the plexus remains very close to the surface, and hence the needle should be directed cautiously while this block is attempted. Smaller doses can be used to provide an adequate blockade of this plexus in infants and children.

#### **Clinical pearls—axillary block.**

- Place a hockey stick probe or a linear small footprint probe in the axilla as proximal as possible.
- The needle is directed from superior to inferior using an in-plane approach.
- The structures are superficial and hence are located fairly superficial and can be easily identified.
- Color Doppler can be used to recognize the vascular structures.
- Local anesthetic is injected to surround the nerves.

**Other Blocks of the Terminal Nerves.** Similar to axillary blockade, there is a lack of any original report describing ultrasound guidance for blocks of the terminal nerves of the brachial plexus within the upper extremity in children. Nevertheless, these blocks could be performed with similar technique to that used in adults. At the level of the wrist, one should be cautioned that there is often difficulty distinguishing the nerves from the tendons due to their similar appearance.

**Outcome Evaluation for Upper Extremity Blocks.** The first controlled study related to ultrasound-guided brachial plexus blockade was performed by Marhofer *et al.*<sup>10</sup> in 2004 for infraclavicular blocks using a lateral approach. Comparing ultrasound guidance to conventional nerve stimulation technique for surgical anesthesia in 40 children undergoing arm or forearm surgery, the authors found ultrasound to be superior in terms of (1) visual analog scores during block puncture (because of reduced discomfort from muscle contractions); (2) sensory onset times (mean times of onset were 9 *vs.*

15 min); (3) longer duration of sensory block (384 *vs.* 310 min); and (4) better sensory and motor block scores 10 min after block insertion. The faster onset and longer duration of the blocks may have been due to the ability of ultrasound to more accurately deposit the local anesthetic to the brachial plexus. At 30 min, all blocks whether placed by ultrasound or nerve stimulation were successful (according to the criteria of Vester-Andersen,<sup>17</sup> which was originally used for evaluating blocks using a large volume [40 ml] of local anesthetic and requires at least two of four nerves to be effectively blocked) and had similar motor and sensory block quality. Although this study was a prospective, randomized controlled blinded study, the authors did not state whether there were sufficient power for statistical significance.

De Jose Maria *et al.*<sup>7</sup> recently compared the success rate, complications, and block performance times of ultrasound-guided supraclavicular and infraclavicular blocks in 80 children scheduled for upper limb surgery. Light general anesthesia was provided to all patients. In addition to the aforementioned outcomes, the block duration and volumes of ropivacaine (0.5%) used were recorded for the supraclavicular approach. Both block approaches were effective (with failure defined as any amount of supplemental analgesia required during surgery or within the first 4 h after the block) and neither was associated with complications. Patients requiring supplemental analgesia intraoperatively had block failure of the radial (one with infraclavicular block) and ulnar (two from both groups) nerves. Two patients receiving infraclavicular block had accidental puncture of their axillary artery. The supraclavicular block was faster to perform (9 *vs.* 13 min; 95% confidence interval for this difference was 2–6 min and was statistically significant). The sensory and motor blocks using the supraclavicular approach lasted 6.5 and 5 h, respectively. Approximately, 6 ml of ropivacaine was used. The randomization process in this study was not described, and there was no sample size calculation. Although there was no blinding described (*e.g.*, of the nurses analyzing postoperative analgesia), most of the outcomes evaluated did not lend to blinding in most cases (*i.e.*, time to perform block, complications).

#### **Lower Extremity Blocks Lumbar Plexus Block.**

**Sonoanatomy.** With the exception of infants, the lumbar plexus and associated psoas major muscle are often difficult to view adequately due to their depth. In a transverse (axial) view using a linear probe in infants, bony structures such as the spinous processes, laminae and transverse processes, and musculature including the erector spinae, and quadratus lumborum muscles can be identified (fig. 6). Deep to these structures, the lumbar plexus can be seen embedded within the psoas muscle, which is often located posterior to the transverse processes and lateral to the vertebral bodies. With potentially difficult visualization using ultrasonography in older children, imaging may be most suitable before the block, rather than for real-time guidance, generally for iden-

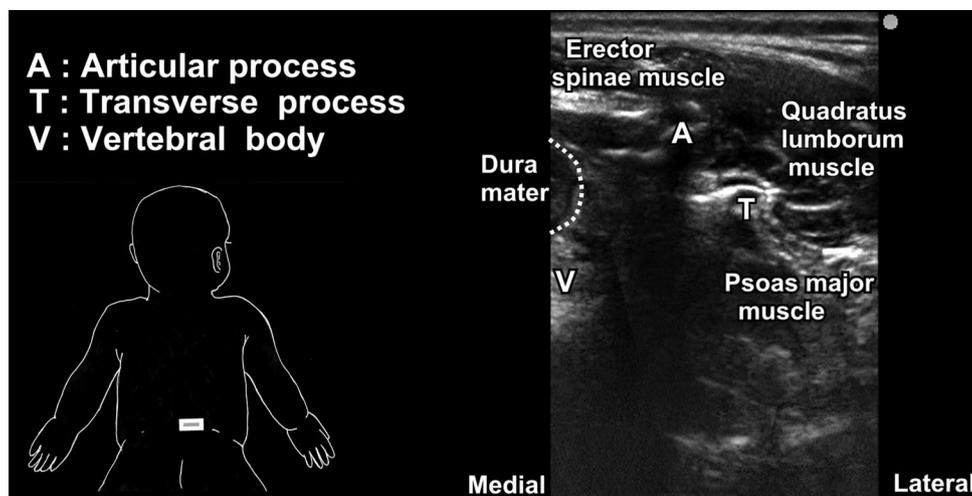


Fig. 6. Sonoanatomy at the lumbar plexus block location using a linear probe (HFL38, 6–13 MHz, 38-mm footprint) placed transversely at L4/5. The lumbar plexus is not identified in this image.

tifying the exact location and depth of the transverse processes. A curved array probe (curvilinear) is placed in the transverse plane in the midline at the level of the L4 spinous process to provide an overview of the L4 vertebra. The probe should be rotated to the longitudinal axis, parallel to the spine, which will allow a lateral scan to be performed to identify the transverse processes. Indeed, the transverse processes (which are the primary landmarks) are still often very vaguely delineated. Therefore, it is important to switch between transverse and longitudinal planes when scanning between the spinous processes and the edge of the transverse processes to survey the area. In the transverse scan, the spinous processes appear hypoechoic (likely due to dorsal shadowing effect) and extend superficially, whereas the transverse processes are hyperechoic masses or lines at the lateral edge of each vertebra. In the longitudinal scan, the lateral edges of the transverse processes will be identified at the most lateral point where multiple hyperechoic nodules are viewed.

**Technique.** Visualization of the lumbar paravertebral region has been described from sonographic imaging in 32 children.<sup>18</sup> By using a HDI 5000 ultrasound system (ATL/Philips, Bothell, WA) with a curved array probe (5–8 MHz, ATL/Philips), the authors placed the probe in longitudinal and transverse planes to view the lumbar plexus and measure the skin-to-plexus distance. By using the longitudinal view, the vertebral level was assessed by counting transverse processes in a cephalad direction from the reflex of the cephalad portion of the sacrum. Subsequently, the transverse sonograms were used in addition to the longitudinal view to capture the plexus in relation to the paravertebral musculature (thus deep to the erector spinae and quadratus lumborum muscles and within the psoas major muscle). The plexus was delineated in most patients at levels L3/4 and L4/5 (fewer at L4/5 in the patients older than 8 yr) and was seen in the posterior part of the psoas major muscle. The transverse sonogram showed hypoechoic dots (fascicles) enveloped by hyperechoic connective tissue (epineurium) elements, whereas the longitudinal sonogram showed hypoechoic parallel

bands bordered by hyperechoic striations. The skin-to-plexus distances were positively correlated with patient weight, age, and height, although the strongest correlation was with weight ( $r = 0.68$  at L3/4 and  $0.64$  at L4/5). Real-time ultrasound guidance, by using a portable ultrasound system with a small footprint hockey-stick probe, was performed during blockade at L4/5 in five patients younger than 2 yr undergoing inguinal herniotomy. The patients were placed in the lateral decubitus position, and after delineating the plexus as described, an insulated needle (25-gauge Sprotte, 35 mm) was aligned out-of-plane to the probe placed in the transverse plane. The longitudinal plane was used to verify the needle placement close to the plexus. The local anesthetic solution (ropivacaine 0.33% 0.3 ml/kg) was seen spreading within the posterior part of the psoas major muscle. The authors report successful intra- and postoperative analgesia.<sup>19</sup>

