SPECIAL ARTICLE

Peripheral regional anesthesia in infants and children: an update

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ABSTRACT

Peripheral regional anesthesia in children has had a recent surge in popularity among pediatric anesthesia providers. The increased prevalence is at least in part explained by the proliferation of ultrasonography in the perioperative arena. Ultrasound-guided peripheral nerve block techniques have given pediatric anesthesiologists confidence to approach the diminutive structures that are in close approximation to sensitive areas. The three major categories of pediatric peripheral nerve blocks are upper extremity, truncal, and lower extremity. The indications, ultrasound anatomy, ultrasound-guided technique, and potential complications of the nerve blocks in each category are reviewed.

Key words: Regional anesthesia; Nerve block; Pediatrics; Pediatric peripheral nerve blocks; Ultrasound; Regional anesthesia; Local anesthetic; Upper extremity; Truncal; Lower extremity

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INTRODUCTION

Regional anesthesia is an indispensable component of the practice of pediatric anesthesia. While neuraxial techniques have a robust history in pediatric anesthesia, peripheral regional anesthesia has more recently gained popularity. In the last decade, the utilization of peripheral nerve blockade in children has increased tremendously.[1] This expansion was in part due to the recognition of the need for better modalities of pain management in children as well as the demonstration of the safety of peripheral regional anesthesia in children.[2] The escalation in peripheral nerve blockade was also greatly influenced by the increased availability and advancements of ultrasound technology. The variable neural anatomy and proximity of vascular structures in children make landmark based and nerve stimulator-guided approaches to peripheral nerve blockade more challenging than in adults. Adding to the difficulty in children is the concern for local anesthetic toxicity secondary to a narrow therapeutic window and the potential for iatrogenic injury related to the child's inability to cooperate with the procedure. In contrast to adults, regional anesthesia in children is most often accomplished under general anesthesia, bypassing the potential safety of patient feedback.[3] However, this concern is outweighed by the need to maintain a motionless patient in order to avoid needle displacement and injury. The safety of this method has been demonstrated.[4] When a nerve stimulation technique is planned before incision, non-depolarizing neuromuscular blocking agents must be avoided on induction. Another advantage of ultrasound is that neuromuscular blockade does not hinder performance of the blockade. Additionally, it has been demonstrated that lower doses of local anesthetic agents can be used under ultrasound guidance thereby decreasing the risks of local anesthetic toxicity.[5] Ultrasound also allows for real-time recognition of local anesthetic misdistribution as well as inadvertent systemic injection thereby allowing repositioning of the needle.

With the proliferation of ultrasound guidance, peripheral nerve blockade in children has become more efficacious, faster, and safer. A testament to its rise is the multi-institutional data of pediatric regional anesthesia that is now being collected in the United States through the Pediatric Regional Anesthesia Network (PRAN). Initiated in 2007, this reporting system is providing data on risk, complications and practice methods on a national level.[1] Peripheral regional anesthesia can be divided into three general anatomical categories: upper extremity, lower extremity, and truncal blockade. Each category consists of several nerve blocks at various locations within the respective anatomical region. This review will delineate the anatomy, indications, ultrasound-guided technique, safety tips, and pitfalls attributable to each of the major nerve blocks in these three categories.

UPPER EXTREMITY BLOCKADE

The brachial plexus is comprised of the C5 – T1 nerve roots that supply the majority of the sensory and motor function to the arm below the acromion. As the nerve roots exit the vertebral foramina, they are covered in prevertebral fascia. This fascia transitions into the brachial sheath as the plexus courses distal to the interscalene muscles. The brachial sheath contains fascial septations which may prevent distribution of local anesthetic to all nerves within the sheath using a single injection technique.[6,7] Furthermore, direct nerve stimulation of the brachial plexus through an intact fascial plane has been reported, with resulting local anesthetic maldistribution.[8] These findings highlight the value of visualizing anatomical structures and local anesthetic distribution through the use of ultrasound.

The brachial plexus may be blocked at several sites. As it passes through the interscalene groove, the nerve roots combine and divide at the supraclavicular site to form the nerve trunks and divisions, becoming the cords at the infraclavicular region. At the axilla, the brachial plexus has branched into its terminal nerves. The appropriateness of each block is determined by the location of the surgery, ability to properly position the patient, and assessment of pre-existing patient morbidities. While the axillary site has previously been a preferred location of brachial plexus block in children, the growth of ultrasound availability has allowed practitioners to confidently approach the more proximal brachial plexus even in infants and young children.[9] Regardless of the site of blockade, brachial plexus blockade will not provide anesthesia for the medial aspect of the proximal arm which is innervated separately by the intercostal brachial nerve. The clinical significance of this nerve is apparent when a tourniquet is applied to the proximal arm. A transverse subcutaneous field block just below the axilla will achieve anesthesia in this region.

Interscalene Brachial Plexus Block

Indications: The interscalene brachial plexus block may be used to provide anesthesia and analgesia to the shoulder girdle and arm above the elbow. The nerve roots of C5, C6, and C7 are anesthetized, with cephalad and subcutaneous spread of local anesthetic commonly covering the branches of the superficial cervical plexus (C3 – C4). Blockade of the cervical plexus will provide additional analgesia of the shoulder and supraclavicular area making this approach to the brachial plexus useful for shoulder and even clavicular surgery. Frequently, the C8 nerve root is spared secondary to inadequate caudad spread of the local anesthetic.[10] This results in intact sensation in the ulnar nerve distribution (ulnar side of forearm and the little finger), generally making the interscalene site of brachial plexus blockade inappropriate for surgery below the elbow.

Sonoanatomy: The brachial plexus at the level of the cricoid cartilage lies between the anterior and middle scalene muscles, posterior-laterally to the sternocleidomastoid muscle (SCM). The plexus is represented in the transverse-oblique sonographic view as three or more hypoechoic circles lying adjacent to each other in linear fashion, resembling a “stop light” configuration (Figure 1). These structures typically comprise the C5, C6, and C7 nerve roots. On either side of the plexus are the two hypoechoic interscalene muscles. In some cases, the hypoechoic SCM may overly a portion of the interscalene muscles. In smaller patients, the internal jugular vein and carotid artery may be seen in the same sonograph window as the plexus, displayed anterio-medially as two anechoic circles.

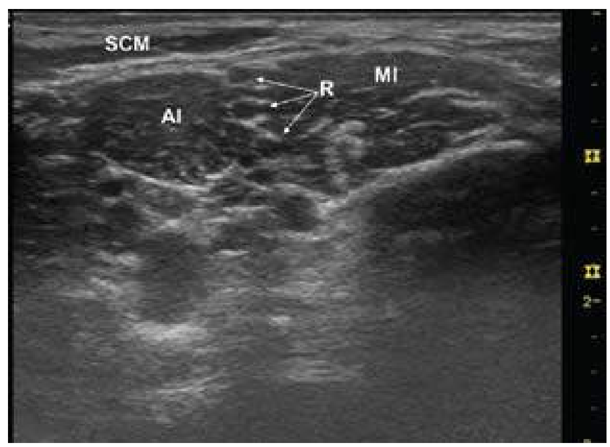

Figure 1: Interscalene brachial plexus block.
AI = anterior interscalene muscle; MI = middle interscalene muscle; N = nerve roots; SCM = sternocleidomastoid muscle.

Technique: The patient is positioned in the supine position with the head turned contralateral to the side of the block. In some instances it may be helpful to elevate the occiput to gain greater distance between the needle insertion site and the bed. A high-frequency (8 – 13 MHz) linear probe is placed in the transverse-oblique orientation over the posterior border of the SCM at the C6 level. A probe with a smaller foot-print (25 mm) may provide better dexterity in smaller patients. If the plexus is not easily identified at this site, the probe may be placed in the supraclavicular fossa and the trunks of the supraclavicular brachial plexus identified. With the probe parallel in orientation to the clavicle, the trunks can then be traced cephalad until the C6 level is reached. Once the interscalene brachial plexus has been identified, a 22 – 24 gauge, 1 – 2 inch needle may be inserted in plane, posterior to the probe, in the anterior-medial direction. With the needle tip juxtaposed to the nerve roots, aspiration is performed followed by injection of the local anesthetic solution until the injectate surrounds the nerve roots. The needle tip may be redirected in relation to the nerve roots to increase circumferential spread. For adults and larger pediatric patients, no more than 10-20 ml of local anesthetic is generally required. Depending on the density of the block desired, bupivicaine concentrations vary from 0.25% to 0.5%. For smaller pediatric patients, the total dose of bupivacaine or ropivacaine should be less than 3 mg/kg. Epinephrine in a concentration of 1:200,000 is added as an additional aid in identifying inadvertent systemic injection. A similar dosing scheme is used for the majority of the blocks discussed in this review.

