Applications of regional anaesthesia in paediatrics

R. D. Shah and S. Suresh*

Department of Pediatric Anesthesiology, Ann & Robert H. Lurie Children’s Hospital, Feinberg School of Medicine, Northwestern University, Chicago, IL 60611, USA
* Corresponding author. E-mail: ssuresh@luriechildrens.org; ssuresh@northwestern.edu

Editor’s key points

- Regional anaesthetic techniques are increasingly used for both acute and chronic pain management in children.
- Advantages in ultrasound guidance and tailored dosing regimens have facilitated their widespread use in paediatrics.
- Evidence supports the safety and efficiency of a number of regional anaesthetic techniques and drug combinations.

Summary. Advances in the field of paediatric regional anaesthesia have specific applications to both acute and chronic pain management. This review summarizes data regarding the safety of paediatric regional anaesthetic techniques. Current guidelines are provided for performing paediatric regional techniques, with a focus on applications for postoperative pain management. Brief descriptions of relevant anatomy followed by indications for commonly performed blocks are highlighted along with the potential of adverse side-effects.

Keywords: caudal analgesia; complications; paediatric anaesthesia, peripheral; regional anaesthesia

Increased use of regional anaesthesia in infants, children, and adolescents has significantly improved the scope of paediatric pain management. Regional anaesthesia is generally accepted as an integral component of postoperative pain relief in paediatric patients.1 Several regional anaesthetic techniques are also playing emerging roles in managing chronic paediatric pain syndromes. Performance of regional anaesthesia can be safely and effectively applied to paediatric patients, and these techniques are becoming increasingly popular.2 3

Regional anaesthetic techniques are commonly performed in paediatric patients4; large prospective databases and expert opinion have demonstrated the ability to safely perform regional anaesthesia in children with minimal risk of neurological damage.5 The use of ultrasound guidance and its incorporation into the practice of regional anaesthesia has dramatically improved routine paediatric perioperative care.

Safety of regional anaesthesia in children

Most regional anaesthetic techniques in adults are performed awake or with mild sedation, allowing patients to report paresthesias or pain during block placement, symptoms of local anaesthetic systemic toxicity (LAST), and progression of sensory or motor block after injection.6 Although several authors have criticized the practice of performing major neuraxial or peripheral nerve blocks in adults under deep sedation or general anaesthesia, this is commonly utilized in infants and children to facilitate patient cooperation while performing the block.7

In contrast to adult practice, the majority of regional anaesthesia in children and infants is performed under either deep sedation or general anaesthesia. Prospective and retrospective safety studies support the notion that performing regional anaesthesia under general anaesthesia is safe practice.5 8 9

The Pediatric Regional Anesthesia Network (PRAN), a multicentre collaborative effort, has facilitated the collection of detailed prospective data for research and quality improvement. Polaner and colleagues10 recently reported on the first 3 yr of data registry, giving an overall favourable impression of the safety of modern paediatric regional anaesthesia practice (Table 1).

Pharmacology and toxicity of local anaesthetics in infants and children

Safe dosing guidelines and age-related trends in local anaesthetic pharmacokinetics and pharmacodynamics have been characterized and have facilitated expansion of paediatric regional anaesthesia practice. 11 12 Neurologic or cardiac toxicity related to excessive local anaesthetic blood concentration is more likely to occur in infants than in adults because of low protein binding and decreased intrinsic clearance.13

Resuscitation measures must be initiated immediately after LAST. Neurotoxicity (seizures) can be treated with barbiturates, benzodiazepines or propofol. Recent evidence indicates that the most successful treatment for LAST-related cardiotoxicity is the administration of a lipid emulsion, which is now considered first-line therapy.14 An emerging number of case reports demonstrate that rapid bolus injections of lipid emulsion reverse the toxic effects of local anaesthetics in paediatric patients.15 Safe dosing limits for lipid resuscitation are important to establish in neonates and children because complications from lipid overload have been reported in neonates receiving i.v. nutritional support.16 The recommended dose of 20% Intralipid6 for paediatric patients is 2–5 ml kg−1. This dose is repeated (up to 10 ml kg−1) if cardiac function does not return (Table 2).17 Although the exact mechanism of lipid

