Review/*Derleme*

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Current Approaches in Pediatric Regional Anesthesia

Pediyatrik Rejyonal Anestezide Güncel Yaklaşımlar

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ABSTRACT

The introduction of ultrasound technology has revolutionized pediatric regional anesthesia and offers greater precision and safety in perioperative pain management. This review examines modern techniques, including the use of local anesthetics tailored to pediatric physiology and the role of adjuncts in prolonging block duration and optimizing analgesia. The advantages of regional anesthesia over general anesthesia are highlighted, particularly minimizing opioid-related side effects and supporting improved recovery protocols. Key techniques such as ultrasound-guided peripheral nerve block and interfascial plane blocks are discussed, highlighting their effectiveness in providing long-lasting analgesia with minimal complications. Catheter-based techniques for prolonged analgesia and their associated risks are also discussed. The safety profile of these techniques, supported by extensive data, underscores their central role in modern pediatric anesthesia practice. This review argues for individualized, ultrasound-guided procedures to improve outcomes and reduce complications. It also draws attention to gaps in pediatric research and calls for future studies to develop evidence-based protocols for this vulnerable population. This review aimed to focus on current approaches to pediatric regional anesthesia and peripheral nerve blocks commonly used in the pediatric population.

Keywords: Pediatric regional anesthesia, peripheral nerve blocks, local anesthetics, ultrasound

ÖZ

Ultrason teknolojisinin kullanıma girmesi pediyatrik rejyonal anestezide devrim yaratmış ve perioperatif ağrı yönetiminde daha fazla hassasiyet ve güvenlik sunmuştur. Bu derlemede, pediyatrik fizyolojiye göre uyarlanmış lokal anesteziklerin kullanımı ve blok süresinin uzatılması ve analjezinin optimize edilmesinde yardımcı maddelerin rolü de dahil olmak üzere modern teknikler incelenmektedir. Rejyonal anestezinin genel anesteziye göre avantajları, özellikle opioidle ilişkili yan etkilerin en aza indirilmesi ve gelişmiş iyileşme protokollerinin desteklenmesi vurgulanmaktadır. Ultrason kılavuzluğunda periferik sinir bloğu ve interfasiyal düzlem blokları gibi temel teknikler tartışılmakta ve bunların minimal komplikasyonlarla uzun süreli analjezi sağlamadaki etkinlikleri vurgulanmaktadır. Uzun süreli analjezi için kateter tabanlı teknikler ve bunlarla ilişkili riskler de tartışılmaktadır. Bu tekniklerin kapsamlı verilerle desteklenen güvenlik profili, modern pediyatrik anestezi uygulamasındaki merkezi rollerinin altını çizmektedir. Bu derleme, sonuçları iyileştirmek ve komplikasyonları azaltmak için bireyselleştirilmiş, ultrason kılavuzluğunda prosedürleri savunmaktadır. Ayrıca, pediyatrik araştırmalardaki boşluklara dikkat çekmekte ve bu hassas popülasyon için kanıta dayalı protokoller geliştirmek üzere gelecekte yapılacak çalışmalar için çağrıda bulunmaktadır. Bu derleme, pediyatrik rejyonal anestezi ve pediyatrik popülasyonda yaygın olarak kullanılan periferik sinir bloklarına yönelik güncel yaklaşımlara odaklanmayı amaçlamıştır.

Anahtar sözcükler: Pediyatrik rejyonal anestezi, periferik sinir blokları, lokal anestezikler, ultrason

INTRODUCTION

With the introduction of ultrasound technology into our lives, applications of pediatric regional anesthesia have gained momentum and will continue to do so. Pediatric regional anesthesia is one of the most valuable and safest tools for managing perioperative pain in pediatric patients without disrupting the physiologic environment and is an important component of modern anesthesia (1-4).

Opioids may also be preferred analgesics in pediatric patients, but considering the side-effect, these agents are now avoided (2,5). Non-steroidal anti-inflammatory drugs should be used with caution in pediatric patients due to their effects on the immature renal system. The most tangible advantage of regional anesthesia is its profound and long-lasting analgesic effect and its lower side-effect profile. Compared to general anesthesia, its positive effects on the surgical stress response cannot be overlooked (2).

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With the advent of 'Enhanced Recovery After Surgery' protocols and concerns about the ongoing global opioid epidemic, it is critical to reduce opioid use in the perioperative period. Reducing opioid use can also contribute to early mobilisation and shorten the length of hospital stay (6). In this regard, the addition of regional anaesthetic techniques to multimodal analgesia provides even more effective analgesia. It also minimises the risk of pain becoming chronic (4,7-9).

This review aimed to focus on current approaches to pediatric regional anesthesia and peripheral nerve blocks commonly used in the pediatric population.