Safety and adverse effects: In the anesthetized child, direct visualization and palpation of the anatomical landmarks for an interscalene approach may prove difficult. The sensitivity of structures in close proximity to the interscalene brachial plexus make precise needle placement imperative mandating the use of ultrasound in younger patients. The vertebral and carotid arteries carry blood directly to the brain, making even small intravascular injections of the local anesthetic solution capable of inducing seizures and adverse effects on the central nervous system. Epidural or intrathecal injections have been reported leading to unconsciousness and respiratory arrest.[11,12] Injection directly into the nerve roots may also lead to complete spinal anesthesia.[13] Ultrasonography aids localization of the plexus and may help avoid these pitfalls of the interscalene block.[14] In fact, the introduction of ultrasound into clinical practice has markedly increased the use of this approach in our clinical practice. The ipsilateral phrenic nerve and recurrent laryngeal nerve are anesthetized by placement of an interscalene block. In children with contralateral hemidiaphramic paralysis or severe respiratory compromise, this block should be avoided. Infants may develop airway compromise related to unilateral vocal cord paralysis secondary to block of the recurrent laryngeal nerve.[15] The development of ipsilateral Horner's syndrome is typical of this block and is not be interpreted as a complication.[16]

Supraclavicular Brachial Plexus Block

Indications: The supraclavicular brachial plexus block will anesthetize the trunks and divisions of the brachial plexus. A block at this site is appropriate for surgery below the shoulder. Because of its more distal location along the brachial plexus, the supraclavicular block spare the supraclavicular nerve (a branch of the cervical plexus) as opposed to the interscalene block. The supraclavicular nerve supplies the skin overlying the acromion and anesthetizing this area is necessary for shoulder surgery.

Sonoanatomy: With the ultrasound probe in the coronal oblique orientation within the supraclavicular fossa, the trunks of the brachial plexus may be visualized as hyperechoic-rimmed ovoid structures containing heterogeneously sized hypoechoic circles (Figure 2). In some instances, the superior, middle, and inferior trunk can be distinguished from each other. The plexus lies lateral to the subclavian artery, seen as a large anechoic pulsating circle, and cephalad and lateral to the first rib, seen as a hyperechoic arcing line with sonographic signal drop-out underneath. The movement of the parietal pleural may be observed as a "shimmering" effect seen slightly deeper than the 1st rib. The subclavian vein is not frequently seen.

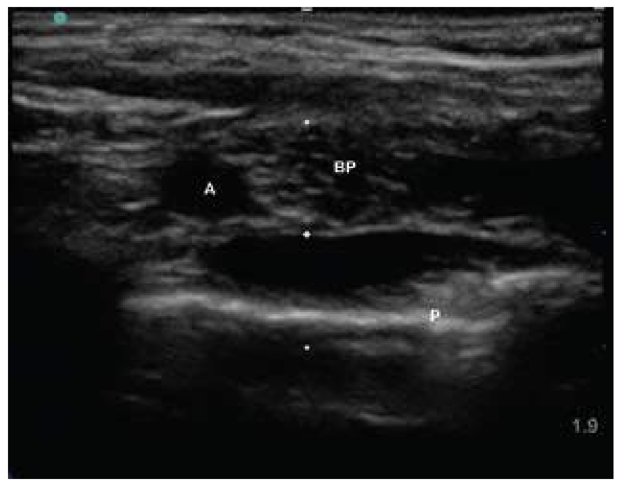

Figure 2: Supraclavicular brachial plexus block.
A = artery; BP = brachial plexus; P = pleura.

Technique: The patient may remain in the supine position with the arm adducted to the body and the head turned slightly to the contralateral side. Raising the back of the bed may help the shoulder fall away from the head and provide greater room for maneuvering the needle in the supraclavicular fossa. The supraclavicular brachial plexus is visualized by placing a high-frequency (8 – 13 MHz) linear probe in the supraclavicular fossa parallel to the clavicle in an orientation that ranges from coronal oblique to transverse oblique. With the trunks and divisions of the brachial plexus and the subclavian artery in view, the needle is passed beneath the probe in plane from lateral to medial toward, but not beyond the first rib. With the needle tip below the plexus, after aspiraton, local anesthetic may be injected to lift the plexus away from the first rib and pleura. Additional increments of local anesthetic may be directed around the perimeter of the trunks to create circumferential spread.

Safety and adverse effects: The proximity of the supraclavicular brachial plexus to the cervical pleura and vascular structures leads to the risk of pneumothorax and intravascular injection. The ability of ultrasonography to continuously visualize the entire needle may decrease the risk of pleural and vascular puncture. The phrenic and recurrent laryngeal nerves are frequently blocked as a consequence of local anesthetic spread. In patients with severe respiratory compromise and infants who are dependent on diaphragmatic function, the absence of function of these nerves may lead to respiratory distress and therefore, the supraclavicular block is best avoided in these populations.[15]

Infraclavicular brachial plexus block

Indications: The infraclavicular brachial plexus block is appropriate for providing surgical anesthesia for procedures below the shoulder, similar to the supraclavicular brachial plexus block. This approach can be used as an alternative to the supraclavicular block when interposing arteries (transverse cervical, dorsal scapular) prevent access to the supraclavicular brachial plexus without risking vascular puncture.[17] Both the infra and supraclavicular approach to the brachial plexus block have the advantage over the axillary block of retaining the arm in neutral position. This may be important in patients where injury or immobilization prevent abduction of the arm.

Sonoanatomy: The axillary artery, inferior to the lateral clavicle, is surrounded by the three cords of the brachial plexus. In the sagittal ultrasonographic view, the subclavian artery is seen in cross-section and the medial, lateral, and posterior cords may be visualized separately as hyperechoic ovoid structures. As their names suggest, the cords will lie medial, lateral, and posterior to the axillary artery in relation to the abducted arm. On ultrasonography, the cords will appear at approximately the 3, 6, and 9 o'clock positions relative to the axillary artery (Figure 3). The cords lie in close proximity to the artery and the posterior cord may be obscured by the acoustic shadow of the artery. The axillary vein is often seen medial to the artery with the medial cord lying between these two vessels. The pectoralis major and minor muscles lie above the plexus and vessels. These two muscles are seen discretely as two horizontal hypoechoic strips with internal striations. The pectoralis major lies superficial to the pectoralis minor. Depending on the set depth of the ultrasound transducer, the pleura may be identified at the deep and medial aspect of the image as a hyperechoic line with hypoechogenicity beyond.

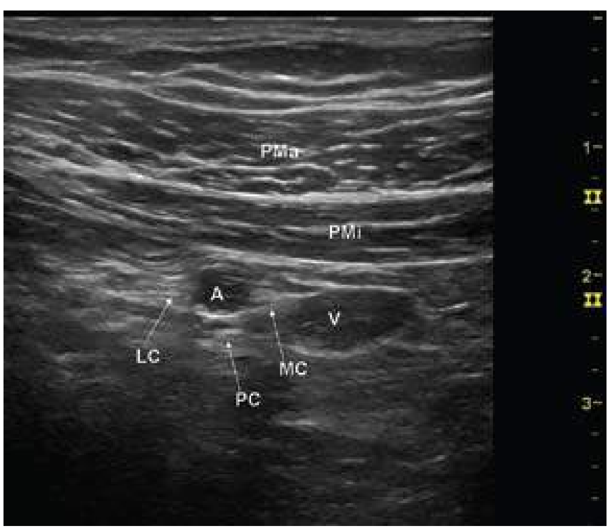

Figure 3: Infraclavicular brachial plexus block.
A = axillary artery; LC = lateral cord; MC = medial cord; PC = posterior cord; PMa = pectoralis major muscle; PMi = pectoralis minor muscle.

Technique: With the patient in the supine position, the arm may remain adducted and rest at the patient's side or be flexed at the elbow with hand resting on the abdomen. In most children, a high-frequency (8 – 13 MHz) linear ultrasound probe is sufficient to visualize all the required structures. The probe is placed in a sagittal orientation just below the clavicle and slightly medial to the coracoid process. The pulsatile anechoic circular cross-section of the subclavian artery is centered in the view. The needle is inserted and may be advanced in plane with the probe in a cephalad to caudad direction toward the cords surrounding the subclavian artery. The plexus may also be approached from the caudad to cephalad direction;, however there may be increased risk of entering the pleura with this technique.[18] The needle is redirected to ensure that local anesthetic is placed adjacent to each cord. It is essential to keep the needle tip in view throughout the block to avoid pleural puncture or intravascular injection of the vessels which lie in close proximity to the nerves. In the event, that one or more of the cords cannot be sufficiently identified, a "horseshoe" shaped depot of local anesthetic may be deposited along the medial, posterior, and lateral aspects of the subclavian artery.

