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INVITED REVIEW ARTICLE

Ultrasound-guided trunk and core blocks in infants and children

Tarun Bhalla · Amod Sawardekar · Elisabeth Dewhirst · Narasimhan Jagannathan · Joseph D. Tobias

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Abstract Regional anesthetic techniques for perioperative analgesia in children are being increasingly utilized with the reported advantages of providing superior analgesia, decreasing opioid consumption, and reducing opioid-related adverse effects. The following article reviews the available literature regarding core and trunk blocks in infants and children; specifically, transversus abdominis plane, ilioinguinal/iliohypogastric nerve, rectus sheath, lumbar plexus, and paravertebral and intercostal nerve blockade. The common indications and potential complications and adverse effects for each block are presented. Additionally, the anatomy and techniques needed for their performance are reviewed. Finally, a summary of the relevant literature in relation to each peripheral nerve block technique is included.

Keywords Pediatric anesthesia · Regional · Pain · Ambulatory anesthesia

T. Bhalla · E. Dewhirst · J. D. Tobias
Departments of Anesthesiology and Pediatrics, Nationwide Children's Hospital and The Ohio State University Medical Center, Columbus, OH, USA

T. Bhalla (✉)
Department of Anesthesiology and Pain Medicine, Children's Memorial Hospital, 700 Children's Drive, Chicago, IL 43205, USA
e-mail: tarun.bhalla@nationwidechildrens.org

A. Sawardekar · N. Jagannathan
Department of Pediatric Anesthesiology, Children's Memorial Hospital, Chicago, IL, USA

Introduction

The literature has clearly demonstrated that the effective treatment of postoperative pain in infants and children is challenging. Despite the recognition of the importance of postoperative analgesia and the potential adverse effects of postoperative pain, significant pain occurs during the postoperative period in both the inpatient and outpatient settings [1–3]. Although the use of opioid analgesics is generally safe, adverse effects do occur, thereby mandating the use of alternative analgesic techniques when feasible [4]. In an effort to improve postoperative analgesia while limiting opioid-related adverse effects, there continues to be an increased use of regional anesthetic techniques in infants and children. Although the caudal remains the most commonly used regional anesthetic technique in infants and children, it has been demonstrated that effective analgesia can be provided with the use of peripheral nerve blockade even in the pediatric-aged patient [5–7]. Additionally, the available literature suggests that peripheral nerve blockade may have a lower incidence of adverse effects when compared with neuraxial techniques including caudal analgesia [8].

Given these data, there is an increasing use of peripheral nerve blockade in infants and children. Although commonly used in the adult population, many of these techniques have been utilized only to a limited extent in the pediatric-aged patient. As in the adult population, ultrasound guidance has proven efficacious in assuring the safe and effective use of these blocks. This article reviews the available literature regarding core and trunk blocks in infants and children, presents the common indications for each block, and highlights the anatomy and techniques needed for their performance.

Regional anesthesia of the core and trunk

Transversus abdominis plane block

Introduction

The transversus abdominis plane (TAP) block was first described as a means of providing analgesia following lower abdominal and laparoscopic procedures in the adult population [9–14]. As originally described, analgesia is provided by the placement of the local anesthetic solution between the internal oblique (IO) and the transversus abdominis muscles using an injection in the triangle of Petit. In the adult population, the TAP block has a well-established efficacy in providing postoperative analgesia for lower abdominal procedures such as bowel resection, retropubic prostatectomy, cesarean section, and total abdominal hysterectomy. In a prospective randomized trial, TAP block with either ropivacaine (0.2 mL/kg of 0.75 %) or placebo was administered to 50 adults following cesarean delivery [12]. The group receiving ropivacaine had decreased postoperative pain scores, a 70 % reduction in postoperative morphine requirements, and a prolonged time to first request for analgesia (220 vs. 90 min).

Indications

The TAP block has been used to provide analgesia to the anterior abdominal wall following several different abdominal surgical procedures including appendectomy, cholecystectomy, cesarean section, and most laparoscopic incisions. Unlike 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 in many cases may provide analgesia that is effective enough to eliminate the need for opioids.

Anatomy and technique

Sensory innervation of the anterolateral abdominal wall is provided by the anterior divisions of spinal nerves T_8–L_1. These nerves course in a plane between the transversus abdominis and IO muscles, and deposition of local anesthetic in this plane, as first described by McDonnell et al. [10], will lead to interrupted innervation and regional anesthesia of the abdominal skin, muscles, and parietal peritoneum. This is achieved with a single injection administered in the triangle of Petit, an anatomical locale on the lateral abdominal wall, bound posteriorly by the latissimus dorsi, anteriorly by the external oblique (EO) muscle, and inferiorly by the iliac crest. McDonnell et al. [10] demonstrated correct placement of this block with a blind, loss-of-resistance technique by cadaveric dissection after the injection of methylene blue dye and also by computed tomography imaging after the infiltration of radiopaque dye.

Ultrasound guidance, with a linear high-frequency probe is now preferred for TAP block placement. 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 [15, 16]. 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 then moved laterally to delineate the three layers of the abdominal wall: the EO, the IO, and the transversus abdominis. The probe is stationed lateral on the anterior abdominal wall at a 70°–90° angle with the patient's bed. A needle is inserted, utilizing the 'in-plane' technique, from the medial aspect of the probe between the IO and the transversus abdominis (Fig. 1). Injection, with incremental aspiration, will create an elliptical opening of the potential space in which the nerves traverse.

Complications

Although complications are uncommon, especially when using ultrasound guidance, it should be noted that 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 [17].