Local Anesthetics

Compared with adults, lower concentrations of local anesthetics (LAs) are sufficient in the pediatric population. Because of the physiologic characteristics of the pediatric population, the onset of blockade is faster, but the duration of blockade is usually shorter. Local anesthetics have a larger volume of distribution, lower clearance, and higher free-fraction in children (10-12). A larger volume of distribution reduces the risk of high serum concentrations of the drug. However, the risk of drug accumulation increases when multiple injections or a continuous infusion are used (11,13). Therefore, the maximum dose should be calculated individually for each child (10). The use of ultrasound improves the success of the block and reduces the volume of LA to be administered, keeping it within safe limits. Table I shows the maximum recommended doses for the pediatric population.

Adjuvants

Although numerous studies can be found in the literature, there is still no clear consensus on adjuvants. The benefits of using adjuvants in regional anesthesia include: Increased duration of block and analgesic effect, decreased need for general anesthesia, improved recovery period, decreased incidence of delirium and tremor on awakening, early postoperative discharge, and decreased cost of care (12).

Table I. Recommended Maximum Doses of Local Anesthetics in the Pediatric Population (3,10)

	Single injection (mg kg^{-1})	Continuous infusion (mg kg^{-1} h^{-1})
Bupivacaine	2.5	0.25
Levobupivacaine	2.5	0.25
Ropivacaine*	3-4	0.4
Lidocaine	5-7	2
Prilocaine**	7-10	Not suitable

*****0.2 mg kg^{-1} h^{-1} in children up to 6 months of age.
****** Not recommended in infants due to risk of methemoglobinemia.

In addition to LAs, a number of adjuncts can be used to prolong and optimise the duration of postoperative analgesia for regional anesthesia in children (1,14). Clonidine (0.5-2 μg kg^{-1} and dexmetedomidine (1-2 μg kg^{-1}) can be used as adjuvants in peripheral nerve blocks, and these agents have been shown to prolong the duration of postoperative analgesia (12,15-18).

Asleep or Awake

In pediatric regional anesthesia, there is still no consensus on whether procedures should be performed awake, under sedation or under general anesthesia. When performing regional blocks in children, several studies have recommended that they should be performed under heavy sedation or general anesthesia (10,19,20). They believe that this is associated with acceptable safety and should be considered the standard of care (16,19). The reasons for this include the following: Any inappropriate movement during the procedure may increase the risk of complications, and an agitated and frightened child cannot be expected to cooperate during the procedure, nor can he or she be expected to report signs of local anaesthetic systemic toxicity (LAST) (1). Taenzer et al. reported data showing that performing blocks while awake or under light sedation was associated with a higher incidence of postoperative neurologic symptoms than performing blocks under general anesthesia. The Pediatric Regional Anesthesia Network found no difference in neurological complications between the two groups when studying more than 50,000 patients awake/sedated and asleep (21). Despite the safety of regional anesthesia techniques performed under general anesthesia or sedation, it should not be overlooked that serious complications can still occur (16,19). Performing peripheral nerve blocks under ultrasound guidance may help to improve the safety of procedures under general anesthesia or deep sedation. In addition, ultrasound guidance allows localization of the needle tip and monitoring of the spread of the LA, which improves the safety of peripheral nerve blocks.

Catheter Techniques

Despite the use of long-acting LAs in regional anesthesia for major surgery in children, postoperative pain management can sometimes be inadequate. In such cases, the use of catheter techniques in regional anesthesia may be preferred (14). There are still concerns about the complications that can occur with the use of catheters in children. In a multicenter study of 2074 peripheral nerve catheters, the incidence of complications was 12.1%. The most common complications were catheter failure, inadequate blockade, infection, and vascular puncture. Patients who developed an infection had used the catheter longer than other patients. However, no serious complications were reported. Results similar to adult studies were obtained, confirming the safety of peripheral nerve catheters in children (22).

Complications

Although rare, complications can occur with regional anesthesia. The reasons for this include the experience of the clinician, the selection of the patient, the correct choice of drugs and dosages, the technique and the equipment used. If all these factors are optimised, it is not surprising that the incidence of complications is negligible. Walker et al. backed this up in their study, in which they analysed more than 100,000 blocks and found no permanent motor neurological deficits. They also found no difference between peripheral and central blocks in terms of complication rates (23). Although peripheral blocks have a good safety record, they are not without risk (10).