Safety and adverse effects: Similar to the supraclavicular brachial plexus block, the infraclavicular technique has risks of infection, hematoma, nerve injury, pneumothorax, and intravascular injection. The latter may potentially lead to seizure and cardiovascular collapse. The proximity of the medial cord to both the axillary artery and vein make approaching this cord particularly challenging.

Axillary Brachial Plexus Block

Indication: The axillary brachial plexus block can be used to provide reliable anesthesia and analgesia to the arm distal to the shoulder. The axillary nerve is not directly blocked, but may become anesthetized by proximal spread along the radial nerve. For proximal tourniquet pain, an intercostal brachial block is indicated. This can be easily provided by a transverse subcutaneous field block just below the axilla. One of the major disadvantages of the axillary block is the need for abduction of the arm which is not possible in all patients.

Sonoanatomy: Axillary brachial plexus block using ultrasound guidance is usually conducted immediately distal to the axillary fossa where the ultrasound probe may lie on more level tissue. At this site, the axillary artery is superficial and identified as a pulsatile anechoic circle deep to subcutaneous tissue. Lateral to the artery are the hypoechoic bellies of the biceps and coracobrachialis muscles. Posterior and medial to the artery is the triceps muscle. The terminal branches of the brachial plexus, which include the ulnar, radial, medial, and musculocutaneous nerves are represented by small hyperechoic clusters (Figure 4). The terminal braches of the ulnar, radial and medial nerves surround the axillary artery but vary widely in anatomical position. The classic positions in relation to the axillary artery include anteromedial for the medial nerve, anterolateral for the ulnar nerve, and posterior-lateral position for the radial nerve. The musculocutaneous nerve is not immediately adjacent to the axillary artery, but is located laterally between the biceps and coracobrachialis muscle. Proximal-distal movement of the probe above the junctional plane between these two muscles will often give the musculocutaneous nerve a traveling "race car" appearance.

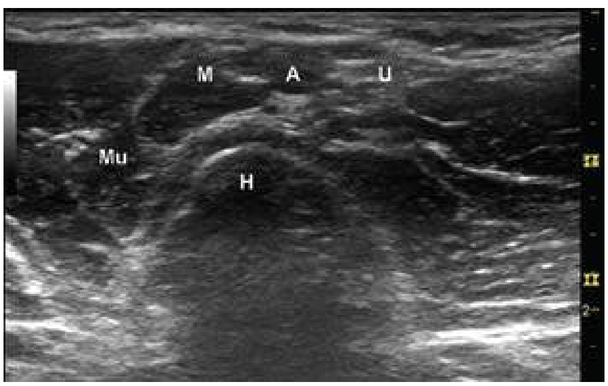

Figure 4: Axillary brachial plexus block.
A = axillary artery; M = median nerve; Mu = musculocutaneous nerve; U = ulnar nerve.

Technique: With the patient supine, the arm is abducted to 90 degrees and flexed at the elbow. A high-frequency (8 – 13 MHz) linear ultrasound probe is positioned transverse to the arm just distal in the axillary fossa. The axillary artery is identified and the surrounding tissue scanned for the four terminal nerves. The musculocutaneous nerve is lateral to the artery and is sometimes unable to be visualized within the same ultrasonographic window as the other branches. The needle can be inserted in-plane from either end of the probe, depending on which direction provides better access to the nerves. A second needle insertion is generally required to reach the musculocutaneous nerve. The needle tip is directed to each nerve in a separate pass of the needle. After negative aspiration, circumferential local anesthetic injection is placed around each terminal branch.

Safety and adverse effects: The risks of axillary brachial plexus block include hematoma, infection, nerve injury, and intravascular local anesthetic injection. The axillary nerve block when performed properly is devoid of significant risk of pneumothorax.

TRUNCAL NERVE BLOCKADE

Truncal nerve blockade provides effective analgesia for a variety of abdominal wall incisions including those associated with herniorraphy and laparoscopy. They are an alternative to caudal epidural anesthesia in children who have neuroaxial abnormalities or stigmata of such pathology (sacral dimple). Truncal nerve blocks are also another option for older children in whom the caudal space may be difficult to access. Tranversus abdominis plain catheters have been reported to be effective adjuncts for postoperative pain management after laparotomy.[19]

The popularity of truncal nerve blocks in pediatrics has been rising as data have shown fewer complications with peripheral nerve blockade versus caudal epidural anesthesia.[20] Although less dramatic in pediatrics than adults, the absence of sympathectomy with truncal nerve blocks versus epidural anesthesia may be desirable in select children.

Transversus Abdominis Plane (TAP) Block

Indications: The TAP block has been used to provide analgesia to the anterior abdominal wall following many different abdominal surgical procedures including appendectomy, cholecystectomy, Cesarean section, and most laparoscopic incisions.[21-23] Unlike central neuraxial techniques, the TAP block does not provide full surgical anesthesia for intra-abdominal manipulation. However, it will decrease both intraoperative and postoperative opioid requirements and may even provide analgesia that is effective enough to eliminate the need for opioids.

Prior publications in regards to infants and children suggests that the TAP block provides effective analgesia following various umbilical and lower abdominal procedures including laparoscopy.[24,25] In comparison to the more commonly used caudal epidural analgesia, the TAP block offers the advantage of being feasible in patients with vertebral anomalies or other anatomical contraindications, and in older pediatric patients, weighing more than 20-25 kg. Current experience from the pediatric literature suggests the use of 0.2-0.3 ml/kg per side of either 0.25% bupivacaine or 0.2% ropivacaine. Where available, ultrasound guidance should be used to improve accuracy and limit the potential for inadvertent damage to intraperitoneal structures. As with any regional anesthetic technique in infants and children, local anesthetic toxicity is a potentially serious adverse event and attention to volume and concentration is imperative with total dose of bupivacaine or ropivacaine not to exceed 3 mg/kg.

Sonoanatomy: Sensory innervation of the anterolateral abdominal wall is provided by the anterior divisions of spinal nerves T_8-L_1. These nerves traverse in a plane between the transversus abdominis and internal oblique muscles (Figure 5). The deposition of local anesthetic in this plane, as first described by McDonnell et al. will lead to interrupted innervation thereby providing regional anesthesia of the abdominal skin, muscles and parietal peritoneum.[26] Ultrasound guidance, with a linear, high-frequency probe is now preferred for TAP block placement.

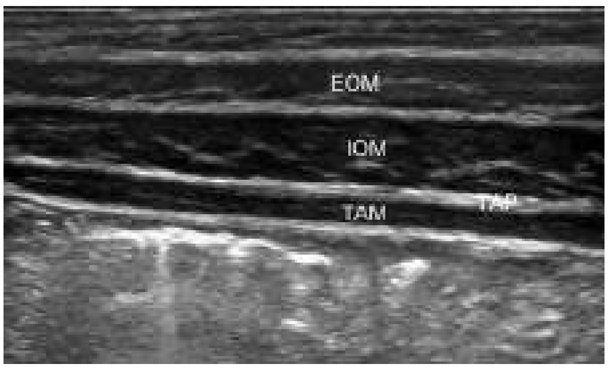

Figure 5: Transversus abdominis plane block.
EOM = external oblique muscle; IOM = internal oblique muscle; TAM- transversus abdominis muscle; TAP- transversus abdominis plane.

Technique: The ultrasound probe is placed in the axial plane in the triangle of Petit just above the iliac crest. A needle is inserted in line with the probe so that the needle can be visualized in the correct fascial plane prior to injection of the local anesthetic solution. Alternatively, the probe can be placed more anteriorly, immediately lateral to the umbilicus so that the rectus sheath can be visualized.[27,28] This approach is advocated in the pediatric population to allow for a more thorough spread of the local anesthetic solution thereby providing more effective analgesia of the anterior abdominal wall. The ultrasound probe is moved laterally to delineate the three layers of the abdominal wall: external oblique (EO), the internal oblique (IO), and transverse abdominis (TA). The probe is stationed lateral on the anterior abdominal wall at a 70-90^o angle with the patient's bed. A needle is inserted utilizing an 'in-plane' technique from the medial aspect of the probe until the tip lies between the internal oblique and the transversus abdominus muscles. Injection, with incremental aspiration, will create an elliptical opening of the potential space in which the nerves traverse.