Pediatric reports

The first reports of the use of the TAP block in pediatric patients appeared in 2008–2009 [14, 18–20]. Mukhtar and Singh [14] placed a bilateral TAP block in 4 patients aged 14–17 years following laparoscopic appendectomy. Ultrasound guidance was used to infiltrate 20 mL of 0.25 % bupivacaine per side, and for the first 12 postoperative hours, patient pain scores did not exceed 2 out of 10 and no patient required supplemental analgesia. Two patients required no analgesic agents during their entire postoperative course. Tobias reported the successful use of TAP block in a cohort of 10 pediatric patients, ranging in age from 8 months to 10 years [18]. The TAP block was placed bilaterally using 0.3 mL/kg of 0.25 % bupivacaine with epinephrine. The surgical procedures included bilateral ureteral reimplantation ($n = 3$), laparoscopy for evaluation

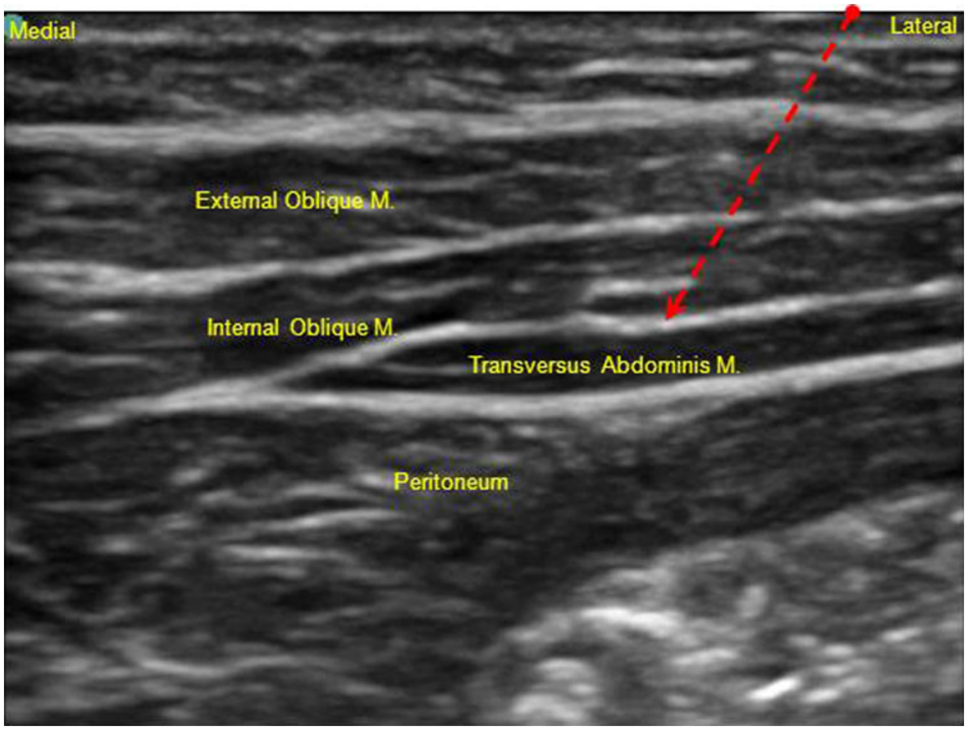

Fig. 1 Technique for transversus abdominis plane (TAP) block. The needle is inserted, utilizing an 'in-plane' ultrasound technique, from the medial aspect of the probe. The needle is positioned between the internal oblique and the transversus abdominis muscle layers. Injection, with incremental aspiration, will create an elliptical opening of the potential space. *Red dashed line* indicates needle placement

of abdominal pain ($n = 2$), colostomy takedown ($n = 2$), laparoscopic appendectomy ($n = 2$), and bilateral inguinal hernia repair ($n = 1$). The TAP block was judged to be successful in 8 of the 10 patients, as no postoperative analgesic agents were needed for the initial 7–11 postoperative hours. The author also noted that the TAP block has advantages over the caudal block in various scenarios including patients with spinal dysraphism or patients larger than 20–25 kg in whom caudal epidural block may be more technically difficult.

Unilateral TAP block was also shown to provide effective analgesia in a prospective study of 8 children undergoing inguinal hernia repair [19]. All patients maintained postoperative pain scores of 0–2, 7 patients required no postoperative opiates; one patient received intravenous morphine to treat emergence agitation. The block was placed preoperatively and 5 patients needed no intraoperative opiate, with fentanyl (<0.5 μg/kg) required in the remaining 3 patients during manipulation of the spermatic cord, which involves stimulation of the genitofemoral nerve, supplied partially by L_2. A case report from 2008 outlined the use of a TAP block to provide postoperative analgesia for a 2-day-old neonate undergoing colostomy placement [20]. Vertebral anomalies associated with the patient's VACTERL syndrome (vertebral anomalies, anal atresia, cardiovascular anomalies, tracheoesophageal fistula, renal and/or radial anomalies, and limb defects) precluded the use of a caudal epidural blockade and prompted the author's choice of TAP block. More recently, Taylor et al. [21] reported the successful placement of TAP catheters to provide postoperative analgesia in 2 pediatric patients with spinal dysraphism.

The final report regarding TAP blocks in the pediatric population outlines the results of a prospective, randomized trial comparing a unilateral TAP block with ropivacaine versus placebo in a cohort of 40 pediatric patients following open appendectomy [22]. The TAP block reduced morphine requirements in the first 48 postoperative hours (total dose of 10.3 ± 12.7 vs. 22.3 ± 14.7 mg, $p < 0.01$) when compared with placebo. The TAP block also resulted in lower pain scores at rest and with movement. There was no difference in the incidence of nausea, vomiting, or sedation.