**Comment.** Sonographic visibility of the lumbar plexus may not be feasible in many older pediatric patients, mainly due to poor ultrasound beam penetration at the depth required but also possibly because the psoas major muscle and plexus are largely similar in echogenicity. In children, it may be easier to directly identify the plexus because the muscle tissue appears relatively more hypoechoic when compared with the nerve structures, which contain hyperechoic connective tissue layers.<sup>18</sup> Despite that ultrasound may enable a sufficient view of the bony landmarks (transverse processes) or plexus itself, lack of clear tracking of the needle tip and an adequate view of the local anesthetic spread may be considered risky especially if the needle is inserted in a relatively medial and caudal location. The use of a nerve stimulator, maintaining a needle puncture relatively lateral and cranial (see Schuepfer and Johr<sup>20</sup>) and performing regular aspiration during injection will help ensure the safety of this block. There must be a risk-benefit analysis when deciding to use this block; although it will be the most suitable block for achieving anesthesia of the entire lumbar plexus, selective blocks of the

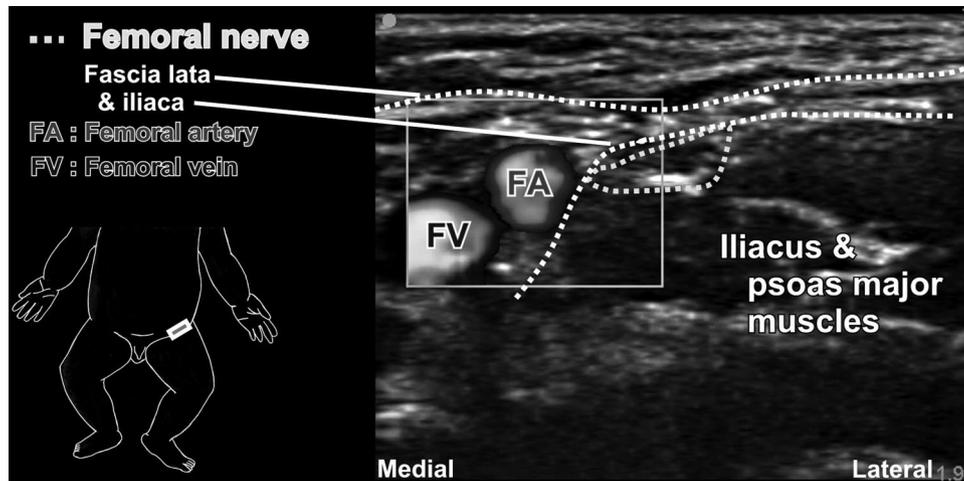


Fig. 7. Sonoanatomy at the femoral nerve block location using a linear hockey stick probe (SLA, 6–13 MHz, 25-mm footprint) placed parallel and inferior to the inguinal ligament. The neurovascular structures from medial to lateral are the femoral vein, femoral artery, and the femoral nerve. The nerve is enveloped under the fascia iliaca and is noted to be hyperechoic as a cluster of fascicles at this point.

separate nerves at more peripheral sites or a caudal block may be more appropriate depending on the procedure.

#### **Clinical Pearls—Lumbar Plexus Block.**

- Ultrasound visualization of the plexus is often limited to young patients, thus real-time technique may be limited to this population. In older patients, it will be more suitable to perform a preblock scan to mark the location and depth of the bony landmarks (*i.e.*, mainly the transverse processes).
- It is important to switch between transverse and longitudinal planes when scanning between the spinous processes and the edge of the transverse processes to survey the area.
- The needle should be inserted in either a cephalad or caudad direction, rather than medially toward the spinal canal.

#### **Femoral Nerve Block.**

**Sonoanatomy.** Similar to when using conventional techniques, the femoral artery is the key landmark when using ultrasound guidance for femoral nerve blockade (fig. 7). With the probe placed perpendicular to the nerve axis (*i.e.*, coronal oblique) at the level of and parallel to the inguinal crease, the nerve appears lateral to the large, circular, and anechoic femoral artery (color Doppler may be used to identify the femoral artery and vein). The nerve often appears triangular in shape and may be of variable size due to its irregular course; early branching above the inguinal ligament can increase the transverse diameter of the nerve. The fascia lata (most superficial) and iliaca (immediately adjacent to the nerve and in fact separating the nerve from the artery) are seen superficial to the femoral nerve and often appear as bright and longitudinally angled echogenic signals.

**Technique.** A comparison of ultrasound guidance to nerve stimulator technique for sciatic and femoral nerve blocks was performed by the same group that previously described and investigated ultrasound guidance for infraclavicular and ilio-inguinal/iliohypogastric blockade.<sup>21</sup> The femoral nerve block was performed in 28 of the 46 children, because not all

children in the study required femoral block in addition to blockade of the sciatic nerve for analgesia. A linear hockey stick probe was placed parallel but inferior to the inguinal ligament to view the nerve in short-axis, lateral to the femoral artery. The needle (22-gauge 40 mm with facette tip and injection line) was aligned out-of-plane to the probe and placed approximately 1 cm from the caudad surface of the probe using an approximate angle of 45°. The needle tip was viewed approaching the nerve and the local anesthetic was injected to surround the nerve, using redirections where necessary. Visualization of the nerve was possible in all cases.

**Comment.** Although there is no direct evidence to prove that ultrasound can reduce the risk of inadvertent vessel puncture, in our experience with ultrasound guidance for this block fewer events have been found than during our previous practice. Although prevention of intraneural local anesthetic injection or direct needle puncture may not be possible in all cases (the view of the needle tip is often not clearly seen and the nerve may not be adequately viewed), ultrasound imaging of the precise placement of the local anesthetic solution may reduce the practice of injecting large volumes of local anesthetic to ensure adequate spread *via* a blind injection. Our preference is to use an in-plane technique, which offers the ability to visualize the needle tip as it enters the fascia iliaca.

#### **Clinical Pearls—Femoral Nerve Block.**

- Place a linear probe along the inguinal–femoral crease.
- Place a needle in an in-plane approach.
- The local anesthetic is injected to surround the nerve.
- The needle has to be placed inside the fascia iliaca compartment, and the local anesthetic is seen surrounding the nerve bundle.

**Other Blocks of the Nerves of the Lumbar Plexus.** There have been no clinical reports in the pediatric literature describing ultrasound guidance for other commonly performed approaches to blocking the nerves of the lumbar plexus, in-

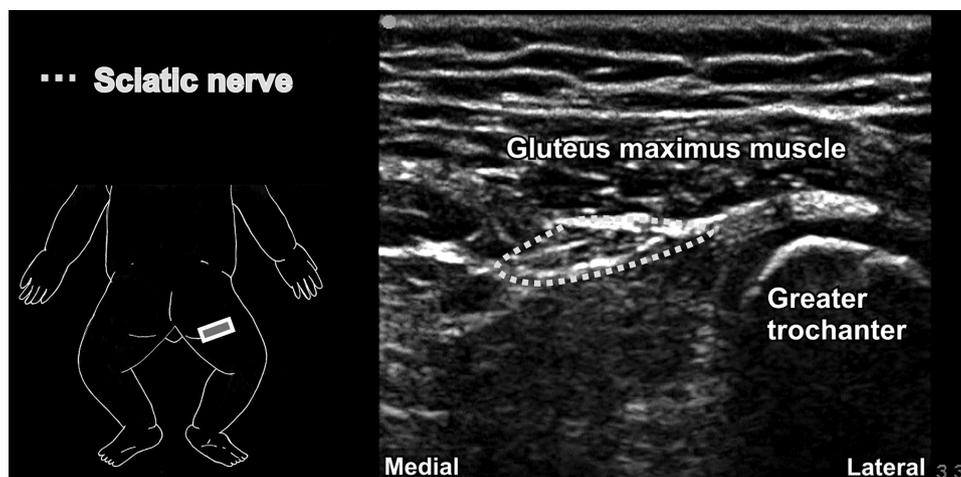


Fig. 8. Sonoanatomy at the subgluteal location where the sciatic nerve lies at the midpoint between the ischial tuberosity (not shown) and the greater trochanter of the femur. Image obtained using a linear probe (HFL38, 6–13 MHz, 38-mm footprint). The sciatic nerve is visualized as a linear structure between the two bony landmarks.