Safety and adverse effects: Although uncommon especially when using ultrasound guidance, the intra-abdominal structures are in close proximity to the site of needle placement. As such, there is the potential for intravascular injection, peritoneal puncture or injury to the bowel or liver.[29]

Ilioinguinal and Iliohypogastric Nerve Block

Indications: Of the peripheral nerve blocks, ilioinguinal/iliohypogastric (IL/IH) nerve blockade remains one of the most commonly placed blocks in infants and children. The ilioinguinal and iliohypogastric (IL/IH) nerve blockade is used commonly to provide perioperative pain relief for children undergoing inguinal procedures. IL/IH nerve blockade is frequently applicable even in patients in whom neuroaxial analgesia including caudal block may be contraindicated. It has historically proven to be safe and effective with landmark-based administration in the pediatric population.[30-32] Although placement of the IL/IH nerve block was initially accomplished using anatomical surface landmarks, the introduction of the ultrasonography has been shown to improve the accuracy and consistency of the IL/IH nerve block.[33,34]

Sonoanatomy: The ilioinguinal and iliohypogastric nerves originate from T_{12} and L_1 of the thoracolumbar plexus. The nerves traverse the internal oblique aponeurosis 1-3 centimeters medial to the anterior superior iliac spine (ASIS) (Figure 6). Weintraud et al. evaluated 62 children scheduled for inguinal surgery receiving IL/IH nerve block based on standard anatomic landmarks with the "single-pop" technique. Following placement of the block using anatomic surface landmarks, the ultrasound probe was placed to evaluate the actual location of local anesthetic deposition. The local anesthetic was administered correctly around the nerves in only in 14% of the blocks.[34]

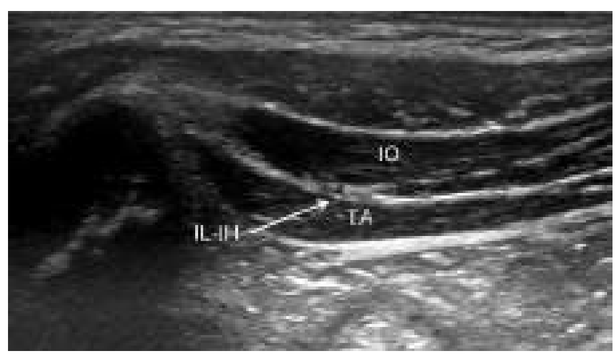

Figure 6: Ilioinguinal and iliohypogstric nerve block.
IO = internal oblique muscle; TA = transversus abdominis muscle; IL-IH = ilioinguinal-iliohypogastric nerves.

Technique: Utilizing the ultrasound-guided technique, a linear ultrasound probe is placed at the ASIS in line with the umbilicus. In approximately half of the cases, only two of the muscle layers can be visualized, the internal oblique and the transversus abdominis. An ovoid structure may be visualized encompassing the neurovascular bundle between these two muscles. The ilioinguinal nerve can often be found close to the iliac crest (4-8 mm) while the iliohypogastric nerve lies more medial, approximately 5-15 mm from the ASIS. The distance from the ASIS or surface to either the IL or IH nerves (depth required for needle insertion) has been shown to vary based on the age of the patient.[35] The needle is inserted in plane with the ultrasound probe from lateral to medial approach with incremental aspiration. It is important to deposit the local anesthetic solution between the internal oblique and transversus abdominis with evidence of layer separation. Many times the IL/IH nerves cannot be directly visualized by ultrasound, but local anesthetic injected between these two muscles will follow the fascial planes and envelope the neurovascular bundles. The volume of local anesthetic solution utilized to anesthetize both nerves ranges from 0.1 to 0.4 ml/kg. More recently, the amount required has been shown to be as little as 0.075 ml/kg when ultrasound is used to ensure accurate placement.[36]

Safety and adverse effects: Bowel puncture and intravascular injection are the most common complications. There have been isolated case reports of pelvic hematoma formation, colonic perforation, and femoral nerve palsy.[37] Complications seem to be increased when using the blind technique as compared with the ultrasound technique.

Rectus Sheath (RS) Block

Indications: The RS block has been used to provide analgesia following procedures including single incision laparoscopic surgery and umbilical herniorrhaphy. The available literature demonstrates the efficacy of the RS block for the provision of analgesia for umbilical hernia repair and other types of peri-umbilical incisions. Anecdotally, RS block has also been used to treat chronic pain of the abdominal wall.[38]

Sonoanatomy: The umbilical region is innervated by the right and left 10th intercostal nerves, which are continuations of the anterior rami of the 10th spinal thoracic nerve root. At the lateral edge of the rectus abdominis muscles, the nerves traverse the rectus sheath, innervate the rectus abdominis muscle, cross the muscle and end as anterior cutaneous branches innervating the periumbilical skin. Two possible anatomic courses of these nerves have been described with the nerves coursing either behind or on top of the rectus abdominis muscle prior to ending in the midline at the umbilical area. The rectus abdominis muscle is a paired muscle on the anterior abdominal wall separated in the midline by the linea alba. In addition to T_{10}, the other thoracolumbar nerves (T_7-T_{11}) traverse the potential space between the rectus abdominis muscle and the posterior sheath just superficial to the peritoneum.

Technique: A linear, high-frequency probe is placed just lateral to the umbilicus. The rectus abdominis muscle is visualized as the first major layer deep to the subcutaneous tissue (Figure 7). The posterior sheath lies just below the rectus abdominis and above the peritoneum. The probe is maintained immediately lateral to the umbilicus. After a needle is placed in-line from the lateral aspect of the probe, the local anesthetic agent is deposited in the potential space between the rectus abdominis muscle and its posterior sheath. The benefit of injecting the local anesthetic at the most lateral edge of the rectus abdominis muscle near the aponeurosis of the transversus abdominis and internal oblique is to ensure blockade of anterior cutaneous branching points. The accuracy of placement of the local anesthetic agent in the correct location can be increased by the use of ultrasound.[39]

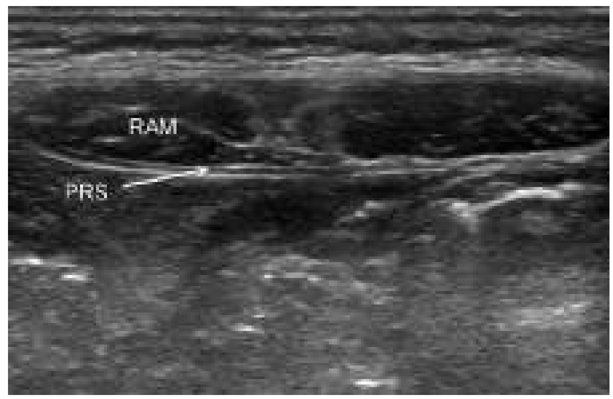

Figure 7: Rectus sheath block.
RAM = rectus abdominis muscle; PRS = posterior rectus sheath

Safety & adverse effects: Bowel puncture is a potential complication as the needle is in close proximity to the peritoneum and bowel when it is deep to the rectus abdominis muscle. Intravascular injection may occur with inadequate negative aspiration prior to local anesthetic injection, as the inferior epigastric artery is also in close proximity to the site of needle placement. Retroperitoneal hematoma formation has also been reported. Given the proximity of the peritoneal structures and the risk of bowel puncture with deep needle insertion, ultrasonography should be used.

LOWER EXTREMITY BLOCKADE

Lower extremity nerve blocks have been used for a wide variety of procedures and surgeries including surgery of the foot and ankle, knee arthroscopy, and hip procedures whether traumatic or congenital.[40-43] Peripheral nerve blocks can be used for intraoperative management of pain, as well as for postoperative analgesia. These techniques can be particularly advantageous in patients diagnosed with muscular or metabolic conditions that could limit the scope of medications given for general anesthesia or who are at increased risk of complications following general anesthesia.[44-47] Previously, caudal epidural anesthesia was widely used for postoperative analgesia following lower extremity procedures, but more recent studies have shown a lower risk of complications with peripheral nerve blockade.[2,20]

Lumbar Plexus Block

Indications: The most common indications for lumbar plexus block are to provide intraoperative and/or postoperative analgesia for hip and femoral procedures such as acetabular or femoral osteotomies. At least one study has demonstrated that continuous lumbar plexus block is comparable to continuous epidural analgesia.[48]

Sonoanatomy: The lumbar plexus includes the roots of L1-L4. The plexus may also include contributions from T12 and L5.[49] The plexus leaves the confines of the psoas muscle, and gives rise to three nerves: femoral, lateral cutaneous and obturator. Important anatomic landmarks for orientation are the spinous processes to identify the midline and the transverse processes to identify the potential block site. Given its depth, a lower frequency probe (5-8 Hz) is required. When imaging in the saggital plane, the spinous processes can be identified in the midline. Moving the probe laterally, the tranverse processes are identifiable as downward arcing hyperechoic lines with sonographic drop-out below. In this view, progressing from superficial to deep, are the erector spinae, quadratus lumborum and the psoas muscle. The lumbar plexus is not generally an identifiable structure using ultrasound, but the plexus is anatomically located at the interface between the quadratus lumborum and psoas muscle fascia. Alternatively, the plexus may lie in the body of the psoas muscle. The posterior border of the psoas muscle is frequently seen as a hyperechoic line deep to the transverse processes. The goal is to advance the needle from superficial to deep relative to, and between, the transverse processes, advancing toward the psoas muscle location.