© The Author [2013]. Published by Oxford University Press on behalf of the British Journal of Anaesthesia. All rights reserved. For Permissions, please email: journals.permissions@oup.com
Table 1  Summary of Single-injection blocks and adverse event rates for all centres. Total adverse event rates reported in parentheses. Rates <1% reported as decimals and >1% rounded to nearest whole number. Note that in the neuraxial category and the lower extremity category, the total number of complications are fewer than the cumulative sums of the individual types. This is because there were 3 cases in which 2 blocks were done in a single patient, 1 successful block after a complication in the other, and because of ambiguity in the data entry, it was impossible to determine which block was placed first. To assign the most conservative complication rate to the specific block category, the complication was counted against both blocks, but the total number of complications in that general block type is accurate. See text for more details. There were no serious complications or sequelae reported in any single-injection group. TAP, transversus abdominis plane. Table reproduced from Polaner and colleagues10 with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health (©2012)

<table>
<thead>
<tr>
<th>Group</th>
<th>Total procedures</th>
<th>Total adverse events (%)</th>
<th>No sequelae</th>
<th>No sequelae—change in treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neuraxial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caudal</td>
<td>6011</td>
<td>172 (3)</td>
<td>60</td>
<td>112</td>
</tr>
<tr>
<td>Lumbar</td>
<td>103</td>
<td>5 (5)</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Thoracic</td>
<td>13</td>
<td>2 (15)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Subarachnoid</td>
<td>83</td>
<td>5 (6)</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Total neuraxial</td>
<td>6210</td>
<td>183 (3)</td>
<td>64</td>
<td>119</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interscalene</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supraclavicular</td>
<td>164</td>
<td>6 (4)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Infraclavicular</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Axillary</td>
<td>99</td>
<td>2 (2)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elbow</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wrist</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>58</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>455</td>
<td>8 (2)</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Lower Extremity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar plexus</td>
<td>78</td>
<td>6 (8)</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Fascia iliaca</td>
<td>221</td>
<td>1 (0.5)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Femoral</td>
<td>872</td>
<td>6 (0.7)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sciatic</td>
<td>413</td>
<td>14 (3)</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Popliteal fossa</td>
<td>319</td>
<td>2 (0.6)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Saphenous</td>
<td>78</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>325</td>
<td>5 (2)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>2307</td>
<td>33 (1)</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Head and neck</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supraorbital/supratrochlear</td>
<td>58</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Infraorbital</td>
<td>139</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Greater auricular/superficial cervical</td>
<td>157</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Occipital</td>
<td>101</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Greater palatine</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>89</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>556</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other block type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercostal</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ilioinguinal/iliohypogastric</td>
<td>737</td>
<td>3 (0.4)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Rectus sheath</td>
<td>294</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Paravertebral</td>
<td>14</td>
<td>1 (7)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Penile</td>
<td>230</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TAP</td>
<td>140</td>
<td>1 (0.7)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>395</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1849</td>
<td>5 (0.3)</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
emulsion therapy is unknown, when administered rapidly after the diagnosis of LAST, lipid resuscitation can be a life-saving measure in paediatric patients, as has been reported to the LipidRescue registry (www.lipidrescue.org).

**Regional anaesthesia for paediatric acute pain management**

A substantial body of literature supports the safety and efficacy of performing regional anaesthetic techniques in children. Evidence-based literature shows that combined regional and general anaesthesia can decrease hospital stay and improve outcomes in paediatric patients. Despite some controversy regarding the performance of regional anaesthesia in sedated children, there is consensus among paediatric anaesthesiologists regarding the importance and feasibility of safely providing regional anaesthetic techniques under general anaesthesia.

**Central neuraxial techniques**

**Caudal analgesia**

Caudal block is one of the most commonly used paediatric regional anaesthetic techniques for postoperative analgesia. Caudal block is performed in children undergoing surgery of the lumbosacral to midthoracic dermatomal levels with anticipated moderate-to-severe postoperative pain. Its popularity originates in part from easily palpable landmarks and relative ease of placement. A styletted needle with a blunt tip is passed through the sacrococcygeal ligament into the caudal space. A distinct ‘pop’ is felt when the caudal block space is entered. Nerve stimulation and ultrasonography have been described as tools to assist in caudal placement. Commonly used local anaesthetics include bupivacaine (0.125–0.25%) or ropivacaine (0.1–0.375%) with 1:200 000 epinephrine at a dose of 1–1.5 ml kg⁻¹ (maximum dosage 30 ml).