The incidence of LAST in children is very low (24). Local anesthetic systemic toxicity occurs when high plasma levels are reached after absorption of high doses of LAs or accidental intravascular injection of the drug (10). Local anesthetic systemic toxicity is difficult to detect in children, especially neonates and infants. It is manifested by electrocardiographic changes and/or signs of cardiovascular collapse during anesthesia. Convulsions are difficult to detect during anesthesia but are more evident with continuous infusions in the postoperative period. To avoid toxicity in pediatric regional anesthesia, appropriate dosing for pediatric patients and choice of LA is important (10,16). Ropivacaine and levobupivacaine may be preferred due to their lower toxic properties compared to bupivacaine. Pre-injection aspiration, slow injection, and the use of ultrasound are key to reducing the risk of LAST (16).

Acute compartment syndrome (ACS) is a rare but serious complication. There is currently no evidence that regional anesthesia techniques increase the risk of ACS or delay diagnosis (1,16,19). Regional anesthesia has been accused of delaying diagnosis by masking ischemic pain. However, when dilute LAs are used, nociceptive pain is blocked while ischemic pain sensation and transmission are preserved. This is because they are transmitted by different nerve fibres. Therefore, if pain increases in a patient who has undergone successful regional anesthesia, this is a pathognomonic finding for ACS. The following measures are recommended to prevent and reduce the risk of ACS: I) the use of bupivacaine, levobupivacaine, or ropivacaine in concentrations of 0.1-0.25% for single injections and 0.1% for continuous infusions, which are less likely to mask ischemic pain and/or cause muscle weakness; II) limiting both volume and concentration in patients at risk of ACS; III) careful use of additives added to LAs; IV) careful monitoring of patients at risk of ACS; V) if ACS is suspected, urgent pressure measurements and initiation of treatment (1,16).

Peripheral Nerve Blocks

Ultrasound-guided peripheral nerve blocks help to localise nerve structures and improve the accuracy of needle placement (25). In addition, the spread of LA can be visualised in real time, improving the quality and success of the nerve block and reducing the incidence of complications (26). In a study of 565 patients, the success rate of ultrasound-guided brachial plexus (BP) block was 94.5%, and no complications were reported (27). This demonstrates the importance of ultrasound guidance in peripheral nerve blocks. Peripheral blocks are preferred over central neuraxial blocks because of their longer duration of action and fewer serious complications. A single-injection block can be converted to a continuous block if the indications are appropriate (1). The dosage of LAs, indications and complications of the types of block discussed in this review are summarized in Table II.

Peripheral nerve blocks of the upper extremities

In the upper extremity, the BP can be blocked at various anatomical sites, and these types of blocks are named according to these anatomical sites. The type of peripheral nerve block should be determined depending on the type of surgery, patient characteristics and physician experience.

Interscalene brachial plexus block: The BP consists of the spinal nerves C5-C8 and T1. The C5-C7 nerves are located between the anterior and middle scalene muscles. The block performed at this anatomical site is called an interscalene brachial pleksus (ISBP) block. After the linear ultrasound probe is placed in the supraclavicular space parallel to the clavicle, the C5-7 spinal nerves can be seen between the anterior and middle scalene muscles when it is tilted slightly cranially. With the in-plane technique, the needle is guided from lateral to medial. The in-plane technique is superior to the out-of-plane technique in terms of the risk of complications. If the optimal ultrasound image cannot be achieved, a nerve stimulator can also be used. The ISBP-block is considered more suitable than the supraclavicular brachial plexus (SCBP) block for shoulder surgery, as the ISBP-block also blocks the suprascapular nerve. Although the ISBP-block does not anaesthetize the distal roots of the plexus, it also blocks the axillary and musculocutaneous nerves, which are often overlooked when performing an ABP-block. Care must be taken when performing an ISBP-block with regard to anatomically closely adjacent structures (such as carotid artery, jugular vein and cervical epidural space). On electrocardiography ST and T wave changes can be observed by adding epinephrine at a ratio of 1:200,000 as an indicator of intravenous injection. In contrast to many previous studies arguing that ISBP-block should be performed awake in view of possible complications, the study by Taenzer et al. argues otherwise (20,28). They found no difference in complications in 390 ISBP-blocks performed under general anesthesia and

Table II. Dose of Local Anesthetics, Indications and Complications in Pediatric Peripheral Nerve Blocks (1-6, 10-12)