cluding the fascia iliaca block, 3-in-1 block, or individual blocks of the lateral femoral cutaneous or obturator nerves. There has been some mention of ultrasound-guided lateral femoral cutaneous and 3-in-1 blocks, during which the visibility of the spread of local anesthetic has been possible as deposited beneath clearly visible fascial layers.<sup>22</sup> Despite the lack of data, these blocks could all benefit from improved localization of the target nerves, or determination of their existence within the plane of needle entry. Furthermore, visual confirmation of the spread of local anesthetic within the correct fascial plane will help predict the success in cases where the nerves may not be seen. There will likely be a reduced reliance on depositing a larger than necessary volume of local anesthetic in hopes of obtaining the block of all related nerves.<sup>22</sup>

#### Sciatic Nerve Blocks.

**Sonoanatomy.** Subgluteal and popliteal approaches are commonly used for sciatic nerve blockade in children; alternatively, the anterior thigh approach can also be effective. In the subgluteal region of a young child placed in Sim's position with the hip and knee flexed and the foot resting on the dependent knee, a probe can be placed transversely at the mid-point of the ischial tuberosity and greater trochanter to obtain a view of the sciatic nerve in cross-section (fig. 8). Typically, only the greater trochanter can be seen when using a small footprint linear probe. Imaging in older children will often require the use of a curved probe (curvilinear) with moderate-low frequency (*e.g.*, 2–5 MHz) to enable deeper ultrasound beam penetration. Palpation of these landmarks will require some close attention, because they do not reach their adult morphology until puberty (*e.g.*, the ischial tuberosity is very thin in children below 1 yr of age).<sup>23</sup> Laterally, the medial aspect of the greater trochanter will appear largely hypoechoic, although its size will be dependant on age of the child because it is only highly recognizable at 6 to 8 yr of age.<sup>24</sup> The sciatic nerve appears predominantly hyperechoic and is often elliptical in a short-axis view.

A caudad-to-cephalad scan can effectively locate the sciatic nerve in the posterior popliteal fossa at a location where the tibial and common peroneal components have yet to separate. At the popliteal crease, a transversely positioned linear probe captures the tibial and common peroneal nerves, the former located medially and lateral to the adjacent popliteal vessels (color Doppler is very valuable here). The tibial nerve is often located in close proximity to the tibial artery and the tibial vein. The nerves appear round-to-oval and hyperechoic compared with the surrounding musculature. The hyperechoic border of the femur (condyles) may be apparent, although the condyles are cartilaginous during the first 1 to 3 yr of life and not at their distinctive shape until 7 to 9 yr of age.<sup>24</sup> Because the probe is moved cephalad, the tibial nerve diverges away from the vessels and moves laterally to approach the common peroneal nerve (fig. 9). The biceps femoris muscle lies superficial to the joining nerves and appears largely oval shaped with less internal punctuate areas (hypoechoic spots) than the nerves. At and beyond its point of bifurcation, the sciatic nerve appears as a large round to flat-oval hyperechoic structure.

**Technique.** Gray *et al.* published the first report on ultrasound-guided peripheral nerve block in children in 2003, in which they performed sciatic nerve block in the subgluteal region of a 7-yr old.<sup>9</sup> A linear probe was placed near the gluteal crease to view the nerve in cross-section, deep to and at the junction where the gluteus maximus muscle meets the biceps femoris–semitendinosus muscle complex. The needle was inserted using an in-plane approach, and the spread of local anesthetic surrounding the nerve was visualized.

Oberndorfer *et al.*<sup>21</sup> recently studied ultrasound-guided sciatic nerve blockade, using a subgluteal approach with a hockey stick probe placed in a more sagittal plane. These authors also used an in-plane approach to the plexus. Moreover, they describe and illustrate how the posterior cutaneous femoral nerve can be viewed adjacent to the sciatic nerve and, using needle redirection, when blocked together with the

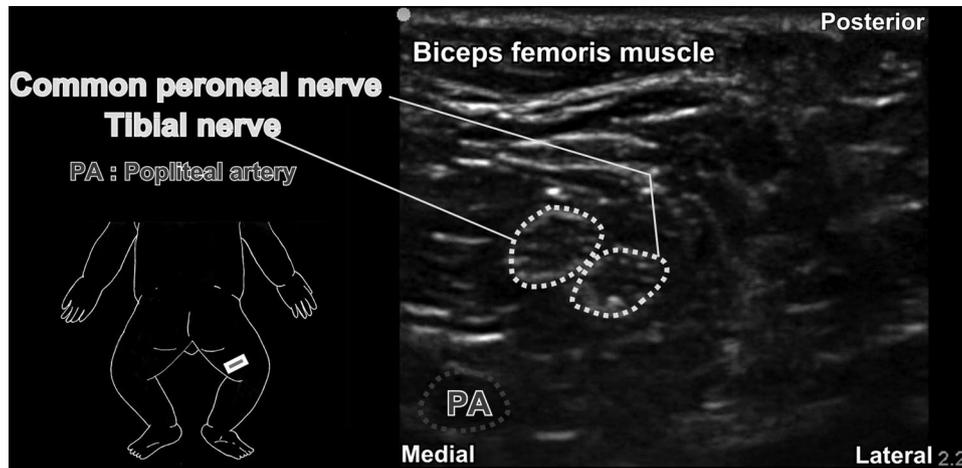


Fig. 9. Sonoanatomy in the popliteal fossa just distal to where the sciatic nerve bifurcates. Image obtained using a linear hockey stick probe (SLA, 6–13 MHz, 25-mm footprint). Note the popliteal artery and its relationship to the tibial nerve; the nerve is located in close proximity to the vessels, although it moves apart as it courses cephalad. The common peroneal nerve is located lateral to the tibial nerve.

sciatic nerve this can prevent tourniquet pain. Other described techniques place the probe in a transverse plane between the greater trochanter and ischial tuberosity.

When the child cannot be placed prone or laterally, an anterior approach to the sciatic nerve can be used with the patient lying supine. Although there has been no clinical investigation published reporting this approach in children, Rapp and Grau<sup>14</sup> comment on their technique, which uses a rostral and dorsally-directed needle aligned to the cross-sectional view of the nerve after palpating the groove between the vastus medialis and adductor muscles. Because of the depth of the nerve, ultrasound-guided technique will likely be augmented with nerve stimulation. Moreover, one of the authors of this review (B.T.) has found that obtaining a longitudinal view of the nerve can help confirm its identity as viewed in cross-section when uncertainty arises.<sup>25</sup>

An out-of-plane placement of the needle during ultrasound-guided subgluteal or popliteal nerve blocks will enable easy introduction of a catheter when continuous blockade is indicated. Continuous nerve blockade of the sciatic nerve using ultrasound has been described in several publications.<sup>3,26–30</sup> For a subgluteal approach, the child can be placed in the Sims position with the operative side uppermost and with the hip and knee flexed and the foot resting on the dependent knee.<sup>28</sup> In a descriptive study, a linear probe was placed in a transverse plane between the greater trochanter and ischial tuberosity to view the nerve in short-axis lateral to the long head of the biceps femoris muscle.<sup>28</sup> The needle was introduced out-of-plane to the probe using a 45° angle to the skin, until the tip of the needle was seen lying adjacent to the nerve. Subsequently, a catheter was introduced and advanced to not more than 3 cm. When using blind catheter insertion, ultrasound imaging can be used after catheter placement to confirm that the local anesthetic spreads around the nerve. Alternatively, in certain patients, an infragluteal approach can be used with the child placed in the prone position.<sup>27</sup> In this case, the authors inserted the needle using a 70° angle to the skin.