Technique: The patient is positioned in the lateral decubitus position, with the intended side to be blocked up, and knees flexed. The patient's low back is prepared with sterile technique. The most typical ultrasound probe used is the curvilinear, low frequency type for better visualization of deep structures. The probe should be covered using a sterile sheath, and after adding sterile gel. The probe may be positioned transverse at the level of L3-L4, or L4-L5, visualizing the space between the transverse processes, and identifying the surrounding structures to the psoas muscle: medially vertebral body, quadratus lumborum laterally, and erector spinae (Figure 8).[50,51] Different needles can be used for this technique depending on the size of the patient and the depth of the plexus. For most patients, either a 20 gauge, 6-inch or a 21 gauge, 4-inch, needle can be used. Tuohy needles can be used to place a catheter. The needle

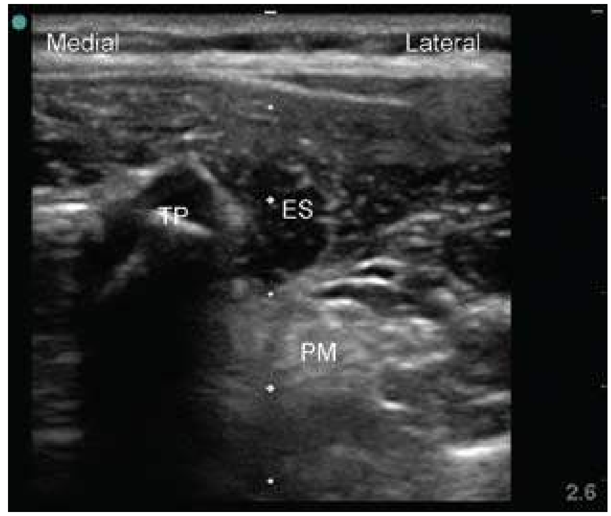

Figure 8: Lumbar plexus block – transverse view.
ES = erector spinae muscle; TP = transverse process; PM = psoas muscle.

is advanced in lateral to medial fashion in plane with the ultrasound probe, and between transverse processes toward the substance of the psoas muscle. In the longitudinal approach, the transverse processes can be identified by positioning the probe parallel to the midline, slightly off-midline, as delineated by identification of the spinous processes. With this position, the quadratus lumborum can be seen laterally, and the psoas muscle can be found deep relative to the transverse processes (Figure 9). The needle is inserted in plane with the probe and advanced between transverse processes toward the psoas muscle as well. As a combined technique, electrostimulation may be used to elicit quadriceps muscle group contraction or a loss of resistance syringe may be used to confirm the needle tip is at the psoas compartment. The volume and concentration

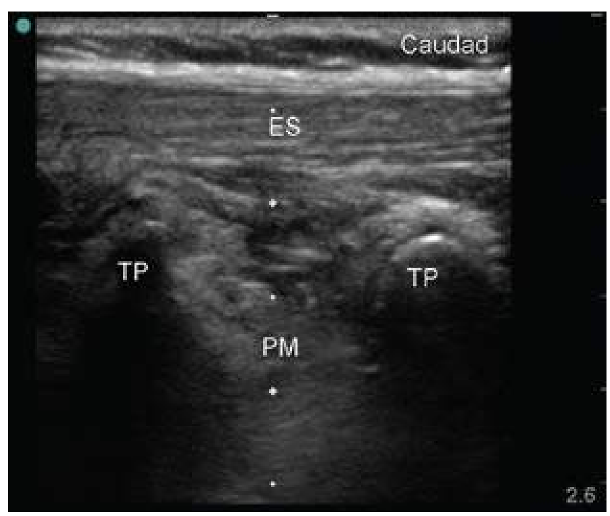

Figure 9: Lumbar plexus block – longitudinal view.
ES = erector spinae muscle; TP = transverse process; PM = psoas muscle.

of local anesthetic used depends on the age, size and desired density or purpose of the block. In most instances, a volume of 0.2-0.4 ml/kg of 0.25% bupivacaine or 0.2% ropivacaine is sufficient. The safety threshold of 3 mg/kg when using either local anesthetic solution should not be exceeded to prevent the risk with local anesthetic toxicity.

Safety and adverse effects: The most commonly reported complications from lumbar plexus block placement are muscular or renal hematomas, retroperitoneal injection, epidural or spinal block, and cardiac arrest from intravascular injection of local anesthetic.[52,53]

Femoral Nerve Blockade: Inguinal Crease Approach

Indications: Common indications for femoral nerve block include procedures involving the anterior and lateral aspects of the thigh. Some of these procedures include femoral osteotomies, knee arthroscopies, anterior-cruciate ligament reconstruction.

Sonoanatomy: The femoral nerve is composed of the fibers of L2-L4. This is one of the nerves arising from the lumbar plexus. Identification of the femoral artery is the cornerstone in anatomical orientation. The nerve will be identified lateral to the artery although it can take on a variety of different shapes (Figure 10).[50,52]

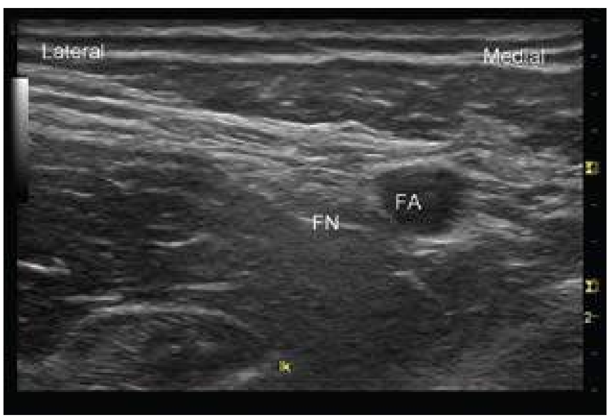

Figure 10: Femoral nerve block.
FA = femoral artery; FN = femoral nerve.

Technique: The skin is prepared into a sterile field. A sterile-covered 8-13 MHz 25 mm linear probe can be used or a larger 35 mm probe for patients weighing more than 30-40 kgs. Ultrasound gel is applied, and the probe is positioned at the inguinal crease on the side of intended block. The probe is placed parallel to the inguinal crease in the transverse position. The femoral artery is identified and the nerve will be seen lateral to this structure. The needle is inserted using a lateral to medial approach, using an in-plane technique. The nerve can be observed to have different shapes and sizes, but its lateral location to the femoral artery will facilitate its identification. Local anesthetic is deposited with the goal of infiltrating the tissue surrounding the nerve in a circumferential fashion. A volume of 0.2-0.4 ml/kg of 0.25% bupivacaine or 0.2% ropivacaine is sufficient for this block. Higher concentrations may be used in older patients when the purpose is to produce a surgical block, keeping in mind the 3 mg/kg total safety dose for either local anesthetic.

Safety and adverse effects: Reported complications are vessel puncture, intravascular injection, hematoma, and intraneural injection.[52]

Lateral Femoral Cutaneous Nerve Block

Indications: This block has been used for treatment of meralgia paresthetica, to ameliorate tourniquet pain, in preparation for skin grafting, and as a complement to femoral nerve block in procedures involving the lateral aspect of the thigh.[55]

Sonoanatomy: The lumbar plexus gives rise to the lateral femoral cutaneous nerve (LFC). It provides sensory innervation to the anterolateral thigh and lateral aspect of the buttocks below the greater trochanter. The nerve can be identified medial to the anterior superior iliac spine (ASIS), lying between the fascia lata and fascia iliaca (Figure 11).