Peripheral nerve blocks of the upper extremities'	Dose of the local anesthetic	Indications	Complications
Interscalene brachial plexus block	0.2% ropivacaine up to 0.5 mL kg^{-1} (max: 20 mL) 0.25% bupivacaine 0.2-0.3 mL kg^{-1} (max: 2 mg kg^{-1}) Continuous infusion; 0.1-0.15 mL kg^{-1} h^{-1} (max: 10 mL h^{-1})	Shoulder or proximal humerus surgery	Horner's syndrome, phrenic nerve palsy, intra-arterial and epidural injection
Supraclavicular brachial plexus block	0.25% bupivacaine, levobupivacaine, 0.2% ropivacaine or 2% lidocaine 0.15-0.5 mL kg^{-1}*	All surgical procedures on the upper arm and distal	Arterial and pleural puncture, paralysis of the phrenic nerve, Horner's syndrome
Infraclavicular brachial plexus block	0.2-0.5% ropivacaine or 0.25-0.5% bupivacaine 0.5 mL kg^{-1} Continuous infusion: 0.4 mg kg^{-1} h^{-1} (max: 8-10 mL h^{-1})	Distal humerus, elbow, forearm and hand surgery	Vascular puncture, nerve injury, pneumothorax
Axillary brachial plexus block	0.25-0.5% bupivacaine, levobupivacaine or ropivacaine 0.2-0.3 mL kg^{-1} 0.5-1 mL for the musculocutaneous nerve	Hand, wrist, mid-arm and elbow surgery	Arterial injury
Peripheral nerve blocks of the lower extremities			
Femoral nerve block	0.25% bupivacaine 0.2-0.5 mL kg^{-1} (max: 2 mg kg^{-1}) or 0.2% ropivacaine (max: 3-4 mg kg^{-1})	Femoral fractures, anterior thigh surgery, knee arthroscopy, reconstruction of the anterior cruciate ligament and for multimodal analgesia in total knee arthroplasty.**	Femoral artery injury, peripheral neuropathy
Adductor canal block	0.25% bupivacaine or 0.2% ropivacaine 0.15-0.5 mL kg^{-1} (max: 10 mL)	Distal anterior thigh surgery and knee arthroscopy	Femoral vascular injury Use of high amounts of local anesthetics increases the risk of motor blockade and nerve damage in the distribution of the femoral nerve
Sciatic nerve block	0.125% bupivacaine or 0.15% ropivacaine 0.5 mL kg^{-1} (max: 20 mL) for subgluteal sciatic nerve block 0.25% bupivacaine, levobupivacaine or 0.20% ropivacaine 0.1-0.5 mL kg^{-1} (max: 20 mL) for popliteal sciatic nerve block Continuous infusion: 0.1 mL kg^{-1} h^{-1}	Lower limbs surgery Subgluteal nerve block: knee surgery involving the posterior thigh Popliteal sciatic nerve block: foot and ankle surgery	Infection, bleeding, nerve injury
Truncal blocks			
Rectus sheath block	0.25% bupivacaine or 0.2% ropivacaine 0.1-0.2 mL kg^{-1}	Midline incisions of the anterior abdominal wall, umbilical, incisional and epigastric hernia repairs, laporoscopic procedures and open pyloromyotomy surgery.	Peritoneal puncture, intestinal injury

Table II. Cont.

Peripheral nerve blocks of the upper extremities'	Dose of the local anesthetic	Indications	Complications
Ilioinguinal/iliohypogastric nerve block	0.25% bupivacaine, levobupivacaine or 0.2% ropivacaine 0.1-0.5 mL kg^{-1} (max: 10 mL)	Orchiopexy, inguinal hernia and hydrocele repair.	Intravascular or intraperitoneal injection, intestinal perforation, pelvic hematoma, femoral nerve palsy
Transversus abdominis plane block	0.2% ropivacaine or 0.25% bupivacaine 0.2-0.3 mL kg^{-1}	Somatic block of the ipsilateral anterolateral abdominal wall (no visceral analgesia) Subcostal transversus abdominis plane block for operations above the umbilicus, lateral or posterior transversus abdominis plane block for operations below the umbilicus Laparotomy, laparoscopy, umbilical surgery, appendectomy, inguinal hernia repair, hydrocelectomy, orchiopexy and other operations on the abdominal wall	Intra-abdominal organ injury, intraperitoneal injection
Quadratus lumborum block	0.25% bupivacaine 0.5 mL kg^{-1} (max: 20 mL)	Ipsilateral somatic and visceral analgesia Ileostomy, unilateral laparoscopic surgery, pyeloplasty, herniorrhaphy Lateral quadratus lumborum block: analgesia of the T12-L1 nerves, for operations below the umbilicus Anterior and posterior quadratus lumborum block: analgesia of the T4-L1 nerves, for abdominal operations above and below the umbilicus	Renal or peritoneal injury, bleeding
Erector spinae plane block	0.25% bupivacaine or 0.2% ropivacaine 0.5 mL kg^{-1} (max: 20 mL) Continuous infusion; 0.1-0.3 mg kg^{-1} h^{-1}	Analgesia for ipsilateral abdominal, thoracic and breast surgeries and rib fractures	Vascular puncture, pleural puncture, pneumothorax
Paravertebral block	0.25% bupivacaine, levobupivacaine or 0.2% ropivacaine 0.2-0.5 mL kg^{-1} Continuous infusion; 0.5 mg kg^{-1} h^{-1}	Ipsilateral somatosensory analgesia in thoracic and abdominal surgery	Hypotension, paravertebral hematoma, contralateral spread of local anesthetic, nerve damage, vascular and pleural puncture, pneumothorax

***** In children younger than 6 months, the dose of local anesthetic should be halved.
****** The femoral nerve block should be combined with the sciatic or popliteal nerve block to achieve complete anesthesia and analgesia in the lower leg.