Ultrasound imaging may be particularly useful for allowing peripheral nerve blocks to be performed in cases where a blind technique would fail. In a letter, Van Geffen *et al.*<sup>29</sup> described how this modality was beneficial when performing continuous sciatic nerve blocks in two children with venous malformations. The sciatic nerves of these children were surrounded by multiple venous structures, and the imaging enabled needle placement while avoiding vascular puncture.

Two unique case series have been published recently, describing ultrasound-guided placement of peripheral nerve block catheters.<sup>3,26</sup> During placement of perineural catheters in two children (mid-femoral sciatic and popliteal blocks), Koscielniak-Nielsen *et al.*<sup>26</sup> were able to view the rigid epidural catheter exiting the needle tip and during advancement while using long-axis views of the nerves. After confirming the nerve identity using a long-axis plane, the probe was rotated 90°, and the needle and catheter were introduced in-plane with a tangential angle. Injection of local anesthetic confirmed the needle tip and catheter location. The authors observed that the catheters were positioned properly with the help of to-and-fro movements and the rotation of the Tuohy needle. Another recent report describes the provision of continuous peripheral nerve blocks on pediatric medical missions in developing countries.<sup>3</sup> The portability of ultrasound machines enabled the performance of these blocks in an environment where there was lack of other specialized regional anesthesia equipment.

**Comment.** The size of the child will determine the type of probe, which will produce the best image. For the subgluteal block, the depth of the sciatic nerve will vary considerably in larger children, and deeper structures will require lower frequency probes to allow sufficient resolution of images for visualization. In contrast, a high-frequency linear probe is sufficient for popliteal blocks. Ultrasound will be particularly beneficial for popliteal blocks, because it has been shown that the division of the sciatic nerve can be highly variant, for example between 32 to 76 mm from the popliteal crease.<sup>31</sup> Similar to the case of needle placement under ultrasound

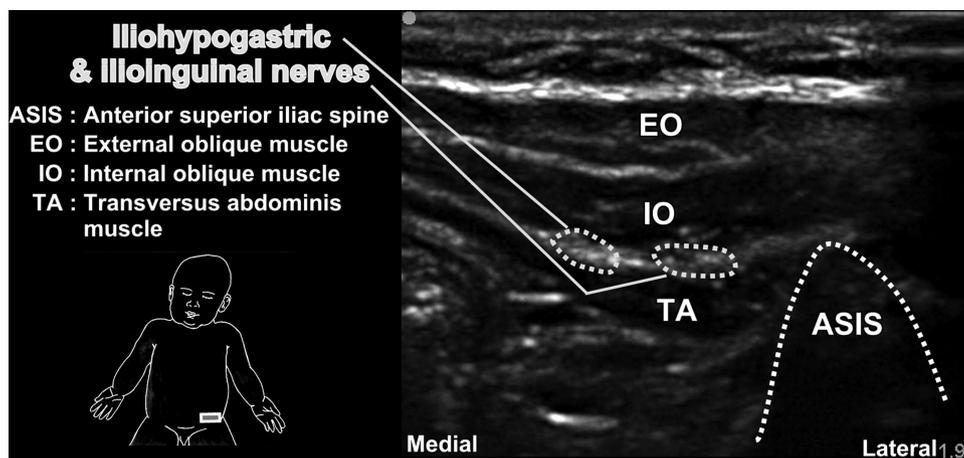


Fig. 10. Sonoanatomy at the ilioinguinal/iliohypogastric nerve block location immediately medial to the ASIS, using a linear hockey stick probe (SLA, 6–13 MHz, 25-mm footprint). Note that the ilioinguinal and iliohypogastric nerves are seen in the fascial plane between the internal oblique muscle and the transverse abdominal muscles as two hypoechoic structures.

guidance, in cases where the beam axis is not in exact alignment with the longitudinal axis of the catheter (highly likely with the flexible material), viewing the tip of a catheter, rather than some cross-sectional point, will require some surrogate marking (movement or fluid injection).

#### **Clinical Pearls—Sciatic Nerve Block at the Popliteal Fossa.**

- Place a linear probe in the popliteal fossa at the crease at the knee.
- Look for the popliteal artery.
- The popliteal vein is noted above the artery.
- The tibial nerve is located superficial and often in close proximity to the popliteal artery.
- The common peroneal nerve is located lateral to the tibial nerve.
- The linear probe is gently moved cephalad until the two nerve branches merge; the tibial nerve will diverge from the vessels.
- By using an in-plane approach, a needle is placed in close proximity to the sciatic nerve, and local anesthetic solution is injected to surround the nerve.

**Outcome Evaluation for Lower Extremity Blocks.** Oberndorfer *et al.*<sup>21</sup> compared ultrasound guidance with nerve stimulator technique for sciatic and femoral nerve blocks in a randomized, blinded study of 64 children. The primary outcome in this study was block duration (defined as the time from injection of local anesthetic to when the child received their first postoperative analgesic medication), although local anesthetic volume was also compared. By using the block techniques described earlier (including multiinjection technique using needle redirection in the ultrasound group to spread the local anesthetic circumferentially around the nerves), the ultrasound-guided blocks lasted longer (508 *vs.* 335 min), using lower volumes of local anesthetic (0.2 ml/kg *vs.* 0.3 ml/kg of levobupivacaine, 0.5%). The ultrasound-guided sciatic nerve block included needle redirection in 45% of cases to ensure that the local anesthetic injection

surrounded both the sciatic and posterior femoral cutaneous nerves. The ultrasound-guided blocks seemed to be more successful than those performed using nerve stimulation, although this study was not powered to reach a meaningful conclusion. A power analysis, however, was performed to determine the primary outcome of the study, *i.e.*, the duration of blockade.

#### **Peripheral Nerve Blocks of the Anterior Trunk**

Among many blocks performed at the anterior trunk, ilioinguinal/iliohypogastric nerve blockade is one of the most commonly performed blocks for surgery in the inguinal region and may be one of the most common peripheral nerve blocks in children (Pediatric Regional Anesthesia Network [PRAN], personal verbal communication, Santhanam Suresh, M.D., Professor, Department of Anesthesiology and Pediatrics, Children's Memorial Hospital, Northwestern University's Feinberg School of Medicine, Chicago, IL, April 2009). Various other nerve blocks are also becoming popular to provide analgesia for procedures in the umbilical or epigastric regions and for penile surgery. Ultrasonography can be particularly beneficial for truncal blocks in children due to the close anatomical relations between the nerves and various critical abdominal structures. The conventional techniques often include subjective detection of "pops," "clicks," or "scratching sensations" on penetration into the respective fascial compartments in which the nerves are typically located. Ultrasound visibility of the musculature, related fascia and aponeuroses, and the local anesthetic spread may improve the success rates and allow for administration of minimal volumes of local anesthetic.<sup>32,33</sup>

#### **Techniques.**

##### **Ilioinguinal/Ilioypogastric Nerve Block.**

**Sonoanatomy.** The probe can be placed immediately medial to the superior aspect of the anterior superior iliac spine (ASIS) to capture a short-axis view of the ilioinguinal nerve sandwiched between the internal oblique and transversus abdominis muscles (fig. 10). The ASIS appears hypoechoic

(due to dorsal shadowing beyond the highly reflective periosteum) and nodular-shaped at the lateral edge of the screen. The lateral abdominal muscles will appear with multiple hyperechoic dots within a hypoechoic background (a “starry night” appearance); there may be hyperechoic divisions between muscles representing the fascial compartments. The nerve can be identified as an elliptical-oval shaped structure with a hyperechoic film surrounding a hypoechoic core. The superiorly and medially situated iliohypogastric nerve courses ventrally between the external and internal oblique abdominal muscles; this nerve may not be adequately viewed in the image. Although a superficial layer consisting of the external oblique abdominal muscle may be present, in many patients, this muscle has already turned into an aponeurotic sheath at this level.<sup>32</sup>

**Technique.** A hockey stick probe will be suitable for many infants and younger children, because the nerves are closely situated beneath the skin (8 mm on average) and medial (7 mm on average) to the ASIS.<sup>32</sup> Descriptions of the technique have included placing the probe immediately medial to the upper aspect of the ASIS to obtain a short-axis view of the nerve(s) situated between the two abdominal muscles (internal oblique and transversus abdominis), with the peritoneum immediately beneath the internal oblique muscle.<sup>32–34</sup> After aseptic preparation of the skin and probe, the needle (*e.g.*, 22 gauge, 40 mm) can be advanced using an out-of-plane technique, placing the needle tip approximately 1 cm caudad to the probe surface to allow for optimal needle tip visibility approximately 1 cm deep.<sup>32</sup> Once the needle tip was viewed usually between the abdominal muscles and in close vicinity to the nerve, the local anesthetic solution was injected under real-time control to view the solution surrounding the nerve.