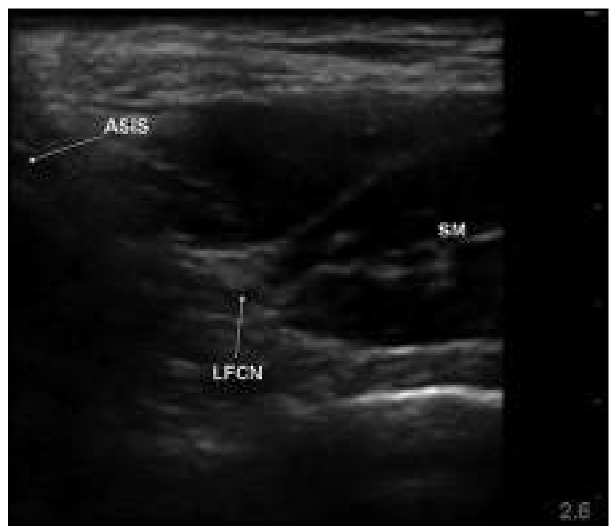

Figure 11: Lateral femoral cutaneous nerve block.
ASIS = anterior superior iliac spine; SM = sartorious muscle; LFCN = lateral femoral cutaneous nerve.

Technique: The femoral nerve and artery can be identified medially at the level of the inguinal ligament. The fascia iliaca may be traced laterally toward the ASIS. The nerve should lie medial to this structure, traveling down to the groin area. The nerve should appear hyperechoic. With an in-plane approach, potentially a femoral block and a LFC block can be performed together. Bupivacaine or ropivacaine can be used for this block. The volume required to produce an adequate block will vary depending on size and weight of the patient, but will require only a few milliliters of solution as this is a relatively small sensory branch.

Safety and adverse effects: Unintended block of the femoral nerve and obturator nerves has been reported using blind technique. Recent reports demonstrate a minimal risk of complications with ultrasound guidance.[54]

Saphenous Nerve Block

Indications: Saphenous nerve block can be used as a supplemental injection to sciatic nerve block to provide blockade of the entire innervation below the knee. Typical indications include foot and ankle procedures, particularly those involving the medial and plantar aspect of the foot.

Sonoanatomy: The key anatomic relationship for this block is identifying the sartorius and gracilis muscle on the medial aspect of the thigh over the mid to distal third of the thigh. Using ultrasound, identifying the geniculate artery can be an important landmark in younger patients as visualization of the nerve can be challenging (Figure 12).[55]

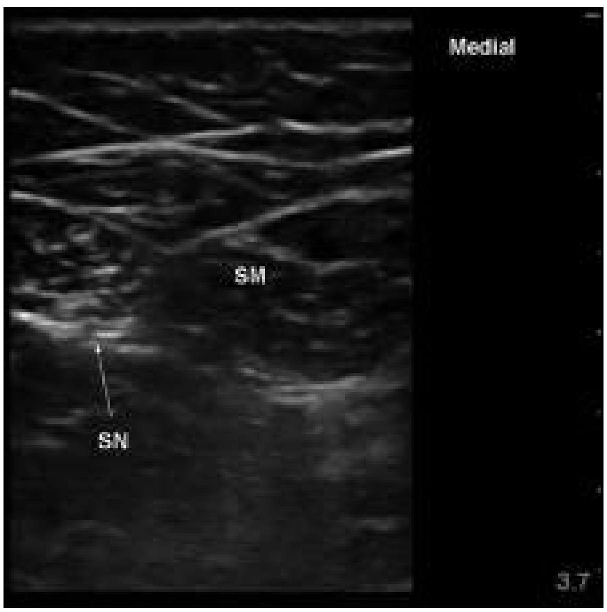

Figure 12: Saphenous nerve block.
SM = sartorious muscle; SN = saphenous nerve.

Technique: Placing a high frequency probe over the medial aspect of the mid to distal one third of the thigh, and with the probe in transverse orientation, the nerve may be identified between the sartorious and gracilis muscles. With the nerve identified, an in-plane approach can be used to deposit local anesthetic. In smaller patients, visualization of the nerve may prove difficult and the local anesthetic is deposited around the geniculate artery. As with LFC block, a clinically adequate block can be obtained with minimal volume using a variety of local anesthetics. When identification of the nerve is challenging, or the previous approach has failed, placement of local anesthetic below the fascia iliaca may be useful. Alternatively, block of the femoral nerve block as described above will provide sensory block in the saphenous nerve distribution for procedures below the knee.

Safety and adverse effects: When using a peri-arterial placement of the local anesthetic solution as described, intravascular injection of local anesthetic with its potential unintended ramifications is possible.[55]

Sciatic Nerve Block- Subgluteal Approach

Indications: The sciatic nerve is a mixed sensory and motor nerve formed by the nerve roots of L4 and L5, S1-3 and variable contributions from S4. This is the longest and largest single nerve in the body. Ultimately it gives rise to the peroneal and tibial nerves. With the exception of the sensory innervation to the medial aspect of the leg and foot, the sciatic nerve provides sensory and motor innervation to the rest of the leg and foot, and the posterior aspect of the thigh. Ultrasound-guided nerve block can be achieved using different approaches, which will be described individually. The subgluteal approach block is useful for procedures involving the leg and foot, but could require supplementation with distal femoral block, depending on the specific location of the procedure. Placing local anesthetic in this location can contribute to the relief of tourniquet pain as well.

Sonoanatomy: The subgluteal approach to the sciatic nerve is the most proximal view. This was also the first ultrasound-based nerve block described in children.[52] With this technique the nerve is both larger, and more hyperechoic, than more distal views (Figure 13). The anatomic landmarks used to obtain view of the nerve are the ischial tuberosity and greater trochanter of the femur. In general, the nerve lies mid-line between these structures

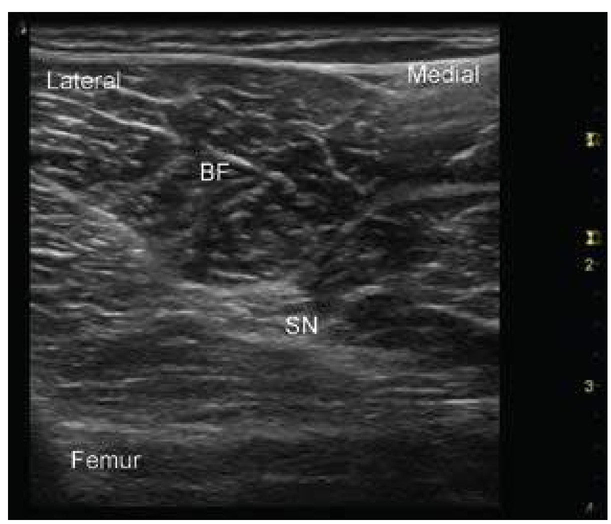

Figure 13: Sciatic nerve block – subgluteal approach.
BF = biceps femoris muscle; SN = sciatic nerve; F = femur.

Technique: The patient may be positioned supine, lateral or prone. For younger patients a rectilinear probe may be used, but for larger patients a curvilinear probe, lower frequency probe may be more appropriate for visualization of nerve. With the probe placed in the transverse position and after sterile skin preparation, the nerve can be found in the area between the greater trochanter and ischial tuberosity. The nerve can be blocked at this site, and or it can be traced more distally. The needle can be placed between the vastus lateralis and biceps femoris, and advanced using an in-plane approach to deposit local anesthetic around the nerve. The nerve can be better visualized by flexing and extending the knee during ultrasound scan, and observing the nerve change shapes with motion of the knee. The out of plane approach has also been used successfully.

Safety and adverse effects: Potential complications with this approach are intraneural injection, and intravascular injection is also possible. At least one study has demonstrated the placement of continuous peripheral nerve block catheter using this technique with minimal risks of complication.[54]

Popliteal Approach to the Sciatic Nerve

Indications: This approach is specifically indicated for procedures of the lower aspect of the leg, foot and ankle.

Sonoanatomy: Identification of the popliteal artery and vein are important steps toward distinguishing the tibial and popliteal nerves sonographically. By identifiying both nerves, and tracing their course cephalad, one can determine the site of sciatic nerve split in its most distal location (Figure 14).