**Continuous neuraxial catheters**

Continuous epidural analgesia is commonly used to manage post-surgical pain in infants and children. Epidural catheters can be placed in the thoracic, lumbar, or caudal regions. It is also possible to insert a caudal catheter and thread it cephalad to the desired dermatomal level. Bupivacaine and ropivacaine are frequently used local anaesthetic solutions. Common additives include opioids and ß₂-agonists, including fentanyl, morphine, hydromorphone, and clonidine. It is imperative that standardized dosing parameters for a single injection, and for continuous infusion, be used in neonates, infants, and children to avoid LAST. Suggested paediatric dosing regimens are listed in Table 3.

**Peripheral nerve block**

Peripheral and truncal nerve blocks are playing an emerging role in paediatric postoperative pain management. Several peripheral blocks have also been described as effective in achieving analgesia in paediatric trauma. These techniques are typically performed under general anaesthesia and are often performed utilizing ultrasound guidance. Head and neck, transversus abdominis plane (TAP), rectus sheath, ilioinguinal/iliohypogastric (II/IH), and upper and lower extremity blocks are commonly performed. Common dosing guidelines have been included as a reference point for practitioners (Table 4).

Peripheral nerve blocks are also increasingly utilized in paediatric chronic pain management to facilitate physical therapy while providing sympathectomy; such interventional approaches have become more plausible with the use of ultrasound-guidance. Serial peripheral nerve blocks can be performed to treat chronic neuropathic pain in children. In such circumstances, the pain relief often outlasts the duration of conduction block, which might be attributable to reduced central sensitization, and interruption of the circuit established between nociceptor, central nervous system, and motor unit. Concomitant corticosteroid administration can contribute to this effect via anti-inflammatory action and suppression of ectopic neuronal discharge. We have noted that the majority of patients with neuropathic pain who undergo serial peripheral nerve blocks experience pain relief that increases in duration after each block.

---

**Table 2** Treatment of LAST

<table>
<thead>
<tr>
<th>Dosing guidelines for lipid resuscitation of paediatric local anaesthetic toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administer 1 ml kg⁻¹ of 20% lipid emulsion i.v. over more than 1 min</td>
</tr>
<tr>
<td>Repeat dose every 3–5 min to a maximum of 3 ml kg⁻¹ (up to total dose 10 ml kg⁻¹)</td>
</tr>
<tr>
<td>Maintenance infusion of 0.25 ml kg⁻¹ min⁻¹ until circulation restored</td>
</tr>
</tbody>
</table>

**Table 3** Paediatric epidural dosing guidelines

<table>
<thead>
<tr>
<th>Medication</th>
<th>Initial bolus</th>
<th>Infusion solution</th>
<th>Infusion limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bupivacaine</td>
<td>≤2.5–3 mg kg⁻¹</td>
<td>0.0625–0.1%</td>
<td>≤0.4–0.5 mg kg⁻¹h⁻¹</td>
</tr>
<tr>
<td>Ropivacaine</td>
<td>≤2.5–3 mg kg⁻¹</td>
<td>0.1–0.2%</td>
<td>≤0.4–0.5 mg kg⁻¹h⁻¹</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>1–2 μg kg⁻¹</td>
<td>2–5 μg ml⁻¹</td>
<td>0.5–2 μg kg⁻¹h⁻¹</td>
</tr>
<tr>
<td>Morphine</td>
<td>10–30 μg kg⁻¹</td>
<td>5–10 μg ml⁻¹</td>
<td>1–5 μg kg⁻¹ h⁻¹</td>
</tr>
<tr>
<td>Hydromorphone</td>
<td>2–6 μg kg⁻¹</td>
<td>2–5 μg ml⁻¹</td>
<td>1–2.5 μg kg⁻¹ h⁻¹</td>
</tr>
<tr>
<td>Clonidine</td>
<td>1–2 μg kg⁻¹</td>
<td>0.5–1 μg ml⁻¹</td>
<td>0.5–1 μg kg⁻¹ h⁻¹</td>
</tr>
</tbody>
</table>

Downloaded from http://bja.oxfordjournals.org at University of Manitoba on February 10, 2014
Nerve block techniques utilized in adult pain management have, in some instances, been applied to paediatric patients. Mesnil and colleagues described the suprazygomatic approach to the maxillary nerve block, an effective procedure for adults with trigeminal neuralgia, as useful to control post-operative pain and facilitate early feeding resumption after cleft palate repair in infants.