Summary

The preliminary literature in infants and children suggests that the TAP block provides effective analgesia following various umbilical and lower abdominal procedures, including laparoscopy. In comparison to the more commonly used caudal epidural analgesia, the TAP block offers the advantage of being feasible in patients with vertebral anomalies and in older pediatric patients weighing more than 20–25 kg. Even in the adult population, it can be confidently performed following the induction of general anesthesia, as the block does not involve needle placement near the neuraxial space or peripheral motor nerves. Use of a TAP block has also been reported in a patient with an intracranial lesion which would preclude the use of neuraxial blockade due to concerns of altering intracranial pressure with epidural anesthesia [23]. Current experience outlined in the pediatric literature suggests the use of 0.2–0.3 mL/kg per side of either 0.25 % bupivacaine or 0.2 % ropivacaine. However, data are limited and further studies would help clarify the optimal dosing regimen. 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 the most likely serious adverse event and attention to volume and concentration is imperative, with the total dose of bupivacaine or ropivacaine not to exceed 3 mg/kg.

Ilioinguinal/iliohypogastric nerve block

Introduction

Unlike most other peripheral nerve blocks, ilioinguinal and iliohypogastric (IL/IH) nerve blockade was initially introduced in the pediatric population in the late 1980s and then later used in the adult population. IL/IH nerve blockade is used commonly to provide perioperative pain relief for children undergoing inguinal procedures. It has proven to be efficacious as well as safe with landmark-based administration in the pediatric population [24–26]. Hannallah et al. [27] described the analgesia provided by the block as comparable to caudal analgesia for same-day surgery procedures over 20 years ago. Although placement of the IL/IH nerve block was initially accomplished using anatomic surface landmarks, the introduction of ultrasound has been shown to improve the accuracy and consistency of the IL/IH nerve block [28–30].

Indications

In the pediatric population, the IL/IH block has been used to provide analgesia for surgical procedures in the inguinal region and lateral scrotum, including inguinal hernia repair, hydrocelectomy, and orchiopexy. It may also be used for diagnostic or therapeutic purposes in patients suffering from chronic pain after previous surgical procedures in the inguinal area. In the adult population, the IL/IH block has proven efficacious in reducing opioid requirements after obstetric and gynecological surgery.

Anatomy and technique

The ilioinguinal and iliohypogastric nerves originate from T_{12} and L_1 of the thoracolumbar plexus. The nerves traverse the IO aponeurosis 1–3 cm medial to the anterior superior iliac spine (ASIS). It has recently been demonstrated that accurate placement of the local anesthetic solution around the IL/IH nerves with the landmark technique results in more failed blocks when compared with ultrasound-based deposition [29]. Weintraud et al. [29] 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.

The classic “fascial click” approach to the IL/IH block recommends needle insertion at a point one-third of the way between the ASIS and the umbilicus. The needle is advanced until a loss of resistance is felt, which should identify the space between the IO and transversus abdominis muscles. Alternatively, for 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 IO and the transversus abdominis. An oval structure may be visualized encompassing the neurovascular bundle. The ilioinguinal nerve can 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 [31].

The needle is inserted in plane with the ultrasound probe from a lateral to medial approach with incremental aspiration. It is important to deposit the local anesthetic solution between the IO and transversus abdominis with evidence of layer separation (Fig. 2). 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 [30].

Complications

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 [32]. Complications seem to be increased when using the blind technique as compared with the ultrasound technique.

Pediatric reports

Most of the recent literature regarding IL/IH nerve blocks confirms the utilization of ultrasound, the latter being

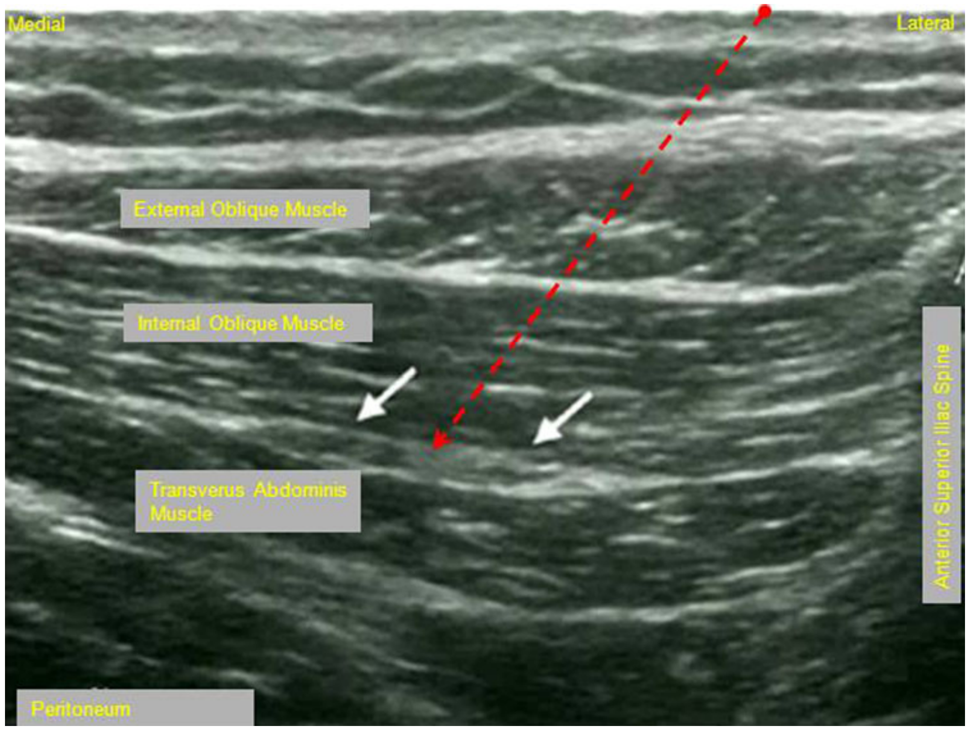

Fig. 2 Technique for ilioinguinal/iliohypogastric blockade. The needle is inserted in plane with the ultrasound probe from a lateral to medial approach. The local anesthetic solution is placed between the internal oblique and transversus abdominis with evidence of layer separation. In 50 % of patients, only the internal oblique and the transversus abdominis layers can be visualized. *Red dashed line* indicates needle placement. *Arrows* show where local anesthetic should be deposited