The probe could be placed in a manner to use another needle puncture point in a more proximal region, such as the point between the third and lateral quarters on a line between the ASIS and umbilicus.<sup>35</sup> As used in adults, the probe could be placed obliquely at a position lateral to the needle puncture site, and an in-plane needle alignment could be used, with the needle directed laterally and slightly caudad.<sup>36</sup> Our preference is to use an in-plane technique with a linear probe with the needle placed overriding the ASIS and pointing toward the umbilicus. This provides a clear view of the various muscle layers and the nerves as they run in the plane between the internal oblique and the transversus abdominis muscle.

**Comment.** Ilioinguinal/iliohypogastric blocks are commonly used for anesthesia and analgesia for surgery involving the inguinal region, including inguinal hernia repair and orchiopexy. When successfully placed, these blocks can be as effective as a caudal block<sup>37</sup> and are especially valuable when caudal block is contraindicated or in larger children with presacral fat that prevents an easy approach to the sacral hiatus. Using the conventional techniques relying on fascial clicks on penetration of the abdominal muscles for the ilioinguinal nerve block have a reported success rate of only approximately 70%.<sup>38</sup> Moreover, with the closely situated

peritoneum, these blocks can lead to colonic or small bowel puncture<sup>39,40</sup> or pelvic hematomas.<sup>41</sup>

Part of the reason for block failures may be the inaccurate localization of the nerves when using one of the traditional landmark-based needle insertion sites (often somewhere along a line between the ASIS and the umbilicus) and the fascial click method for determination of injection. Occasionally, the blocks seem to fail due to pain experienced during spermatic cord manipulation, and ideally, the genitofemoral nerve block should be performed.<sup>36,42</sup> The blockade of these nerves could benefit greatly from visualization of the correct plane of nerve localization (between internal oblique abdominal and transversus abdominis muscles), the needle trajectory (adjacent to the nerves and outside the closely situated peritoneum), and the local anesthetic deposition. Weintraud *et al.*<sup>43</sup> used ultrasonography to determine the actual location where local anesthetic is administered when using the conventional fascial click or pop method for injection. In 62 children, the local anesthetic solution was noted to surround the nerves in only 14% of blocks. This was despite the fact that the needle puncture site was determined by an initial ultrasound scan of the region. The remainder of the injections (performed by an anesthesiologist blinded to the images) were deposited within the muscles in the abdominal region (82% in the internal oblique abdominal, transversus abdominis, iliac, or external oblique abdominal muscle), subcutaneously (2%), or within the peritoneum (2%). This study only had a 55% success rate, based on viewing the local anesthetic surrounding the nerves or on clinical signs during skin incision 15 min after the block. In a related letter, Thibaut *et al.*<sup>44</sup> reported that many adult patients (12 of 14) who received injections into the internal oblique abdominal muscle (as viewed with ultrasound) experienced successful blockade, as determined by an anesthesia area more than 25 cm<sup>2</sup>. Five of 19 injections were located either subcutaneously or within the external oblique abdominal muscle, of which most were unsuccessful.

#### Clinical pearls—ilioinguinal nerve block.

- Place a linear probe or a hockey stick probe along the ASIS with the probe oriented toward the umbilicus.
- The three layers of the abdominal wall muscles can be recognized.
- The ilioinguinal nerve and iliohypogastric nerves are seen as two hypoechoic structures between the internal oblique and transversus abdominis muscles.
- By using an in-plane approach, the needle (22 gauge for most children) is advanced and placed between the internal oblique abdominal and the transversus abdominis muscle.
- Use a small (1–2 ml) test injection of a dextrose solution to confirm the spread of local anesthetic between the muscles and close to the nerves, then aspirate and inject local anesthetic to expand the plane. Inject between 0.1 and 0.2 ml/kg based on experience, duration of surgery expected and analgesia desired, and concentration of local anesthetic solution.

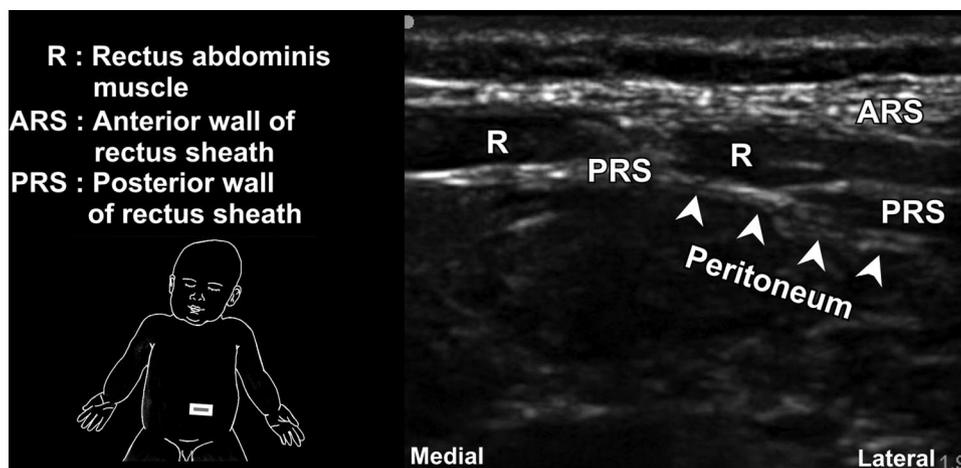


Fig. 11. Sonoanatomy at the rectus sheath block location lateral to the midline over the semilunaris. Image obtained using a linear hockey stick probe (SLA, 6–13 MHz, 25 mm footprint). The rectus abdominis muscle is seen between the anterior and posterior walls of the rectus sheath. The sensory nerve root T10 runs between the rectus abdominis muscle and the posterior rectus sheath.

### Rectus Sheath and Umbilical Nerve Blocks.

**Sonoanatomy.** A small footprint probe will be suitable for viewing unilateral anatomy (fig. 11), although a larger field of view (e.g., 38 - mm footprint) may be helpful in some children to capture the lateral abdominal muscles and rectus sheath and muscle. In the figure, the probe was placed just below the umbilicus (i.e., above the arcuate line). The anterior and posterior aspects of the rectus sheath and the enclosed rectus abdominis muscle are visualized. The sheath appears hyperechoic with multiple linear layers, lying on the anterior and posterior aspects of the rectus muscle.

One publication highlights how a preprocedural scan can be an important consideration for the rectus sheath block. McCormack and Malherbe<sup>45</sup> recommend a longitudinal scan of the rectus abdominis muscle at the level of the umbilicus to exclude any anatomical variations, including bowel herniation or aberrant blood vessels.

**Technique.** For the rectus sheath block, the probe is placed over the linea semilunaris (at the lateral aspect of the rectus abdominis muscle) at a level beneath the umbilicus, and the lateral edge of the rectus muscle is positioned at the edge of the screen. The posterior wall of the sheath may be poorly defined at locations caudad to the umbilicus (i.e., below the arcuate line).<sup>46</sup> Color Doppler can be used to identify the epigastric vessels within the rectus abdominis muscle; this may be helpful to avoid hematoma formation.<sup>46</sup> The peritoneum appears thick with a hyperechoic border beneath the muscles.