Continuous peripheral nerve block

Continuous peripheral nerve blocks (CPNBs) are increasingly used in paediatrics as a method of providing extended duration of pain relief and facilitating physical therapy in children with chronic pain syndromes. CPNBs have been reported to be effective in both reducing pain and enabling participation in physical therapy in children with CRPS. Despite such reports, limited data exist regarding the safety, feasibility, and efficacy of CPNBs in children.

Perineural catheters can be placed at various locations to ensure site-specific analgesia. Brachial plexus catheters are useful for surgical procedures of the shoulder, elbow, forearm, and hand. Perineural catheter placement in the axillary region can provide pain control, but concerns over catheter sterility and migration exist. Catheters placed in the supraclavicular region are effective and reduce these concerns. Placement of a catheter into the TAP provides continuous analgesia and decreases supplemental postoperative systemic opioid requirements. In addition, use of continuous TAP catheters in paediatric patients can serve as an alternative to conventional neuraxial catheters. TAP catheters can also provide analgesia in patients with severe spinal deformities that preclude neuraxial anaesthesia.

CPNBs are also useful in providing lower extremity analgesia for extended periods. Femoral catheters have been used safely and effectively in children. Continuous femoral nerve blocks are commonly used to treat pain from surgery on the distal femur and anterior knee and to treat complex regional pain syndrome and cancer-related pain. Risks associated with indwelling catheter placement include infection, nerve damage, and falls as a result of block-induced quadriceps motor weakness. Continuous sciatic nerve block can also be used to provide analgesia to the lower extremity in infants and children, with fewer adverse effects than epidural anaesthesia in children undergoing major foot and ankle surgery.

CPNBs are evolving as a novel extended analgesic modality in paediatrics. Ultrasound guidance can facilitate and confirm placement of the catheter, which can reduce pain and potentially eliminate the need for opioids and their undesirable side-effects.

**Ultrasound-guided peripheral nerve block techniques**

Advances in ultrasonography have expanded the scope of regional anaesthesia practice in paediatrics. Ultrasound guidance improves the ease and safety of peripheral nerve block. This section reviews some of the more common peripheral nerve blocks in children and provides a straightforward approach to performing these blocks.

**Upper extremity blocks**

Brachial plexus block can be performed at various locations and is applicable to upper extremity surgical procedures. Axillary, infraclavicular, interscalene, and supraclavicular approaches are possible, supraclavicular brachial plexus block being the most common upper extremity block performed in children (personal communication, PRAN database). The use of ultrasound guidance when performing regional anaesthesia allows performance of brachial plexus blocks at any location safely and effectively by allowing better recognition of brachial plexus anatomy and improved localization of adjacent structures during needle placement.

**Axillary block**

**Anatomy and indications** The axillary approach to the brachial plexus block supplies analgesia to the elbow, forearm, and hand via the radial, median, and ulnar nerves. The radial nerve most commonly lies posterior to the axillary artery, and the ulnar nerve lies anterior and inferior to the artery. The median nerve is most often located anterior and superior to the axillary artery. The musculocutaneous nerve is situated outside of the axillary neurovascular sheath between the biceps brachii and coracobrachialis muscles, and must be blocked separately from the radial, median, and ulnar nerves.

**Technique** Although axillary block techniques are not well described in the literature, ultrasound-guided axillary techniques used in adults can be applied in children. An in-plane technique is utilized with the ultrasound probe positioned transverse to the humerus (Fig. 1). Multiple injections with needle repositioning facilitate circumferential spread of the local anaesthetic around each nerve. Careful ultrasound-guided needle advancement should be completed because of the superficial depth of the axillary sheath.