particularly important given the issue of the variance in the anatomy of the IL/IH nerves during maturation. Ultrasound has been shown to allow significantly less total local anesthetic use when compared with the conventionally recommended doses of 0.3–0.5 mL/kg [30]. In a prospective trial with a 50 % volume reduction at each level that resulted in 100 % success of the IL/IH nerve block, the effective volume of 0.25 % levobupivacaine required to achieve 100 % success was 0.075 mL/kg. Jagannathan et al. [33] have shown the benefit of a single-shot caudal in conjunction with an IL/IH nerve block as compared with a caudal alone in reducing postoperative pain scores in a cohort of 48 pediatric patients following unilateral groin surgery. The two groups in the cohort received a caudal epidural block prior to the start of surgery, with 0.7 mL/kg of 0.25 % bupivacaine, and then were randomized to receive an IL/IH block at the end of surgery with 0.1 mL/kg of either preservative-free normal saline or 0.25 % bupivacaine. Patients who received the combination caudal with an IL/IL block had a decrease in the pain score (scale of 0–10) by 0.72 ± 0.58 during their time in the recovery room. The difference was greatest in patients undergoing inguinal herniorrhaphy. No difference was noted in time to first request for analgesic medication or the amount of rescue analgesics required.

A recent study compared the efficacy of an IL/IH nerve block with a TAP block, both placed using ultrasound guidance, following inguinal surgery in a cohort of 41 pediatric patients [34]. The TAP block was less effective, as demonstrated by the presence of pain while patients were in the recovery unit (76 vs. 45 %, $p = 0.040$) and the need for rescue analgesia with ibuprofen (62 vs. 30 %, $p = 0.037$). No difference was noted between the two groups in regard to total morphine consumption, post-discharge ibuprofen use, comfort scores, and satisfaction scores. Ultrasound image quality was poorer and needle time under the skin was longer in the IL/IH block group.

Summary

Of the peripheral nerve blocks, IL/IH nerve blockade remains one of the most common blocks in infants and children. The use of IL/IH nerve blocks in the pediatric population has increased owing to the increased surgical volume of inguinal procedures in the pediatric population. The recent advent of ultrasound has proven to be beneficial in the accuracy and effectiveness of this block. Even if the IL/IH nerves cannot be directly visualized by ultrasound, the local anesthetic agent can be injected between the IO and TA muscles. It will follow the fascial planes and envelope the neurovascular bundles. The block provides superior analgesia in comparison to intravenous opioids or even a TAP block. The IL/IH block is frequently applicable even in patients in whom neuraxial analgesia including a caudal may be contraindicated.

Rectus sheath block

Introduction

The rectus sheath (RS) block was first described by Schleich, in the nineteenth century, to provide relaxation of the anterior abdominal wall in the adult population. More recently, Smith et al. [35] utilized the RS block for adult laparoscopic gynecological procedures. In 1996, Ferguson et al. [36] suggested the use of the RS block to provide analgesia for umbilical hernia repair in the pediatric population. One year later, Courreges et al. [37] described a new technique for providing analgesia for children undergoing umbilical hernia repair, and described it as the paraumbilical block. The difference in these techniques is mainly based on the site of needle injection, with the latter block being placed using 4 injections (two on each side) at the level of the umbilicus rather than two injections (one on each side) above the level of the umbilicus. Since its original description, the use of the RS block has increased with reports of its use for umbilical hernia repair, pyloromyotomy, and midline laparoscopic incisions.

Indications

The RS block is used in analgesia for peri-umbilical surgical procedures including single-incision laparoscopic surgery and umbilical herniorrhaphy.

Anatomy and technique

The umbilical region is innervated by the right and left 10th intercostal nerves, which are 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 them 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.

A linear high-frequency probe is placed just lateral to the umbilicus. The rectus abdominis muscle is visualized as the first major layer beyond the subcutaneous tissue. 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 (Fig. 3). The accuracy of placement of the local anesthetic agent in the correct location can be increased by the use of ultrasound [38].