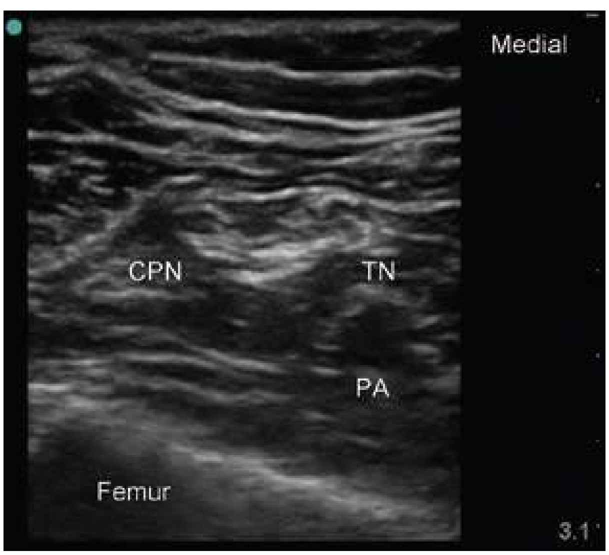

Figure 14: Sciatic nerve block – popliteal approach.
CPN = common peroneal nerve; TN = tibial nerve; PA = popliteal artery.

Technique: After sterile skin preparation, the ultrasound probe is placed in a transverse position at the level of the popliteal fossa in the crease of the knee. Medially, the popliteal artery and vein may be identified a few centimeters cephalad to the crease of the knee. The tibial nerve is usually found in close proximity to those vessels. The peroneal nerve will be found lateral to the tibial nerve. By sliding the probe even more cephalad, the tibial and peroneal nerves can be seen joining together to form the sciatic nerve. At this point, the needle can be inserted into the lateral thigh in plane with the ultrasound probe and advanced medially to inject local anesthetic solution around the sciatic nerve.

Safety and adverse effects: Intravascular injection is the greatest risk undertaken with this approach as both the popliteal artery and vein are near the nerves of interest.

CONCLUSION

The primary benefit of regional anesthesia is its ability to provide powerful analgesia with minimal risk and few adverse effects. It provides an effective solution to our heavy reliance on opioids for postoperative pain relief. This holds as true in children as in adults. Despite this fact, the escalation of the use of peripheral nerve blocks in children has trailed behind that of adults. However, in recent years, the use of peripheral regional anesthesia has gained substantial ground in pediatric perioperative care.[56] This is in no doubt largely due to the increased availability and portability of ultrasonography, which has given practitioners confidence to approach the diminutive structures of children and use smaller doses of local anesthetic. Furthermore, there has been the development of appropriately sized needles for these techniques in infants and children.

The large proportion of ambulatory surgeries in children has resulted in increased use of nerve block catheters with ambulatory local anesthetic pumps.[57,58] These pumps require a substantial investment in time and staff to follow them on an outpatient basis.[59] Future trends in pediatric regional anesthesia may include the more frequent use of efficacious local anesthetic adjuvants, such as dexamethasone, to prolong the duration of analgesia.[60] Liposomal bupivicaine, newly approved in the United States for wound infiltration in adults, may eventually become a mainstay for providing long-term regional analgesia without the need for catheters. As ultrasound technology has progressed we are seeing greater levels of anatomic detail than ever before. The refinement of 3 and 4 dimensional ultrasonography will likely remove some of its limitations and make it affordable enough to become an important tool in the armamentarium of the pediatric regional anesthesiologists.

REFERENCES

1. Polaner DM, Taenzer AH, Walker BJ, Bosenberg A, Krane EJ, Suresh S, et al. Pediatric Regional Anesthesia Network (PRAN): A multi-institutional study of the use and incidence of pediatric regional anesthesia. Anesth Analg 2012;115:1353-64. [PubMed]
2. Eccoffey C, Lacroix F, Gainfre E, Orliaquet G, Courreges P, Association des Anesthesistes Reanimatueurs Pediatriques d'Expression Francaise (ADARPEF). Epidemiology and Morbidity of regional anesthesia in children: a follow up one year prospective survey of the French-Language Society of Paediatric Anesthesiologists (ADARPEF). Pediatr Anesth 2010;20:1061-1069. [PubMed]
3. Bromage PR, Benumof JL. Paraplegia following intracord injection during attempted epidural anesthesia under general anesthesia. Reg Anesth Pain Med 1998;23:104-7. [PubMed]
4. Krane EJ, Dalens BJ, Murat I, Murrell D. The safety of epidurals placed during general anesthesia. Reg Anesth Pain Med 1998;23:433-8. [PubMed]
5. Casati A, Baciarello M, Di Cianni S, Danelli G, De Marco G, Leone S, et al. Effects of ultrasound guidance on the minimum effective anaesthetic volume required to block the femoral nerve. Br J Anaesth 2007;98:823-7. [PubMed] [Free Full Text]
6. Partridge BL, Katz J, Benirschke K. Functional anatomy of the brachial plexus sheath: implications for anesthesia. Anesthesiology 66;1987:743-7. [PubMed]
7. Clendenen SR, Riutort K, Ladlie BL, Robards C, Fanco CD, Greengrass RA. Real-time three-dimensional ultrasound-assisted axillary plexus block defines soft tissue planes. Anesth Analg 108;2009:1347-50. [PubMed]
8. Veneziano GC, Rao VK, Orebaugh SL. Recognition of local anesthetic maldistribution in axillary brachial plexus block guided by ultrasound and nerve stimulation. J Clin Anesth 2102;24:141-4. [PubMed]
9. Marhofer P, Harrop-Griffiths W, Kettner SC, Kirchmair L. Fifteen years of ultrasound guidance in regional anaesthesia: Part 1. Br J Anaesth 2010;104:538-46. [PubMed] [Free Full Text]
10. Vester-Andersen T, Christiansen C, Hansen A, Hansen A, Sorensen M, Meisler C. Interscalene brachial plexus block: area of analgesia, complications, and blood concentrations of local anesthetics. Acta Anaesthesiol Scand 1981;25:81-4. [PubMed]
11. Tetzlaff JE, Yoon HJ, Dilger J, Brems J. Subdural anesthesia as a complication of an interscalene brachial plexus block. Case report. Reg Anesth. 1994;19:357-9. [PubMed]
12. Yanovski B, Gaitini L, Volodarski D, Ben-David B. Catastrophic complication of an interscalene catheter for continuous peripheral nerve block analgesia. Anaesthesia. 2012;67:1166-9. [PubMed]
13. Passannante AN. Spinal anesthesia and permanent neurologic injury after interscalene block. Anesth Analg 1996;82:873-4. [PubMed]
14. Hadzic A, Sala-Blanch X, Xu D. Ultrasound guidance may reduce but not eliminate complications of peripheral nerve blocks. Anesthesiology 2008;108:557-8. [PubMed] [Free Full Text]
15. Kempen PM, O'Donnell J, Lawler R, Mantha V. Acute respiratory insufficiency during interscalene plexus block. Anesth Analg 2000;90:1415-6. [PubMed]
16. Urmey WF, Talts KH, Sharrock NE. One hundred percent incidence of hemidiaphragmatic paresis associated with interscalene brachial plexus anesthesia as diagnosed by ultrasonography. Anesth Analg 1991;72:498-503. [PubMed]
17. Murata H, Sakai A, Hadzic A, Sumikawa K. The presence of transverse cervical and dorsal scapular arteries at three ultrasound probe positions commonly used in supraclavicular brachial plexus blockade. Anesth Analg 2012;115:470-3. [PubMed]
18. Grefer M, Retzl G, Niel P, Kamolz, Marhofer P, Kapral. Ultrasonographic assessment of topographic anatomy in volunteers suggests a modification of the infraclavicular vertical brachial plexus block. Br J Anaesth 2002;88:632-6. [PubMed] [Free Full Text]
19. Visoiu M, Boretsky KR, Goyal G, Cladis FP, Cassara A. Postoperative analgesia via transversus abdominis plane (TAP) catheter for small weight children-our initial experience. Paediatr Anaesth. 2012;22:281-4. [PubMed]
20. Giaufre E, Dalens B, Gombert A. Epidemiology and morbidity of regional anesthesia in children: a one-year prospective survey of the French-language society of pediatric anesthesiologists. Anesth Analg 1996;83:904-12. [PubMed]
21. Shin HJ, Oh AY, Baik JS, Kim JH, Han SH, Hwang JW. Ultrasound-guided oblique subcostal transversus abdominis plane block for analgesia after laparoscopic cholecystectomy: a randomized, controlled, observer-blinded study. Minerva Anestesiol. 2014;80:185-93. [PubMed]
22. Niraj G, Searle A, Mathews M, Misra V, Baban M, Kiani S, Wong M. Analgesic efficacy of ultrasound-guided transversus abdominis plane block in patients undergoing open appendicectomy. Br J Anaesth. 2009 Oct;103(4):601-5. doi: 10.1093/bja/aep175. [PubMed] [Free Full Text]
23. Tan TT, Teoh WH, Woo DC, Ocampo CE, Shah MK, Sia AT. A randomised trial of the analgesic efficacy of ultrasound-guided transversus abdominis plane block after caesarean delivery under general anaesthesia. Eur J Anaesthesiol. 2012;29:88-94. [PubMed]
24. Sahin L, Sahin M, Gul R, Saricicek V, et al. Ultrasound-guided transversus abdominis plane block in children: a randomised comparison with wound infiltration. Eur J Anaesthesiol. 2013;30:409-14. [PubMed]
25. Carney J, Finnerty O, Rauf J, Curley G, McDonnell JG, Laffey JG. Ipsilateral transversus abdominis plane block provides effective analgesia after appendectomy in children: a randomized controlled trial. Anesth Analg. 2010;111:998–1003. [PubMed]
26. McDonnell JG, O'Donnell B, Curley G, Heffernan A, Power C, Laffey JG.. The analgesic efficacy of transversus abdominis plane block after abdominal surgery: a prospective randomized controlled trial. Anesth Analg. 2007;104:193-7. [PubMed]
27. Suresh S, Chan VW. Ultrasound guided transversus abdominis plane block in infants, children and adolescents: a simple procedural guidance for their performance. Paediatr Anaesth. 2009;19:296-9. [PubMed]
28. Pak T, Mickelson J, Yerkes E, Suresh S. Transverse abdominis plane block: a new approach to the management of secondary hyperalgesia following major abdominal surgery. Paediatr Anaesth 2009;19:54-6. [PubMed]
29. Farooq M, Carey M. A case of liver trauma with a blunt regional anesthesia needle while performing transverses abdominis plane block. Reg Anesth Pain Med 2008;33:274-5. [PubMed]
30. Trotter C, Martin P, Youngson G, Johnson G. A comparison between ilioinguinal-iliohypogastric nerve block performed by anaesthetist or surgeon for postoperative analgesia following groin surgery in children. Paediatr Anaesth 1995;5:363-7. [PubMed]
31. Epstein RH, Larijani GE, Wolfson PJ. Plasma bupivacaine concentrations following ilioinguinal-iliohypogastric nerve blockade in children. Anesthesiology 1988;69:773-6. [PubMed] [Free Full Text]
32. Gunter JB, Gregg T, Varughese AM, Wittkugel EP, Berlin RE, Ness DA, Overbeck DE. Levobuivicaine for ilioinguinal/iliohypogastric nerve block in children. Anesth Analg 1999;89:647-9. [PubMed]
33. Willschke H, Marhofer P, Bosenberg A, Johnston S, Wanzel O, Cox SG, et al. Ultrasonography for ilioinguinal/iliohypogastric nerve blocks in children. Br J Anaesth 2005;95:226-30. [PubMed] [Free Full Text]
34. Weintraud M, Marhofer P, Bosenberg A, Kapral S, Willschke H, Felfernig M, et al. Ilioinguinal/Iliohypogastric blocks in children: where do we administer the local anesthetic without direct visualization? Anesth Analg 2008;106:89-93. [PubMed]
35. Hong JY, Kim WO, Koo BN, Kim YA, Jo YY, Kil HK. The relative position of ilioinguinal and iliohypogastric nerves in different age groups of pediatric patients. Acta Anaesthesiol Scand 2010;54:566-70. [PubMed]
36. Willschke H, Bösenberg A, Marhofer P, Johnston S, Kettner S, Eichenberger U, et al. Ultrasonographic-guided ilioinguinal/iliohypogastric nerve blocks in pediatric anesthesia: What is the optimal volume? Br J Anaesth 2005;95:226-30. [Journal Abstract] [Free Full Text]
37. Johr M, Sossai R. Colonic puncture during ilioinguinal nerve block in a child. Anesth Analg 1999;88:1051-2. [PubMed]