---

Table 4: Suggested dosing of local anaesthetics for peripheral nerve blocks

<table>
<thead>
<tr>
<th>Block technique</th>
<th>Dose (ml kg(^{-1}))</th>
<th>Maximum volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>Axillary</td>
<td>0.1–0.2</td>
<td>10</td>
</tr>
<tr>
<td>Infraclavicular</td>
<td>0.2–0.3</td>
<td>15</td>
</tr>
<tr>
<td>Intercostal</td>
<td>0.05–0.1</td>
<td>5</td>
</tr>
<tr>
<td>Rectus sheath</td>
<td>0.1–0.2</td>
<td>5</td>
</tr>
<tr>
<td>Ilioinguinal</td>
<td>0.1–0.2</td>
<td>10</td>
</tr>
<tr>
<td>Femoral nerve</td>
<td>0.2–0.3</td>
<td>15</td>
</tr>
<tr>
<td>Sciatic nerve</td>
<td>0.2–0.3</td>
<td>20</td>
</tr>
<tr>
<td>Popliteal fossa</td>
<td>0.2–0.3</td>
<td>15</td>
</tr>
<tr>
<td>Lumbar plexus</td>
<td>0.2–0.3</td>
<td>20</td>
</tr>
<tr>
<td>Penile</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>Digital nerve</td>
<td>0.05–0.1</td>
<td>5</td>
</tr>
<tr>
<td>Transversus abdominus plane (TAP)</td>
<td>0.2 (per side)</td>
<td>10 (per side)</td>
</tr>
</tbody>
</table>
Complications  Potential complications include neural injury, intravascular injection, haematoma, skin puncture site infection, and skin tenderness. Utilization of ultrasound guidance to facilitate needle advancement can help to reduce the likelihood of haematoma formation from inadvertent vascular puncture, intravascular injection, or nerve injury.

Interscalene block  

Anatomy and indications  Analgesia of the shoulder and proximal humerus is achieved by blocking the brachial plexus at the level of the interscalene groove. At this site, the trunks and roots of the brachial plexus lie posterior to the sternocleidomastoid muscle and are situated between the anterior and middle scalene muscles. The C5, C6, and C7 nerve roots are easily seen between the anterior and middle scalene muscles using this approach.

Technique  The ultrasound probe is positioned in the transverse oblique plane at the level of the cricoid cartilage at the lateral border of the sternocleidomastoid muscle (Fig. 2). The anterior and middle scalene muscles, which make up the interscalene groove, lie deep to the sternocleidomastoid muscle and lateral to the subclavian artery. The hyperechoic structures that comprise the neurovascular bundle of the C5, C6, and C7 nerve roots are contained within this groove. Nerve stimulation can be used to guide local anaesthetic delivery to the brachial plexus at this level; however, ultrasound guidance might decrease the required total amount of local anaesthetic. The ultrasound probe is positioned in the coronal-oblique plane, just superior to the upper border of the mid-clavicle. The subclavian artery, which is identified as a hypoechoic and pulsatile structure, lies adjacent to the brachial plexus. The needle is advanced medially towards the brachial plexus, just superior and lateral to the subclavian artery, using an in-plane approach. Potential risk of intraneural injection or vascular puncture is minimized by directing the needle in a lateral-to-medial fashion.

Complications  Pneumothorax, haematoma, infection, and intravascular injection are possible complications of the supraclavicular block. The potential for pneumothorax is present as the lung parenchyma is located just medial to the first rib. Direct visualization of the needle tip with ultrasonography might decrease the likelihood of this complication.

Infraclavicular block  

Anatomy and indications  Like the supraclavicular block, the infraclavicular block provides analgesia to the upper arm and elbow. This approach to the brachial plexus allows nerve block at the level of the cords of the plexus that lie medial and inferior to the coracoid process. The axillary artery and vein are deep to the cords. The pectoralis major and minor muscles are superficial to the brachial plexus. The lateral cord of the plexus is seen on ultrasound as a hyperechoic structure. The posterior cord is situated deep to the axillary artery. The medial cord can be difficult to identify because of its anatomical position between the axillary artery and vein.
Technique A lateral approach for performing the ultrasound-guided infraclavicular block is described in the paediatric literature. The ultrasound probe is positioned in a transverse orientation below the clavicle to identify the brachial plexus. The needle is inserted inferior to the probe and advanced using an out-of-plane technique. The needle is directed lateral to the cords of the brachial plexus; careful attention is needed to avoid vascular structures as the local anaesthetic is deposited into the deeper portions of the neurovascular sheath. De Jose Maria and colleagues described an alternative technique in which the probe is positioned parallel to the clavicle in a parasagittal plane, and the needle is directed cephalad towards the brachial plexus.