123 sedated/awake blocks. Of note here is that 88% of these blocks were performed under ultrasound guidance (28).

Supraclavicular brachial plexus block: The block of the BP in the supraclavicular fossa is referred to as SCBP-block. The supraclavicular brachial plexus block is also known as “spinal block of the upper extremities”. The patient is placed in the supine position with the head facing the contralateral side. In young children, a roller may need to be placed between the shoulder blades. The ultrasound probe is placed coronal-oblique to the supraclavicular fossa. The subclavian artery, the first rib and the pleura should be visible on the ultrasound image. Postero-lateral to the subclavian artery is the BP. The image of the BP in the supraclavicular fossa is also called ‘cluster of grapes’. Colour Doppler can be used to identify the vascular structures when performing the blockade. With the in-plane technique, the needle is guided from lateral to medial in the direction of the BP lateral to the subclavian artery. The needle should always be directly visible in order to avoid penetrating the nerve bundles, vascular structures and the pleural cavity. To avoid intravascular injection, aspiration should be performed before the injection, which should be repeated every 1-2 mL. Deposition of the LA around the plexus increases the success of the blockade (29).

The SCBP-block also eliminates pain caused by tourniquet-induced pain in the limb. Successful block reduces opioid consumption and opioid-related side effects. As the risk of complications with this blockade using a blind technique can be very high, it is recommended that this blockade is performed under ultrasound guidance. Although paralysis of the phrenic nerve is not as common as with ISBP-block, caution is advised in patients with limited respiratory reserve (30).

Infraclavicular brachial plexus block: The infraclavicular brachial plexus (ICBP) block targets the BP cords surrounding the axillary artery. The BP is located in the infraclavicular fossa below the clavicle in the form of lateral, medial and posterior cords. Although there are many anatomical variations, the lateral, posterior and medial cords are located superior, posterior and inferior to the axillary artery respectively. In the ICBP-block, all nerves of the humerus and forearm can be blocked, with the exception of the intercostobrachial nerve, which originates at T2. The infraclavicular BP is bounded anteriorly by the pectoralis major and minor muscles, superiorly by the clavicle and the coracoid process, medially by the costae and laterally by the humerus. The most important anatomical structure that can be identified with ultrasound is the axillary artery, which is located behind the pectoralis major and minor muscles. In the supine position, the ultrasound probe is placed in the parasagittal plane medial to the coracoid process and below the clavicle. When the arm is abducted 90° and the elbow is flexed, the cords become more superficial and visualisation may be easier. While a linear probe is sufficient for this block, a curved probe may be preferred in older children. Colour Doppler allows you to confirm the location of the axillary artery and vein. The in-plane technique is safer as there is less risk of pleural puncture. With the in-plane technique, the needle is advanced from cranial to caudal in the direction of the axillary artery. The target point is at the 7-8 of the clock level of the axillary artery. By injecting at this point, the LA encircles the axillary artery in a ‘U-shape’ and thus provides analgesia and anesthesia for all cords. The ICBP-block is also very suitable for catheter placement as it is deeper than the SCBP-block and axillary brachial plexus (ABP) blocks (1,31).

Axillary brachial plexus block: In ABP-block, the ulnar, radial, median and musculocutaneous nerves are blocked. In ABP-block, the target nerves are located in different positions around the axillary artery. The patient is placed in the supine position. The arm is abducted by 90°, the shoulder is externally rotated and the elbow is flexed by 90°. The optimal visualisation of the BP is most proximal to the axillary apex. The linear ultrasound probe is placed in the axilla and the axillary artery is visualised. The target nerves are visualised in a ‘honeycomb-shape’ around the axillary artery. The musculocutaneous nerve is visualised as a hyperechoic structure in the plane between the coracobrachialis and biceps muscles. You may prefer the in-plane or out-of-plane technique. However, the in-plane technique is more reliable as it allows better distribution of the LA and better visualisation of the needle. The LA is injected into the ulnar, radial and median nerves around the axillary artery and the musculocutaneous nerve. ABP-block provides intraoperative and postoperative analgesia, it reduces opioid consumption and allows earlier discharge from the hospital (32).

Peripheral nerve blocks of the lower extremities

In peripheral nerve blocks of the lower extremities, we avoid anesthesia or analgesia in the contralateral extremity and urinary retention, which is one of the most common effects of neuraxial blocks (1). As with peripheral nerve blocks of the upper extremities, the type of block should be decided on a case-by-case basis.