38. Skinner AV, Lauder GR. Rectus sheath block: successful use in the chronic pain management of pediatric abdominal wall pain. Paediatr Anaesth 2007;17:1203-11. [PubMed]
39. Dolan J, Lucie P, Geary T, Smith M, Kenny GN. Accuracy of local anesthetic placement by trainee anesthesiologists using loss of resistance or ultrasound guidance. Reg Anesth Pain Med 2009;34:247-250. [PubMed]
40. Tobias JD, Mencio GA. Regional anesthesia for club foot surgery in children. Amer J Ther 1998;5:273-7. [PubMed]
41. Manion SC, Tobias JD. Lumbar plexus blockade in children. Amer J Pain Manage 2005;15:120-6.
42. Johnson CM. Continuous femoral nerve blockade for analgesia in children with femoral fractures. Can J Anaesth 1994;22:281-3. [PubMed]
43. Tobias JD. Continuous femoral nerve block to provide analgesia following femur fractures in Paediatric ICU population. Anaesth Intensive Care 1994;22:616-8. [PubMed]
44. Gielen M, Viering W. 3-in-1 lumbar plexus block for muscle biopsy in malignant hyperthermia patients. Amide anaesthetics may be used safely. Acta Anaesthesiol Scand 1986;30:581-3. [PubMed]
45. Maccani RM, Wedel DJ, Melton A, et al. Femoral and lateral femoral cutaneous nerve block for muscle biopsies in children. Paeditr Anaesth 1995;5:223-7. [PubMed]
46. Ion T, Cook-Sather SD, Finkel RS, et al. Fascia iliaca block for an infant with arthrogryposis multiplex congenital undergoing muscle biopsy. Anesth Analg 2005;100:82-4. [PubMed]
47. Vincent CR, Turchiano J, Tobias JD. Fascia iliaca block for a muscle biopsy in an infant with undiagnosed hypotonia. Saudi J Anesth 2008;2:22-4.
48. Dadure C, Bringuier S, Mathieu O, et al. Continuous epidural block versus continuous psoas compartment block for postoperative analgesia after major hip or femoral surgery in children: a prospective comparative randomized study. Ann Fr Anesth Reanim 2010;29:610-5. [PubMed]
49. Tsui B, Suresh S. 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. Anesthesiology 2010;112:473-92. [PubMed] [Free Full Text]
50. Ganesh A, Gurnaney H. Ultrasound guidance for pediatric peripheral nerve blockade. Anesthesiol Clin 2009;27:197-212. [PubMed]
51. Capdevila X, Macaire P, Dadure C, et al. Continuous compartment block for postoperative analgesia afer total hip arthroplasty new landmarks, technical guidelines and clinical evaluation. Anesth Analg 2002;94:1606-16. [PubMed]
52. Flack S, Anderson C. Ultrasound guided lower extremity blocks. Pediatr Anesth 2012;22:72-80. [PubMed]
53. Hurdle M, Weingarten T, Crisostomo R, Psimos C, Smith J. Ultrasound-guided blockade of the lateral femoral cutaneous nerve: technical description and review of 10 cases. Arch Phys Med Rehabil. 2007;88:1362-4. [PubMed]
54. Van Geffen G, Gielen M. Ultrasound-guided subgluteal sciatic nerve blocks with stimulating cathters in children: a descriptive study. Anesth Analg. 2006 Aug;103:328-33. [PubMed]
55. Horn JL, Pitsch T, Salinas F, Benninger B. Anatomic basis to the ultrasound-guided approach for saphenous nerve blockade. Reg Anesth Pain Med. 2009;34:486-9. [PubMed]
56. Kuo C, Edwards A, Mazumdar M, et al. Regional anesthesia for children undergoing orthopedic ambulatory surgeries in the United States, 1996-2006. HSS J. 2012;8:133-6. [PubMed] [Free Full Text]
57. Ganesh A, Cucchiaro G. Multiple simultaneous perineural infusion for postoperative analgesia in adolescents in an outpatient setting. Br J Anaesth 2007;98:687-9. [PubMed] [Free Full Text]
58. Ganesh A, Rose JB, Wells L, Ganley T, Gurnaney H, Maxwell LG, et al. Continuous peripheral nerve blockade for inpatient and outpatient postoperative analgesia in children. Anesth Analg 2007;105:1234-42. [PubMed]
59. LeRiger M, Bhalla T, Martin D, et al. Comparison of flow rate accuracy and consistency between on-Q, baxter, ambu pain infusion devices. WJA 2014;3:119-23
60. Choi S, Rodseth R, McCartney CJ. Effects of dexamethasone as a local anaesthetic adjuvant for brachial plexus block: a systematic review and meta-analysis of randomized trials. Br J Anaesth 2014;112:427-39. [PubMed] [Free Full Text]

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