Complications The infraclavicular block confers risks similar to those of the supraclavicular block, including the risk of a pneumothorax because of the close proximity of the cervical pleura. The close location of the axillary artery and vein make haematoma because of vascular puncture a potential complication.

Truncal blocks

The frequent use of ultrasonography has increased the success and safety of truncal blocks in paediatric regional anaesthesia practice. The emerging role of minimally invasive surgical techniques in children has expanded the spectrum of patients that benefit from these blocks.

Transversus abdominus plane block

Anatomy and indications The TAP block supplies analgesia to the anterior abdominal wall and facilitates effective postoperative pain control, but does not provide surgical analgesia. This block is frequently utilized for laparoscopic procedures to provide analgesia at port placement sites and for larger abdominal incisions. Three muscle layers are identified lateral to the rectus abdominis: the external oblique, internal oblique, and the transversus abdominis (Fig. 3). The TAP plane, which lies between the internal oblique and transversus abdominis muscles, encases the thoracolumbar nerve roots (T8–L1), which deliver sensory innervation to the skin and muscles of the anterior abdominal wall.

Technique An ultrasound-guided in-plane approach is used to advance the needle into the TAP plane. The ultrasound probe is positioned adjacent to the umbilicus and moved laterally, away from the rectus abdominus, to facilitate visualization of the three muscle layers of the abdominal wall. The needle is advanced in-plane starting from either the lateral or medial side. Injection of the local anaesthetic creates an elliptical pocket within the TAP plane.

Complications Potential complications include infection, peritoneal, bowel puncture, or both, and intravascular injection.

IL/IH nerve block

Anatomy and indications The IL/IH nerves originate from T12 and L1 of the thoracolumbar plexus and provide sensation to the inguinal area and the anterior scrotum. The IL/IH nerves are blocked medial to the anterior superior iliac spine where they traverse the internal oblique aponeurosis. Successful IL/IH nerve block can provide equivalent relief to caudal block for inguinal surgery with the benefit of increased duration of postoperative analgesia.

Technique The ultrasound probe is positioned medial to the anterior superior iliac spine, in-line with the umbilicus (Fig. 4). Three abdominal muscle layers are identified (internal oblique, external oblique, and transversus abdominus). At this level, the external oblique muscle layer can be aponeurotic and only two muscle layers may be seen. The IL/IH nerves appear as oval structures that lie between the internal oblique and transverse abdominal muscles. The needle is advanced in-plane to the IL/IH nerves and the local anaesthetic is injected. In children, ultrasound-guided block dramatically reduces the volume of local anaesthetic required to produce analgesia compared with landmark-based techniques.

Complications Complications associated with IL/IH nerve block are rare but include needle-insertion site infection, intravascular injection, bowel puncture, pelvic haematoma, and femoral nerve palsy.

Rectus sheath block

Anatomy and indications The rectus sheath block provides analgesia along the midline of the anterior abdominal wall. The rectus abdominis muscle, lying on the anterior abdominal wall, is divided by the linea alba. The thoracolumbar nerves (T7–T11) lie posterior to rectus abdominis, immediately anterior to the posterior sheath. The rectus sheath block is commonly utilized to provide postoperative pain relief for umbilical hernia and single-incision laparoscopic surgery.
Technique

The ultrasound probe is placed lateral to the umbilicus and the rectus abdominis is identified. The posterior rectus sheath lies immediately under the rectus abdominis and sits above the peritoneum. The needle is advanced in-plane from lateral to medial, and the local anaesthetic is placed between the rectus abdominis and the posterior rectus sheath.66

Complications

Potential complications of the rectus sheath block include infection, intravascular injection, and bowel puncture.

Lower extremity blocks

Femoral nerve block

Anatomy and indications

The femoral nerve, which innervates the anterior thigh and the knee, originates from the L2, L3, and L4 nerve roots and is commonly blocked in paediatrics for surgical interventions of the knee. The femoral nerve sits lateral to the femoral artery and vein and is encased in a neurovascular bundle that is easily seen with ultrasonography.67 In addition to performing a ‘single-shot’ block, a perineural catheter can be safely placed to provide extended analgesia.