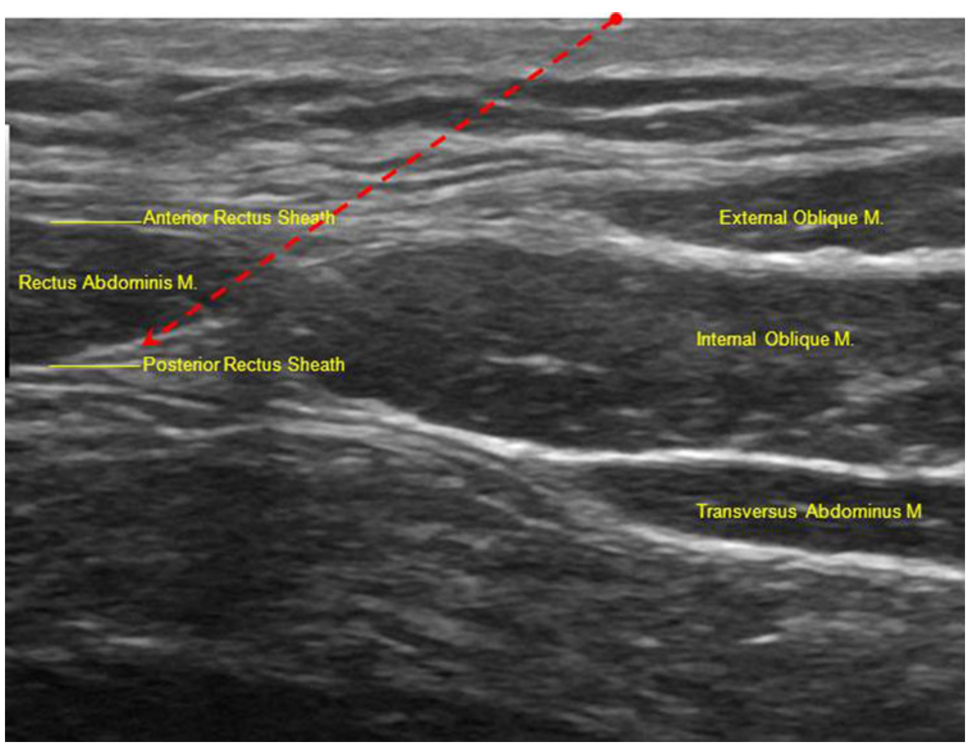

Fig. 3 Technique for the rectus sheath block. The ultrasound probe is maintained immediately lateral to the umbilicus. A needle is placed using an in-line approach from the lateral aspect of the probe. The local anesthetic agent is deposited in the potential space between the rectus abdominis muscle and its posterior sheath. *Red dashed line* indicates needle placement

Complications

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 as the inferior epigastric artery is also in close proximity to the site of needle injection. Retroperitoneal hematoma formation has also been reported.

Pediatric reports

The first interest in the applications of the RS block in the practice of pediatric anesthesia began in 1996 [36]. This was followed by the report of Courreges et al. [37] who presented a slight variation on the technique, calling it a para-umbilical block. In that report, they described the use of the para-umbilical block in a cohort of 11 children, ranging in age from 2 months to 9 years, undergoing umbilical hernia surgery. They reported successful postoperative analgesia at 1 h following surgery in 10 of the patients and at 6 h following surgery in 8 of the 11 patients. Willschke et al. [39] were the first to report the use of ultrasound-guided RS blocks in the pediatric population. The study started with a sono-anatomic evaluation in 30 children which noted a poor correlation between the depth of the posterior RS and the weight of the child, body surface area, or their height. In the second part of the study, the authors demonstrated the efficacy of RS block using 0.1 mL/kg of 0.25 % levobupivacaine in providing analgesia following umbilical hernia surgery in 20 children.

De Jose Maria et al. [40] recently described a new approach to the classic technique. The modified technique included avoidance of the epigastric vasculature as well as isolating the 10th intercostal nerve at the lateral edge of the rectus abdominis muscle before the anterior cutaneous branching points. Ten children scheduled for umbilical hernia repair were included and underwent a bilateral RS block as described above. The needle was localized to the lateral edge of the rectus muscle at the junction of the aponeurosis of the IO and transversus abdominis muscles, using ultrasound guidance followed by the administration of 0.1 mL/kg of 0.25 % bupivacaine. Effective analgesia was achieved in all patients without the need for supplemental intraoperative or postoperative opioids. Despite the uniform efficacy noted in the previous studies, Isaac et al. [41] demonstrated no difference in the postoperative effects when comparing RS block and local infiltration in a cohort of 14 children (1–8 years of age).

Summary

Although it may be difficult to visualize the 10th intercostal nerve with an 8- to 10-MHz linear probe, ultrasound allows for visualization of the deposition of the local anesthetic agent within the potential space between the rectus abdominis and its posterior fascial sheath. The benefit of injecting the local anesthetic at the most lateral edge near the aponeurosis of the transversus abdominis and the IO is to ensure the blockade of anterior cutaneous branching points. 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 [42].

Lumbar plexus block

Introduction

The lumbar plexus block (LPB) or psoas compartment block (PCB), first described in 1976, traditionally has been performed using surface anatomic-based landmarks and a loss-of-resistance technique verified by paresthesias [43]. The technique was subsequently modified with the use of a nerve stimulator with quadriceps contraction to improve the success rate. In 2004, Kirchmair et al. [44] described the relevant sono-anatomy for a posterior LPB. In a cadaver population, they were able to accurately guide a needle under ultrasound guidance to the posterior aspect of the psoas muscle and localize the roots of the lumbar plexus. Unlike the brachial plexus, which is enveloped between the fascia of the anterior and middle scalene muscles, the lumbar plexus frequently traverses the substance of the psoas major muscle. Thus, the anatomic variability reinforces the benefit of utilizing ultrasound guidance to enhance the success rate of the LPB.

Indications

Lumbar plexus blocks are utilized intraoperatively and postoperatively for procedures of the hip and proximal lower extremity including the knee. The LPB is also used as both a diagnostic and therapeutic tool for both acute and chronic pain disorders. The block is ideal for unilateral proximal lower-extremity procedures where a neuraxial technique may be undesirable and/or contraindicated.