Willschke *et al.*<sup>47</sup> described their approach for ultrasound-guided rectus sheath block in the clinical portion of their two-part study evaluating the sonoanatomy and clinical feasibility of this block. They stated that their injection site was situated at the location where an optimal view of the posterior sheath was obtained. A short-beveled needle (e.g., 22 gauge, 40 mm with facette tip) was inserted in an in-plane approach at the inferior edge of a linear hockey stick probe, using an angle most suitable for the depth of the sheath. The needle tip was placed just inside the rectus sheath near the posterior aspect of the rectus abdominis muscle. After nega-

tive aspiration (for epigastric vessel puncture), local anesthetic solution was injected; expansion of the space between the sheath and posterior aspect of the rectus muscle denoted proper placement of the needle.

For the umbilical nerve block, the field of view should be increased to include the medial aspect of the lateral abdominal muscles and the region where their aponeuroses join to form the rectus sheath. Laterally, the lateral abdominal muscles may be delineated with oblique hyperechoic lines separating them. The external oblique abdominal muscle lies outermost, overlying the internal oblique abdominal and transversus abdominis muscles. The thick rectus abdominis muscle can be identified medially, as can the rectus sheath, formed by the aponeurosis of the transversus abdominis muscle and internal and external oblique abdominal muscles. The intercostal nerve(s) will likely not be visualized by ultrasound imaging. The nerves are small and run longitudinally, thus tangential, to the probe.<sup>46</sup> The hyperechoic and linear appearance of the nerves will closely resemble the aponeurosis of the musculature in this region.

De Jose Maria *et al.*<sup>46</sup> have described their approach to an ultrasound-guided umbilical nerve block. The probe (10 MHz frequency) was placed where a line between the tenth intercostal space and the umbilicus intersects the rectus abdominis muscle. They rotated the probe between transverse and longitudinal planes to obtain a good view clearly delineating the musculature and rectus sheath. The longitudinal plane was used during the block, and the ideal position of the probe was that which best captured the formation of the rectus sheath, by the aponeuroses of the transversus abdominis and internal oblique abdominal muscles. The needle was inserted using an in-plane approach to place the tip close to the lateral edge of the rectus muscle and between the aponeurosis of the abdominal muscles. The local anesthetic spread was observed behind the rectus abdominis muscle and under the internal oblique abdominal muscle.

**Comment.** The eighth through eleventh intercostal nerves travel laterally between the transverse and internal oblique

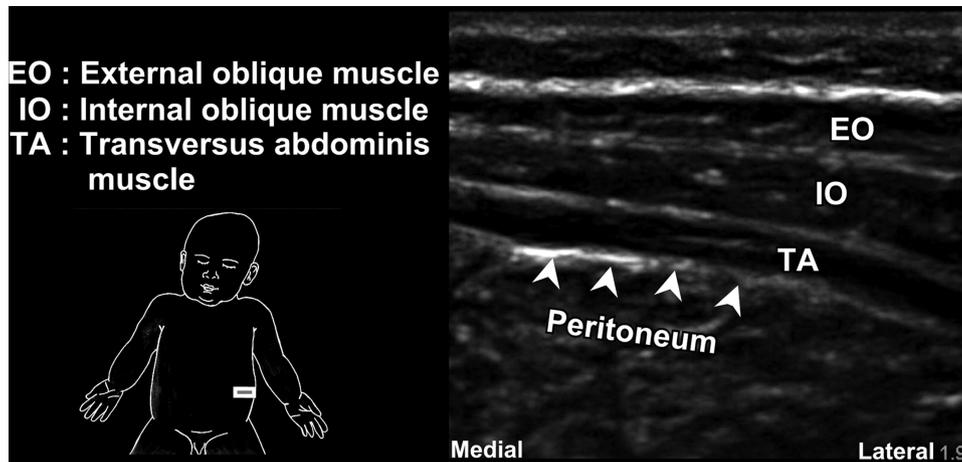


Fig. 12. Sonoanatomy at the transversus abdominis plane (TAP) using a linear hockey stick probe (SLA, 6–13 MHz, 25 mm footprint). Note the three layers of the abdominal wall, the external and internal oblique, and the transverse abdominal muscles. The TAP is located in the fascial plane between the transversus abdominis muscle and the internal oblique muscle.

abdominal muscles and, at the level of the linea semilunaris, penetrate the rectus sheath to travel between the posterior wall of the rectus sheath and the rectus abdominis muscle. Bilaterally, the aponeuroses of the lateral three abdominal muscles form the rectus sheath; the sheaths join at the linea alba and together enclose the rectus abdominis muscle. The rectus sheath block aims to place local anesthetic between the posterior aspect of the rectus sheath and the rectus abdominis muscle. The posterior wall of the sheath is not attached to the muscle and thus can be separated during the block injection (*i.e.*, represents a potential space). The median depth of the posterior sheath in 30 children was 8.0 mm (range, 5–13.8); moreover, there was poor correlation between the depth of the posterior rectus sheath and weight, height, or body surface area.<sup>47</sup> With the sheath's proximity to the peritoneum and without the possibility of reliable estimations or calculations of optimal needle depth, ultrasound imaging during the block is especially useful. It is also important to note that the posterior wall of the sheath is poorly defined below the arcuate line.<sup>46</sup> Placing the needle more lateral, and thus potentially avoiding puncture into the peritoneum, the umbilical nerve block targets the region lateral to the sheath where the nerves exit from their course between the transversus abdominis and internal oblique abdominal muscles.

Although the techniques described for the rectus sheath and umbilical blocks used an out-of-plane needle alignment, an alternative technique using in-plane needle alignment could be used and is preferred by one of the authors of this review (S. S.). For this, a short footprint probe is preferred and direct visualization of the needle insertion can be performed. An out-of-plane technique may be suitable in some cases, particularly in obese children where the depth of insertion may be significant.

#### Clinical pearls—rectus sheath block.

- Place a linear high-frequency probe or a hockey stick probe at the level of the umbilicus.

- The rectus abdominis muscle is identified along with the anterior and posterior walls of the rectus sheath.
- By using an in-plane technique, a 27-gauge needle is advanced until it penetrates the space between the rectus abdominis and the posterior rectus sheath.
- After a small test injection to confirm the spread of local anesthetic, 0.1–0.2 ml/kg local anesthetic solution is injected into the potential space between the posterior rectus sheath and the rectus abdominis muscle.
- Hydrodissection can be used to find the exact plane because the space is small and exact localization may be required.

#### Transversus Abdominis Plane Block.

**Sonoanatomy.** Ultrasound can readily visualize the muscle layers at the lateral abdominal wall, although not allowing clear distinction between the individual muscles. Linear and parallel hyperechoic striations are apparent, beneath which lie a hypoechoic-appearing region representing the peritoneum (fig. 12). The external oblique abdominal muscle will lie superficial, overlying the internal oblique and transversus abdominis muscles. As for the rectus sheath and umbilical blocks, the nerves (in this block the lower thoracic and first lumbar spinal nerves) will not be viewed with clarity because they would appear with similar echogenicity as the muscle layers and travel tangentially to the ultrasound beam axis at this location.