Technique

With the patient in the supine position, the femoral nerve, artery, and vein are located within the inguinal crease. The femoral nerve is identified lateral to the artery and the femoral vein is seen just medial to the artery as a collapsible vessel. An in-plane or out-of-plane approach can be used to guide the needle towards the lateral portion of the femoral nerve. The local anaesthetic circumferentially surrounds the nerve as it is injected.50 Careful needle visualization with advancement decreases the likelihood of inadvertent puncture of the femoral vessels.

Complications

Potential complications of the femoral nerve block include infection, nerve injury, and haematoma formation secondary to femoral vessel puncture.

Saphenous nerve block

Anatomy and indications

The saphenous nerve innervates the knee and the medial portion of the leg below the knee. It is a branch of the femoral nerve and courses within the adductor canal, running adjacent to the sartorius muscle before continuing onto the medial aspect of the knee (Fig. 5). It can be blocked proximally to provide sensory analgesia to the anterior knee or can be blocked more distally to provide analgesia solely to the medial aspect of the lower extremity.

Technique

With the patient in the supine position, the leg is abducted and laterally rotated as the probe is placed on the medial aspect of the knee. The sartorius muscle is identified; the saphenous nerve lies adjacent to this structure. The needle is directed using an in-plane technique towards the saphenous nerve and the local anaesthetic is injected.

Complications

Potential complications of saphenous nerve block include nerve injury, haematoma formation from arterial puncture, and infection at the needle-insertion site.

Sciatic nerve block

Anatomy and indications

The sciatic nerve, which originates from the nerve roots of L4 to S3, innervates the posterior thigh and the portion of the leg distal to the knee (excluding the medial component). The nerve exits the pelvis via the greater sciatic foramen and courses inferior to the gluteus maximus muscle, travelling distally through the posterior popliteal fossa, where it splits into the tibial and common peroneal nerves. The nerve can be blocked via the subgluteal, anterior thigh, or popliteal approaches in children. Continuous sciatic nerve block, and a ‘single-shot’ technique, can provide extended analgesia in children.68 69

Technique

The subgluteal approach to the sciatic nerve requires the patient to lie either in the lateral decubitus position, with the hip and knee flexed, or in the prone position. The ultrasound probe is placed between the greater trochanter and the ischial tuberosity and the gluteus maximus muscle is identified; the sciatic nerve is situated...
deep to this structure. An in-plane or out-of-plane technique can be utilized for needle guidance. The local anaesthetic is injected until it circumferentially surrounds the nerve. A perineural catheter can also be placed to deliver continuous nerve block.

An anterior approach to sciatic nerve block can be performed with an ultrasound-guided approach. This technique is ideal for the non-anesthetized patient with lower extremity discomfort, as the block is performed in the supine position with the patient’s leg abducted and laterally rotated. The probe is placed inferior to the inguinal crease and the femur is identified; the probe is moved medially to reveal the sciatic nerve in its location deep and medial to the femur. The nerve often lies deeper in larger patients, which can make this approach technically challenging to complete in older children.

The sciatic nerve can also be blocked more distally in the popliteal fossa. The patient is positioned prone or can remain supine and the ultrasound probe is placed in the popliteal crease. The popliteal artery is seen; the tibial nerve, which lies adjacent to the artery, can be followed proximal to the junction with the common peroneal nerve, merging together to form the sciatic nerve. The sciatic nerve can be blocked here or the tibial and common peroneal nerves can be individually targeted at this location.

Complications Complications of sciatic nerve block include skin puncture site infection, haematoma formation from vessel puncture, and local anaesthetic toxicity.

Lumbar plexus block
Anatomy and indications The lumbar plexus originates from the T12 to L5 nerve roots. Its branches, which include the femoral, genitofemoral, lateral femoral cutaneous, and obturator nerves, innervate the lower abdomen and the upper leg. The plexus is located within the psoas muscle, deep to the paravertebral muscles, and can be blocked with the ipsilateral sciatic nerve to achieve complete analgesia to the lower extremity. Lumbar plexus block can be safely performed in children.