Femoral nerve block: The femoral nerve (FN) arises from the anterior branches of the L2-L4 spinal nerves before exiting the pelvis and entering the thigh below the inguinal ligament. The FN runs laterally and behind the femoral artery. FN-block provides analgesia to the quadriceps muscle, periosteum, anterior thigh, leg, ankle and medial aspect of the foot. The patient is in the supine position and the lower limb is placed in slight abduction and external rotation. The ultrasound probe is placed parallel under the inguinal ligament. The FN visualised lateral to the femoral artery (11,33). The needle is advanced from lateral to medial using an in-plane technique. In a randomised controlled trial in adults comparing the in-plane technique with the out-of-plane technique, it was found that the contact between needle and nerve was less with the in-plane technique (34).

Adductor canal block: The adductor canal (AC) is surrounded anterolaterally by the vastus medialis muscle, medially by the sartorius muscle and posteromedially by the adductor magnus muscle. The AC contains the femoral artery and vein and the saphenous nerve. The saphenous nerve is a sensory nerve and is the largest cutaneous branch of the FN. The patient is placed in the supine position. The ipsilateral hip is externally rotated and the knee is slightly flexed. The saphenous nerve can be visualised in the AC by scanning the femoral artery caudally under the inguinal ligament. Another method is to place a linear probe on the anteromedial surface in the mid-thigh and identify the femoral artery below the sartorius muscle and medial to the vastus medialis muscle. The saphenous nerve is visualised as a hyperechoic structure in the fascial plane between the sartorius and vastus medialis muscles, anterior or lateral to the femoral artery. The needle is guided from lateral to medial using an in-plane technique. Although the risk of motor blockade of the adductor and quadriceps muscles is less than with FN-block, it is still present (11). It allows earlier mobilisation and rehabilitation than FN-block.

Sciatic nerve block: The sciatic nerve (SN) is a motor and sensory nerve that consists of the tibial and common peroneal nerves and arises from the L4-5 and S1-3 nerves. The SN emerges from the greater sciatic foramen and then enters the popliteal fossa between the greater trochanter and the ischial tuberosity. In the popliteal fossa it divides into the tibial nerve and the common peroneal nerve. While the SN lies deeper in the subgluteal region, it becomes more superficial towards the distal region. The SN innervates the entire leg and foot with the exception of the posterior aspect of the thigh and knee and the medial aspect of the leg. SN-block can most commonly be performed via the subgluteal or popliteal approach (11). A linear probe can be used for both approaches. In older and overweight children, a curved probe may be preferred for the subgluteal approach.

The landmarks of the subgluteal-SN-block are the greater trochanter, the posterior superior iliac spine, the ischial tuberosity and the sacral hiatus. In the subgluteal-SN-block, the patient is placed in the lateral or prone position. In the lateral position, the hip is flexed and the knee is slightly extended. The probe is placed transversely under the hip crease. After the greater trochanter and ischial tuberosity are identified under ultrasound guidance, the SN is visualised between the biceps femoris and the gluteus muscles (11). If the SN is difficult to visualise in the subgluteal region, it can also be visualised by scanning proximally from the apex of the popliteal fossa or the bifurcation point. In-plane or out-of-plane technique may be preferred.

For the popliteal approach, the patient is placed in the lateral, prone or supine position. In the supine position, the knee is flexed and the popliteal artery is visualised by placing the probe transversely to the popliteal possa. In general, the nerves lateral to the popliteal artery can be identified, but it should be borne in mind that deviations can occur. The probe is directed cranially and followed until the tibial nerve and the common peroneal nerve merge. The popliteal-SN-block can be performed with a posterior or lateral approach (11).

Truncal blocks

Ultrasound-guided truncal blocks do not require the identification of a nerve or plexus. The LA injected into the targeted plane spreads to the nerve within the plane and block occurs (35), Blocks at the interfascial plane provide analgesia in the intraoperative and postoperative periods (36). When incorporated into the multimodal analgesia regimen for appropriate surgical procedures, these blocks can provide effective analgesia and reduce the need for opioids (6,36). With the introduction of ultrasound into our lives, interfascial plane blocks are considered safer and have a lower side effect profile compared to neuraxial blocks (37).