Anatomy and technique

The lumbar plexus is formed by the union of the anterior rami of the first four lumbar nerves (L_{1-4}) with variable input from the 12th thoracic nerve (T_{12}) and L_5. The lumbar plexus lies in the "psoas compartment" in the paravertebral space with the anterior border formed by the psoas major muscle and the posterior border formed by the quadratus lumborum. As noted above, the lumbar plexus in many cases may actually lie within the body of the psoas major muscle. As it emerges from the paravertebral space or the psoas muscle, it divides into the three nerves that innervate the anterior portion of the upper aspect of the lower extremity: femoral, lateral femoral cutaneous, and obturator nerves. The femoral nerve provides sensory innervation to the anterior and medial aspects of the thigh and motor innervation to the quadriceps muscles. The lateral femoral cutaneous nerve is purely sensory, providing sensory innervation to the lateral aspect of the thigh. It branches from the lumbar plexus and enters the thigh deep to the inguinal ligament, medial to the ASIS. The obturator nerve provides motor innervation to the adductors of the leg, as well as sensory innervation to part of the medial aspect of the lower portion of the thigh. The obturator nerve also innervates the knee joint, making it imperative to anesthetize it to achieve analgesia following procedures involving the knee.

The most common approach in performing LPB is the transverse approach. Utilizing a 40- to 60-mm curvilinear probe oscillating at 2–5 MHz, the transducer is placed midline at the L_4 level to visualize the spinous process. The transducer is then moved laterally (approximately 2–4 cm) away from the midline toward the paravertebral space. Both the articular and transverse processes of the vertebral column should be in view. The structures from superficial to deep include the erector spinae, transverse process, and psoas muscle (Fig. 4). If the quadratus lumborum is in view the probe is likely too lateral. If the articular process and/or vertebral body are in view, the probe is too medial. If a bony prominence is encountered during needle advancement, it is likely the transverse process. The needle should be "walked-off" in a caudad or cephalad direction. A loss of resistance is frequently felt as the psoas compartment is entered.

Complications

Rare but serious complications include trauma to intraperitoneal viscera, renal trauma and hematoma, and epidural spread of local anesthetic. In a recent randomized controlled trial of continuous LPB for hip arthroplasty, there was a 7 % incidence of epidural spread of local anesthetic [45]; postoperatively, two of the catheters clotted, while 3 % of the continuous catheters were ineffective.

Pediatric reports

Prior to the widespread use of ultrasound, various reports appeared outlining the efficacy of lumbar plexus blockade as a means of providing analgesia following hip and femur surgery in infants and children [46–48]. These reports used either a loss-of-resistance technique or nerve stimulation to identify the correct location for the deposition of the local anesthetic agent. In 2004, Kirchmair et al. [44] published sonographic findings in children, showing that anatomical skin-to-plexus distance was correlated with weight rather than with age; these findings enhanced the utility of the

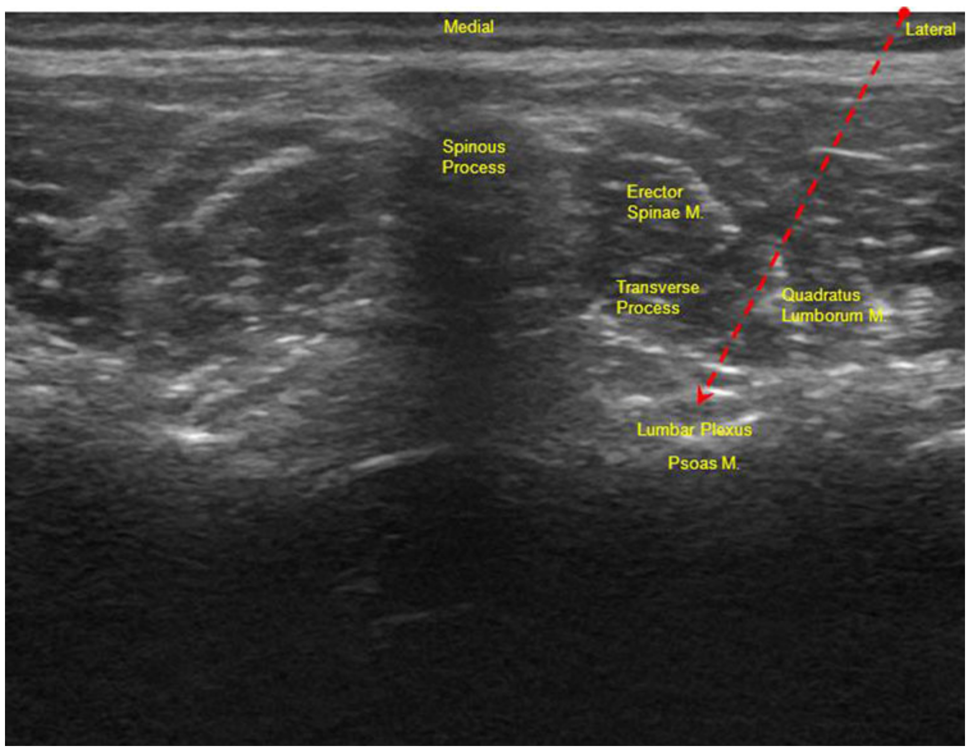

Fig. 4 Technique for the lumbar plexus block. The ultrasound (2–5-MHz curvilinear) probe is placed at the L_4 in the transverse orientation approximately 2–4 cm from the midline. After the psoas major muscle is identified, the needle is inserted using an in-line approach from the lateral aspect of the probe. Local anesthetic is deposited in the posterior one-third of the muscle in the perineural region. *Red dashed line* indicates needle placement

posterior approach to the LPB. Walker et al. [49] measured the depth from the skin to the lumbar plexus in 350 consecutive patients and noted that the strongest correlation for the lumbar plexus depth was the distance between the posterior superior iliac spine (PSIS) and the intercristal line (ICL). These measurements can be used as a guide for ultrasound location and may reduce potential unwanted complications associated with the LPB in children.