**Technique.** Laghari *et al.*<sup>48</sup> were first to describe an approach to perform an ultrasound-guided transversus abdominis plane (TAP) block in children. In a 9-yr-old girl, these authors used an out-of-plane needle alignment to a linear probe placed in the flank above the iliac crest. The needle (21 gauge, 50 mm insulated) was placed approximately 2 cm above the highest point of the iliac crest and directed cranially using a shallow angle. The needle was advanced until its tip was viewed in the TAP, thus between the transverse and internal oblique abdominal muscles. Local anesthetic was injected incrementally, and the spread was observed within

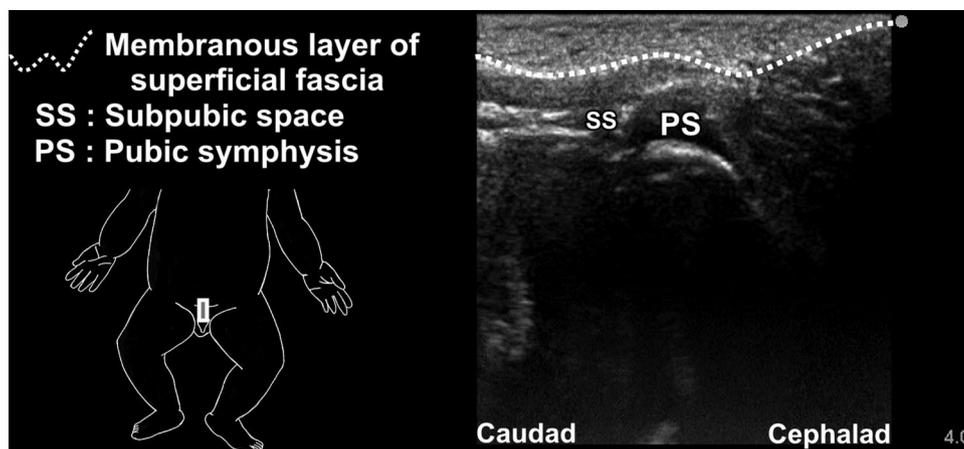


Fig. 13. Sonoanatomy of the subpubic space using a linear probe (HFL38, 6–13 MHz, 38-mm footprint).

the plane. No intraoperative analgesia was required and excellent pain scores (0/10) were recorded soon after the open appendectomy.

Fredrickson *et al.*<sup>42</sup> have described their early experience with TAP block under ultrasound guidance. They placed a linear probe in the axial plane above the iliac crest or at a location where the three lateral abdominal muscle layers were most evident on the ultrasound screen. An in-plane needle alignment was used, with the needle (a short 22-gauge spinal needle) directed from anterior to posterior to allow the needle to be viewed along its axis. On viewing the needle tip in the TAP, the local anesthetic was injected while observing the spread within the plane. The blocks were successful, with the exception of those patients who required intraoperative opioid supplementation due to spermatic cord manipulation (genitofemoral nerve). A recent simple technique for placement of the TAP block in infants and children has been described with a step-by-step approach to perform this block in infants and children by one of the authors of this review (S. S.).<sup>49</sup>

**Comment.** The TAP block provides analgesia to the abdominal wall, through blockade of the lower thoracic and first lumbar spinal nerves at the lateral aspect of the abdomen before their course between the transversus abdominis and internal oblique abdominal muscles. In adults, there may be reliance on palpating the lumbar triangle of Petit (above the highest point of the iliac crest and between the posterior border of the external oblique and the lower lateral border of the latissimus dorsi muscle) at the base of which lies the internal oblique muscle.<sup>50</sup> Because there is no distinctly palpable triangle of Petit in children (or one only enabling sensation of a tiny hole), ultrasound may be especially valuable for determining the point of needle puncture during this block. Indications for the TAP block include postoperative pain control after abdominal surgery including colostomy and laparotomy especially when a central neuraxial block is contraindicated as in children with spinal dysraphism or in children with coagulation abnormalities. Because this block includes blockade of the first lumbar nerve root, it may substitute the ilioinguinal/iliohypogastric block in cases when the region anterior and medial to the ASIS offers suboptimal

imaging; the muscles in this region are apparently prone to anisotropy (*i.e.*, artifactual images produced due to the beam penetration angle in relation to the muscles).<sup>42</sup>

#### Clinical pearls—transversus abdominis plane block.

- Place a high-frequency linear probe or a hockey stick probe lateral to the umbilicus.
- Slide the probe laterally until the three muscle layers of the abdominal wall are recognized (external and internal oblique abdominal and transversus abdominal).
- At or just posterior to the midaxillary line, by using an in-plane approach, place a needle between the internal oblique and the transversus abdominal muscles.
- As local anesthetic is injected, the plane is seen to expand with posterior movement of the transversus abdominis muscle.
- Hydrodissection can be performed to recognize the exact plane of injection of the local anesthetic solution.

#### Dorsal Penile Nerve Block.

**Sonoanatomy.** By placing a probe sagittally along the shaft of the penis, the subpubic space can be located as a triangle containing the deep penile fascia (inferiorly), the pubic symphysis (superiorly), and the membranous layer of the superficial (Scarpa's) fascia.<sup>51</sup> Although the pubic symphysis and the membranous layer of the superficial fascia can generally be visualized, one may find that it is often difficult to clearly identify the deep fascia (fig. 13).

**Technique.** In a case report, Sandeman and Dille<sup>51</sup> describe placing a linear probe sagittally along the shaft of the penis to view the subpubic space. Penile block can be accompanied by bilateral injections into the subpubic space. Injection deep to Scarpa's fascia can be guided by ultrasound imaging to confirm the spread of local anesthetic solution to the deep fascia. The fundiform ligament, forming a midline septum within the deep fascia of the penis, appears fan-shaped. The needle was introduced on both sides of the fundiform ligament (thus on either side of the probe separately), to reach the region adjacent to the penile shaft structures. The authors state that they avoided injecting beneath the deep fascia to avoid nerve injury or intravascular injection.

tion. The local anesthetic can be seen spreading throughout the subpubic space.

**Comment.** This block is indicated for children undergoing penile procedures where a caudal block may be contraindicated. It can also be used in older children and adolescents where presacral fat can make the performance of the caudal block difficult. The performance of this block under ultrasound guidance is not well established at this time.

**Clinical pearls—dorsal penile nerve block.**

- The probe is placed sagittally along the shaft of the penis to view the subpubic space.
- The spread of local anesthetic deep to Scarpa's fascia can be confirmed using ultrasound.
- Performance of an ultrasound-guided penile block may likely remain uncommon in children because ultrasound imaging may be cumbersome to use due to the limited contact area for the probe.

**Outcome Evaluation for Blocks at the Anterior Trunk.**

Willschke *et al.*<sup>32</sup> performed a prospective, randomized double-blinded study with 100 children scheduled for inguinal surgery to compare block efficacy between ultrasound-guided and conventional ilioinguinal/iliohypogastric nerve block. The end point in the ultrasound group was obtaining a view of the local anesthetic solution surrounding the nerves, whereas detecting a fascial click was used to determine injection in the traditional block group. Fewer children received intraoperative or postoperative (up to 4 h) analgesia in the ultrasound group (4% and 6%, respectively) than in the fascial click group (26 and 40%). Furthermore, the volume of local anesthetic injected was lower in the ultrasound group (0.19 *vs.* 0.30 ml/kg).

Further evaluation of the optimal volume of local anesthetic required for ultrasound-guided ilioinguinal/iliohypogastric blocks was performed by this group in a subsequent study.<sup>33</sup> By using a modified step-up-step-down approach, with 10 patients in each group starting at 0.2 ml/kg, a volume of 0.75 ml/kg was found to achieve 100% block success for the first 4 h of postoperative care (longer analgesia may require higher volumes). These authors state that using lower volumes of local anesthetic could reduce the risk of local anesthetic toxicity and the incidence of adverse side effects, such as femoral nerve palsy.