Rectus sheath block: The rectus abdominis muscle (RAM) is an anterior abdominal wall muscle that is divided in the midline by the linea alba. The RAM is broad and thin above the umbilicus, while its thickness increases below the umbilicus. This muscle is surrounded by the rectus sheath (RS) (38). Posterior to the muscle and anterior to the posterior RS are the thoracic 9-11 intercostal nerves that innervate the anterior abdominal wall (6). With the patient in the supine position, the ultrasound probe is placed transverse to the lateral anterior abdominal wall (38). The RAM is visualised as an oval shape. The needle is inserted from lateral to medial using the in-plane technique into the space between the RAM and the posterior RS (10,38). A catheter can also be inserted for continuous infusion (3,39). For large midline incisions, more effective analgesia in certain dermatomes can be achieved with multiple injections (10,39,40). Rectus sheath block has been shown to provide greater analgesia than infiltration with LA in pediatric patients undergoing midline laparoscopic surgery (38).

Ilioinguinal/iliohypogastric nerve block: The ilioinguinal/iliohypogastric nerves (II/IHNs) originate from the L1 nerve and superior to the lateral edge of the psoas major muscle (3,6). They run medial to the anterior superior iliac spine in the interfascial plane between the internal oblique muscle (IOM) and the transversus abdominis muscle (TAM) (36). The location of these nerves changes with age in pediatric patients, so ultrasound guidance increases the safety and efficacy of nerve block (3). The II/IHNs innervate the posterolateral gluteal region, the inguinal region and the anterior scrotum. The ultrasound probe is positioned obliquely medial to the anterior superior iliac spine (the line from the anterior superior iliac spine to the umbilicus), and the LA is injected into the interfascial plane between the IOM and TAM from lateral to medial or medial to lateral (36). The in-plane or out-of-plane technique may be preferred, but the in-plane technique is more reliable in terms of complications. One study has shown that there was no need for perioperative opioids in infants who underwent II/IHNs-block in inguinal hernia repair and another study has shown that 80 infants did not require opioids in the postoperative period (41,42).

Transversus abdominis plane block: Transversus abdominis plane (TAP) block is performed by injecting a LA into the plane between the IOM and the TAM (43,44). The anterior branches of the thoracolumbar nerves T7-L1 lie in the interfascial plane between the IOM and the TAM (3,45,46). These nerves provide sensory innervation to the anterior abdominal wall and the parietal peritoneum. The T7-T9 nerves innervate above the umbilicus, T10 around the umbilicus and T11-L1 below the umbilicus (45). Analgesia is achieved in the dermatomal segments T10-L1 with a lateral TAP block, while analgesia at higher dermatomal levels can be achieved with a subcostal TAP block (47). The TAP-block is performed in the supine position (48). Using a linear probe, the external oblique, IOM and TAM are identified from superficial to deep. The most prominent of these three muscles is the IOM. The abdominal cavity lies below the TAM and can be defined by the movement of the intestinal loops. If it is difficult to identify these three muscles, the ultrasound probe is placed transversely in the midline, the RAM is identified, and the target muscles can be visualised by moving the probe laterally. The needle is advanced from anterior to posterior using in-plane technique toward the interfascial plane between the IOM and TAM (35).

There are three types of TAP-blocks: lateral, posterior and subcostal. The ultrasound probe is placed transversely in the anterior axillary line between the costal margin and the iliac crest and the lateral TAP-block is performed (45,49,50). The posterior TAP-block is performed at the end point of the TAM (45). In the subcostal TAP-block, the ultrasound probe is placed obliquely just below the costal margin and the RAM is identified. After the TAM has been visualised below the RAM, the needle is directed to the interfascial plane between the posterior RS and the TAM (35,51). The posterior TAP-block provides more effective analgesia than the lateral TAP-block. The reason for this is probably the spread of the LA along the nerve pathways through the quadratus lumborum (QL) muscle into the paravertebral (PV) space in the posterior TAP-block.

In children undergoing bilateral ureteral reimplantation, the TAP-block has been shown to provide more effective analgesia than the caudal block, while the caudal block has been shown to be more effective for bladder spasm with visceral pain (52). In a randomised controlled trial by Sahin et al, the TAP-block was shown to provide longer postoperative analgesia and less postoperative analgesia consumption than skin infiltration in children undergoing inguinal hernia repair (53). Unilateral TAP-block has been shown to reduce postoperative opioid consumption in children undergoing open appendectomy (54). It is an essential component of multimodal analgesia (1,45). When 1994 children who underwent TAP-block were evaluated for complications, complications (vascular blood aspiration and peritoneal puncture before injection of LA) occurred in only 2 children (55). This study demonstrates that the incidence of complications with ultrasound-guided TAP-blocks is negligible.

Quadratus lumborum block: The QL muscle is located dorsolateral to the psoas major muscle on the posterior wall of the abdomen. The thoracolumbar fascia consists of aponeuroses and fascial layers covering the dorsal muscles. Therefore, it plays an important role in the distribution of the infiltrated LA in the thoracic PV region (56). The types of QL-block are: anterior, lateral, and posterior QL-block (3). It is applied in the lateral position. While a linear probe may be sufficient in children, a curved probe is preferred in older children.