Summary

To date, there are limited centers with widespread expertise regarding the use of the LPB in the pediatric population. It remains a technique that is used more commonly in the adult population. However, with ultrasound guidance, attention to proper technique, and the use of simple tools to estimate the depth of the lumbar plexus from the skin, it appears that there are useful applications of this technique in the pediatric population, especially for patients who have major surgical procedures involving the hip and proximal femur, such as derotation osteotomies.

Paravertebral block

Introduction

The first paravertebral block was performed in 1905 by Hugo Sellheim in an attempt to find a replacement for spinal anesthesia owing to concerns about its effects on cardiovascular function. Sellheim and his surgical resident studied small injections of procaine at the emergence of spinal nerves to prevent pain in patients undergoing laparotomy. This led to the mapping of the segmental innervation of the intra-abdominal organs. Subsequent investigations of the anatomy of the cervical region led to the modern-day techniques of paravertebral anesthesia including cervical plexus blockade. Although initially described in the early 1900s, the popularity of the paravertebral block has cyclically emerged in the literature, with a resurgence during this past decade. Like the literature on many regional anesthetic techniques, the majority of the literature regarding these techniques deals with the adult population. Although considered separately above, the LPB may be considered to be a paravertebral block at the lumbar level.

Indications

Paravertebral nerve blocks can provide excellent postoperative analgesia with fewer adverse effects and fewer contraindications than central neuraxial blockade. Thoracic paravertebral blocks have been shown to be effective for several types of unilateral procedures of the trunk (thoracic or lumbar area), including thoracotomy, breast surgery, cholecystectomy, renal surgery, and herniorrhaphy [50–55]. Typically, two to three dermatomes are covered with a single injection in the paravertebral space. More recently, the block has been used for major abdominal and vascular surgery, as well as in the treatment of various chronic pain syndromes including malignant neuralgia and complex regional pain syndrome [56–58].

Anatomy and technique

The paravertebral space is a potential space, filled with intercostal and sympathetic nerves. It becomes a wedge-shaped cavity when filled with a local anesthetic [59, 60]. At this level, the spinal nerve lacks both an epineurium and part of the perineurium and is therefore easily penetrated by the local anesthetic agent owing to a thin membranous sheath. The boundaries of the paravertebral space include the superior costotransverse ligament posteriorly, the parietal pleura anteriorly, intervertebral discs medially, and the head and neck of ribs superiorly.

In the pediatric population, following the induction of general anesthesia, the patient is placed lateral or prone. At the appropriate spinous process, under sterile conditions, a linear array transducer is moved longitudinally in the cephalo-caudad direction until the corresponding transverse process is identified (hypoechoic structure with a hyperechoic border). The ultrasound probe is then rotated 90° perpendicular to the spinal column. Using this point for the view, both the transverse process and the pleura can be visualized using the ultrasound. Utilizing an in-plane approach from lateral to medial, a Tuohy needle is incrementally advanced with a loss-of-resistance syringe attached. The needle traverses the intercostal muscles and is advanced to a point which is just prior to the pleural border (Fig. 5). At this point, the contents of the syringe should be easily injected. The local anesthetic agent can be injected and/or a catheter placed into the space.

Complications

In a retrospective study, the overall incidence of adverse effects or complications of the paravertebral block were <5 % even before the advent of ultrasound-guided techniques [61, 62]. With a unilateral paravertebral block, the risk of accidental pleural puncture was 0.8 %, with the development of a pneumothorax in 0.5 % of the total patient population. Although their incidence is low, additional adverse effects include hypotension from local anesthetic spread centrally with central sympathetic blockade, the potential for neurological damage with intrathecal or extradural entry, and paravertebral hematoma formation. There also has been a case report describing the development of Horner's syndrome [62].

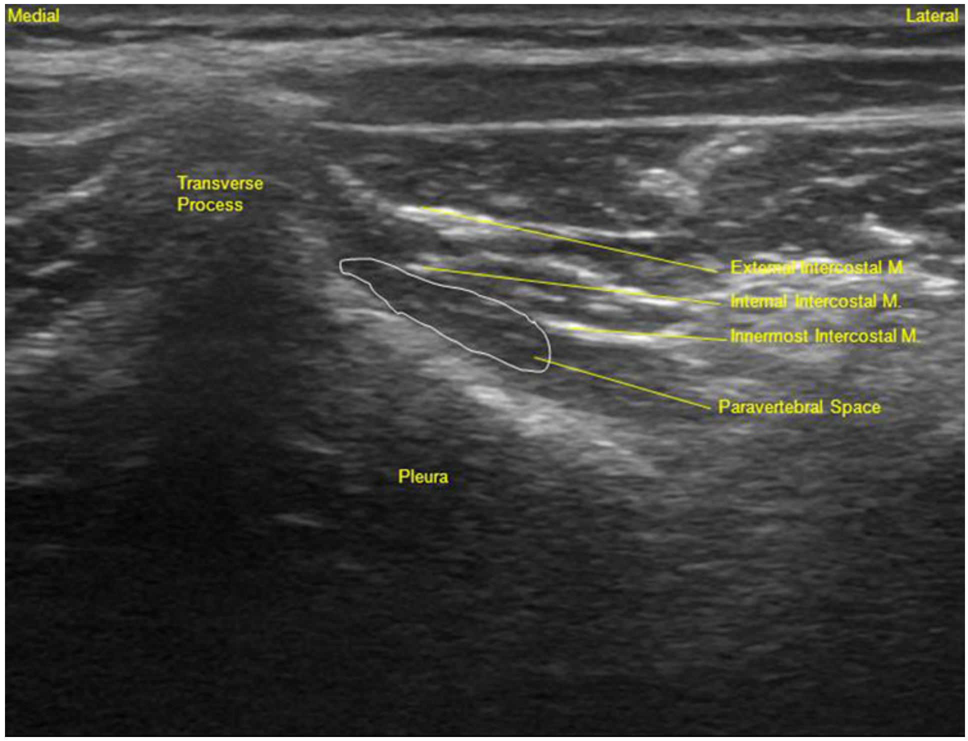

Fig. 5 Ultrasound demonstrating the anatomy for a thoracic paravertebral block. An ultrasound probe is placed at the vertebral level to be anesthetized in a transverse orientation immediately lateral to the midline spinous process. The needle is advanced from the lateral aspect of the probe utilizing an in-plane approach. The needle is advanced deep to the costotransverse ligament with hydro-dissection of the potential paravertebral space. Local anesthetic is deposited to expand the wedge-shaped paravertebral space