Interesting findings have been published recently, which tend to support the use of lower volumes of local anesthetic when placing ilioinguinal blocks under ultrasound guidance when compared with the use of landmark-based technique. In a pharmacokinetic study, plasma levels of ropivacaine were found to be higher using ultrasound guidance when compared with a single pop technique (Cmax: 1.78 [0.62] *vs.* 1.23 [0.70]  $\mu$ g/ml). Although this finding is interesting and will likely encourage the planning of similar studies, the plasma levels reached in this study have never been associated with any clinical signs of toxicity.<sup>34</sup>

There have been no controlled or comparative studies published related to any of the other trunk blocks described

previously. Earlier reports of the rectus sheath block, using blind techniques, describe successful blocks as performed in small numbers of patients.<sup>52,53</sup> By using ultrasound guidance for rectus sheath blocks in 20 children, Willschke *et al.* reported a 100% success rate for intra operative and postoperative analgesia (until time to discharge at 4 h), using (predetermined volumes in their study) lower doses of local anesthetics (*i.e.*, levobupivacaine 0.25% 0.1 *vs.* bupivacaine 0.5% 0.2 ml/kg) than previously described when using blind technique with the same injection protocol.<sup>47,53</sup> Similar doses of local anesthetic have been used for the umbilical nerve block as those for the ultrasound-guided rectus sheath block (*i.e.*, bupivacaine 0.25% 0.1 ml/kg).<sup>46</sup>

**Discussion**

The performance of various peripheral nerve blocks, including single-shot techniques of the lumbar and sacral plexuses, has increased in recent years.<sup>54</sup> Even though the success and safety of peripheral blocks is usually good to excellent, in certain cases, improvements can be made (*e.g.*, ilioinguinal block success), and there are questions related to the reliability of the conventional techniques of nerve localization. Although much of the difficulty when performing peripheral nerve blocks in children stems from their relatively small anatomical structures and close proximity of their nerves to critical structures, the superficial position of many of the relevant structures enables the use of high-resolution ultrasound imaging, which can enable excellent real-time block guidance. Thus, real-time ultrasound imaging may improve the ability of the anesthesiologist to identify the neural structures, place the block needle in close proximity to the target, and precisely administer optimal volumes of local anesthetic.

Ultrasound may enable lower volumes of local anesthetic solution to be used in some cases where local anesthetic toxicity is a concern (*e.g.*, combined femoral and sciatic nerve blocks) or unwanted side effects are common (*e.g.*, spillover causing femoral nerve palsy during ilioinguinal blocks). Although some reports suggest that ultrasound should be used to minimize volumes of local anesthetic, it should be stressed that the volume used should maintain the desired parameters of the block, including its extent and duration. Some practitioners, especially those without similar expertise, may not obtain the degree of success to those reporting higher qualities of blockade with such low dosages. In addition, one recent study in adults found (using Dixon and Massey up-and-down methodology) that similar doses were required for ultrasound-guided supraclavicular block (minimum effective anesthetic volume in 50% of patients was 23 ml and calculated effective volume in 95% of patients was 42 ml) to those commonly used without ultrasound.<sup>55</sup> Although commonly recommended doses of local anesthetic<sup>56,57</sup> will maintain plasma concentrations in ranges, which have not been shown to cause toxicity, the thresholds for toxicity are not accurately known and ultrasound-guided placement of local anesthetic may have effects on plasma concentrations as recently shown

**Table 1.** Useful Landmarks for Identification of Nerves Using Ultrasound

Block	Useful Ultrasound Landmark	Comments
Interscalene	Scalene muscles and subclavian artery	At the posterolateral aspect of the sternocleidomastoid muscle, the superficially located sternocleidomastoid muscle appears triangular in shape and overlies the internal jugular vein and common carotid artery.
Supraclavicular	Subclavian artery	Brachial plexus lies lateral and often superior to the artery.
Infraclavicular	Subclavian artery and vein	Brachial plexus cords surround the artery. Posterior and medial cord can be difficult to visualize clearly.
Axillary	Axillary artery	Terminal nerves surround the artery. Important to avoid the multiple vessels present.
Lumbar plexus	Transverse processes	Plexus lies between and just deep to the lateral tips of the processes when using a longitudinal view. In pediatrics, the transverse view can be used to visualize the psoas muscle.
Femoral	Femoral artery	Nerve lies lateral to artery (vein most medial).
Sciatic Subgluteal	Greater trochanter and ischial tuberosity	Nerve lies between the two bone structures. With a linear probe, only the lateral bone ( <i>i.e.</i> , femur) is often seen.
Popliteal	Popliteal artery	Traceback from the popliteal crease where the tibial nerve is adjacent to the artery. Scanning proximally to the sciatic bifurcation, the artery becomes deeper and at a greater distance from the tibial nerve, which is joined by the peroneal nerve.
Trunk		
Transversus abdominis plane block	Three muscles layers (external and internal oblique and transverse abdominal)	No nerve can be seen.
Rectus sheath and umbilical block	Rectus sheath and rectus abdominal muscle	No nerve can be seen.
Ilioinguinal/iliohypogastric	Two to three layers of muscle (external oblique oftentimes aponeurosis) and anterior superior iliac spine	Nerve(s) can be seen.

for ilioinguinal blocks.<sup>34</sup> More studies will hopefully direct us to the appropriate dose of local anesthetic to be used during ultrasound-guided techniques while maintaining optimal success without risks of toxicity and unwanted side effects.

Although anatomical knowledge may be acquired through reviewing textbooks, the fact that sonoanatomy is highly dependant on the system used and on the plane of view makes it particularly important to obtain hands-on imaging experience. Nevertheless, 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 during ultrasound guidance of extremity and trunk blocks. Bony, vascular and /or soft tissue landmarks are often essential to help visually guide the operator to the neural structures. Although more impressive during dynamic viewing, the pulsatile nature of arteries is commonly evident and can be very helpful at many block locations (*e.g.*, supra clavicular and infraclavicular, femoral, and popliteal); alternatively color or power Doppler can be used and will help with future reference to a static image. Bony structures often serve as good reference landmarks for

many block locations, especially when the nerves may not be clearly viewed. For instance, the transverse processes can be used to mark the block site for lumbar plexus block in patients older than infancy where the nerves are not clearly delineated. If there is not a readily identifiable landmark in close vicinity to the nerve at the traditional block location (or the nerve remains to be identified), it may be of great help to first identify the nerve in relation to a prominent landmark at a "satellite" location and thereafter trace the nerve to the block location. Table 1 provides some examples of landmarks commonly used by the authors and others for identifying nerves during many ultrasound-guided peripheral nerve blocks. Of course, there are many variations to the "usual" anatomy, and although not discussed here, this fact greatly supports the use of direct, real-time imaging to view each individual's related anatomy. It is imperative to practice dynamic viewing while obtaining control of the block needle's trajectory and ultimately the deposition of local anesthetic. Although a discussion of the aforementioned technique is beyond this review, there are multiple publications and workshops (presented at various society meetings and other gatherings) describing and providing hands-on experience of particular techniques, which may be of use to the novice or experienced.

The authors only discussed those articles that were either published in English or which contained English abstracts. Of three reviews obtained, which were written in alternate languages,<sup>58-60</sup> one had an English abstract<sup>58</sup> but within this there was no relevant information on technique of ultrasound-guided blockade. One of the reviews may have included some description of technique, which would be of interest,<sup>59</sup> although the other<sup>60</sup> was written by experts in ultrasound guidance who have published several of the articles, which have been described in this review. Another limitation is the inclusion of only those papers specifically pertaining to the pediatric population. This was partly due to the vast expanse of general review articles of ultrasound in regional anesthesia, but mainly because those general reviews which include a section on pediatrics are often written by those experts who have published the studies, which were included in this review.

This review has focused on published descriptions of ultrasound-guidance techniques and study outcomes based on comparisons of ultrasound to conventional nerve localization techniques. There is an increasing amount of literature being published describing ultrasound-guidance techniques for extremity and trunk nerve blocks in children. Although the outcomes documented suggest that there may be benefits, there is insufficient evidence to make such claims based from a few relatively small studies. More studies are needed with particular emphasis on establishing whether superior analgesic efficacy can be achieved with this imaging technology, particularly in relation to specific surgical procedures. However, it is reasonable to postulate that ultrasound, primarily used during the performance of upper extremity and

trunk blocks, may reduce complications such as mechanical nerve injury and arterial, pleural, or peritoneal puncture.

The authors thank Jennifer Pillay, B.Sc. (Research Assistant, Department of Anesthesiology and Pain Medicine, University of Alberta, Edmonton, Alberta, Canada), for her contributions, Jenkin Tsui (Medical Illustrator, Department of Anesthesiology and Pain Medicine, University of Alberta) for his line drawings and assistance with the figures, and Sonosite Inc., Bothell, Washington for its generous equipment support.

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