In the lateral QL-block, the ultrasound probe is placed transversely in the midaxillary line. The thoracolumbar fascia at the junction of the TAM and the QL muscle, lateral to the QL muscle, is targeted. In anterior QL-block, the ultrasound probe is placed as in lateral QL-block. The LA is injected into the interfascial plane between the psoas major and the QL muscle. In posterior QL-block, the target point is the interfascial plane between the QL and the erector spinae muscle. The QL-block is a deep fascial plane block used for analgesia in various abdominal surgeries (3). Öksüz et al. found that QL-block provides more effective analgesia than caudal block and QL-block provides better and longer postoperative analgesia compared to TAP block (57,58). As shown in these studies, QL-block is thought to provide more effective analgesia due to the anatomic location of the thoracolumbar fascia.

Erector spinae plane block: The erector spinae muscle is a muscle group that includes the iliocostalis, the longissimus and the spinal muscles. These muscles extend from the skull to the pelvis and sacral region, from the transverse processes to the ribs. They are covered by a retinaculum. The ultrasound probe is placed parallel to the vertebrae. It is performed by injecting LA into the interfascial plane between the end of the transverse process of the spine and the erector spinae muscle (3,59). The retinaculum surrounding the erector spinae muscle provides a craniocaudal spread of the LA (3). Because the erector spinae muscle extends along the thoracolumbar spine, it provides a greater craniocaudal spread than the epidural (59). It also reduces the risk of accidental spinal anesthesia, central nervous system infection or injury in children compared to the epidural and caudal block (60). The erector spinae plane (ESP) block is preferred in children because it is easier to administer and safer than the PV-block (61). In the ESP-block, the LA spreads to the anterior and posterior rami according to the injection site in a craniocaudal direction and provides analgesia. It is an easy-to-apply block (3). It provides effective analgesia when used in conjunction with multimodal analgesia regimens (62). In 60 pediatric patients undergoing splenectomy, it was shown that opioid and non-opioid consumption decreased in the group that received ESP-block (63). Another case report supporting the findings of this study reported that ESP-block resulted in fewer drug-related side effects, earlier mobilisation, and shorter hospital stay (62). Because ESP-block is an interfascial block, the success of the block depends on the amount of LA injected (3).

Paravertebral block: The boundaries of the PV space are as follows: anterolaterally, the endothoracic fascia and the parietal pleura; posteriorly, the anterior aspect of the transverse process and the superior costotransverse ligament, which continues to the internal intercostal membrane; medially, the posterolateral aspect of the vertebral body, the intervertebral disc and the foramen. The spinal nerves leave the dura mater through the intervertebral foramen and enter the PV space. The block of the spinal nerves entering the PV space is called a PV-block. The patient is placed in the lateral or prone position. The appropriate vertebral level for thoracic and abdominal surgery is T5 and T10. The linear ultrasound probe is placed in the transverse paramedian position. The pleura, the erector spinae muscle, the internal intercostal membrane and the PV space are clearly visible. The PV space is visualised in a wedge shape. The needle is advanced into the PV space from lateral to medial using an in-plane technique. As the injection continues, the parietal pleura is observed to be displaced anteriorly. Paravertebral block can be safely used in place of epidural block in patients with coagulopathies (1). In addition, PV-block does not carry the risk of spinal hematoma and spinal cord injury, which are complications of epidural block. Paravertebral block causes less motor blockade in the extremities than epidural block unless the lumbar spinal nerves are affected. Paravertebral block is associated with less hypotension, urinary retention, motor weakness, and opioid-related side effects compared with thoracic epidural anesthesia (64). It is recommended that the method not be used if the lungs and pleura are infected (1).

CONCLUSION

In conclusion, pediatric regional anesthesia has emerged as a cornerstone of perioperative pain management, offering significant benefits over traditional techniques. With the integration of ultrasound guidance, the precision and safety of these blocks have been markedly improved, minimizing complications and optimizing analgesia. Local anesthetics, adjuncts, and advanced techniques like interfascial plane and peripheral nerve blocks allow for tailored approaches that meet the unique physiological needs of pediatric patients.

While the safety profile of pediatric regional anesthesia is well-supported by current evidence, further research is essential to refine dosing guidelines, evaluate the long-term outcomes of adjunctive therapies, and address gaps in the literature. As the global focus on reducing opioid use intensifies, regional anesthesia will remain integral to multimodal analgesia strategies, enhancing recovery and improving quality of care in this vulnerable population.

AUTHOR CONTRIBUTIONS

Conception or design of the work: FS
Data collection: OO
Data analysis and interpretation: OO
Drafting the article: OO, FS
Critical revision of the article: FS
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The author (OO, FS) reviewed the results and approved the final version of the manuscript.

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