Technique The patient is positioned lateral decubitus and the iliac crest and spinous processes are identified. The ultrasound probe is placed lateral to the midline and the L4 or L5 transverse process is located. The erector spinae and quadratus lumborum muscles lie deep to the transverse process, and deep to these, within the psoas major muscle, is the lumbar plexus. Because of this anatomical location, the plexus is often difficult to demarcate from the similar echogenicity to muscle. Nerve stimulation can be used in conjunction with ultrasonography to confirm needle positioning near the plexus.

Complications Complications include infection, haematoma, and retroperitoneal bleeding because of the location of the plexus.

Paravertebral block
Anatomy and indications The paravertebral space is a potential wedge-shaped area that contains intercostal and sympathetic nerve fibres. Boundaries of the paravertebral space include the superior costotransverse ligament posteriorly, the parietal pleura anteriorly, intervertebral discs medially, and the head and neck of the ribs superiorly. Paravertebral block has been described as an effective modality for achieving postoperative analgesia with fewer adverse effects and fewer contraindications than central neuraxial block. Indications include thoracotomy, breast surgery, cholecystectomy, renal surgery, and inguinal herniorrhaphy. Ultrasound-guided paravertebral block has been utilized for postoperative pain management in children undergoing thoracic and cardiac surgery procedures. Lonnqvist described continuous paravertebral block as a viable option for extended postoperative analgesia.

Technique The patient is placed in the lateral or prone position. A linear array transducer is placed at the appropriate spinous process and moved longitudinally in the cephalo-caudal direction until the corresponding transverse process is identified. The ultrasound probe is then rotated 90° until it lies perpendicular to the spinal column. The transverse process and the pleura can both be seen at this point. A needle is advanced in-plane until it traverses the intercostal muscles to a point superficial to the pleural border (Fig. 6). A local anaesthetic solution can be injected, a catheter placed into this space, or both.
Complications Potential complications of paravertebral block include accidental pleural puncture, hypotension from local anaesthetic spread centrally with sympathetic block, neurological injury because of intrathecal or epidural entry, and paravertebral haematoma formation.

Discussion
The practice of paediatric regional anaesthesia has made tremendous strides in recent years. Advances in ultrasonography and precise dosing regimens have facilitated widespread applications of regional anaesthetic techniques in infants, children, and adolescents. Prospective studies indicate that these techniques can be safely performed and positively impact on the outcomes of paediatric patients undergoing painful procedures and those who suffer from chronic pain. Large prospective databases in the USA and Europe will allow ongoing monitoring of regional techniques in children and allow meaningful decisions regarding their safety and efficacy.

Authors’ contributions
R.D.S. and S.S.: responsible for the conception of this review, interpretation of the data, drafting the review, and final approval of the published version.

Declaration of interest
None declared.

Funding
None.

References
1 Johr M. Practical pediatric regional anesthesia. Curr Opin Anaesth 2013; 26: 327 –32
9 Llewellyn N, Moriarty A. The national pediatric epidural audit. Paediatr Anaesth 2007; 17: 520 –33
12 Mazoit JX. [Regional analgesia: things are moving ahead]. Ann Fr Anesth Reanim 2012; 31: 105 –6
14 Weinberg G. Lipid rescue resuscitation from local anaesthetic cardiac toxicity. Toxicol Rev 2006; 25: 139 –45
26 Broadman LM. Blocks and other techniques pediatric surgeons can administer before thyroid surgery: is a regional block better than opioids? Anesthesiology 1998; 87: 1256 –8
33 Tobias JD. Continuous femoral nerve block to provide analgesia following femur fracture in a paediatric ICU population. Anaest Intensive Care 1994; 22: 616–8
46 Taylor LJ, Birmingham P, Yerkes E, Suresh S. Children with spinal dysraphism: transversus abdominis plane (TAP) catheters to the rescue! Paediatr Anaesth 2010; 20: 951–4
54 Fredrickson MJ. Ultrasound-assisted interscalene catheter placement in a child. Anaest Intensive Care 2007; 35: 807–8
69 van Geffen GJ, Scheuer M, Muller A, Ginderniers J, Gienlen M. Ultrasound-guided bilateral continuous sciatic nerve blocks with
stimulating catheters for postoperative pain relief after bilateral lower limb amputations. *Anaesthesia* 2006; 61: 1204–7


*Handling editor: H. C. Hemmings*