Pediatric reports

Lonnqvist [53] was the first to describe the use of continuous paravertebral blocks in children, in 1992. This study suggested that the paravertebral block was a promising technique for acute pain management as well as for postoperative recovery in the pediatric population. Fifteen years later, Berta et al. [63] published their study on the successful use of a single-injection paravertebral block in children undergoing renal surgery. This prospective observational study evaluated 24 children undergoing major renal surgery with a standardized general anesthetic, with postoperative analgesia provided by a single lumbar paravertebral injection using a loss-of-resistance technique. Effective analgesia was demonstrated using clinical pain scores, including the FLACC (face, legs, activity, cry, consolability) score, as well as by evaluating postoperative opioid consumption. A successful block was achieved in 23 of the 24 patients (95.8 %). The median duration of the analgesia following the block was 600 min, with 10 children not requiring any supplemental analgesia during the 12-h postoperative period. Vascular puncture was observed in 2 of the 24 children (8.3 %), but did not result in serious sequelae.

More recently, paravertebral nerve blocks have been used in patients that may have contraindications to neuraxial analgesia or anatomic issues which preclude central blockade. Bilateral paravertebral blocks have been shown to be an effective alternative to epidural analgesia for midline surgery. Visoiu and Yang [57] described bilateral paravertebral continuous nerve catheters for postoperative analgesia in a coagulopathic pediatric patient undergoing an exploratory laparotomy for a bowel resection.

Summary

Overall, with the increasing utility of ultrasound, the placement of paravertebral blocks has increased for both intraoperative and postoperative pain relief in the pediatric population. There has been a shift from a paradigm of block placement as an alternative to neuraxial anesthesia in patients with co-morbid conditions to a primary form of analgesia, with increasing success. Additional studies are needed to evaluate the utility of both unilateral and bilateral paravertebral catheters as a means of providing analgesia following major surgical procedures in infants and children.

Intercostal nerve block

Introduction

First described by Braun in 1907, intercostal nerve blocks are used to provide analgesia for a variety of thoracic and abdominal surgeries or injuries, although the majority of the literature reports their use for post-thoracotomy analgesia. Reports in adults indicate excellent analgesia, reduced opioid requirements, increased compliance with pulmonary exercises, and reduced pulmonary complications such as atelectasis and pneumonia. Reports in children are more limited, but generally concur with adult findings and demonstrate the safety of this technique. Intercostal nerve block may be achieved with a single injection of local anesthetic or by a continuous infusion using a catheter placed into the intercostal space.

Indications

The intercostal nerve block is useful for providing analgesia for thoracic trauma such as rib fractures and surgical procedures involving the thorax and upper abdomen, such as thoracotomy, open cholecystectomy, and liver resection. This nerve block may also have a role in chronic pain involving the same anatomy.

Anatomy and technique

The intercostal nerves are the ventral (anterior) rami of the thoracic spinal nerves T_{1-12} and supply sensation to the skin and muscles of the thorax and upper abdomen. The nerves travel in the space between the internal and innermost intercostal muscles along with the intercostal artery and vein below the inferior edge of the rib. They are not surrounded by a fascial sheath, which facilitates their blockade with local anesthetic. As the lateral cutaneous branch originates in the mid-axillary line, injection of local anesthetic proximal to this area is ideal. In children, an intercostal block is most commonly placed at the posterior axillary line, as this allows them to rest in a semi-prone position during the procedure. Medial to the posterior angle of the rib, there is a rare chance of infiltrating the dural sheath, an increased risk of pneumothorax, and increased difficulty in palpating the rib owing to the overlying sacrospinalis muscle.

Using an aseptic technique, the intended skin entry sites are marked and infiltrated with lidocaine. For a single-shot block, a short 20- to 22-gauge Tuohy or block needle, directed 20° cephalad with the bevel facing up, is advanced to hit the posterior rib surface. Walking the needle caudad at the inferior border of the rib, the needle is slowly advanced. There may be a subtle ‘pop’ as the needle passes through the fascia of the internal intercostal muscle. In adults, the average distance from the posterior border of the rib and the parietal pleura is 8 mm [64], but no such measurements have been made in children. After negative aspiration of blood, 0.2–0.5 mL/kg of either 0.2 % ropivacaine or 0.25 % bupivacaine with 1:200,000 epinephrine is injected. Although there will be some spread of local anesthetic, in part owing to natural defects in the intercostal muscles, separate injections for the blockade of one intercostal nerve above and below the desired dermatomes are recommended to cover overlapping fibers.

Utilizing ultrasound imaging, the probe is applied in a sagittal plane lateral to the surgical incision site (anterior approach) or along the posterior axillary line (posterior approach). The ribs are imaged as hyperechoic streaks. In between and just deep to the ribs are hyperechoic lines, which represent the pleura. Next, the probe is rotated so that it is in plane with the rib; it then can be shifted to a cephalad or caudad direction to differentiate between rib and pleura. As the patient breathes, the visceral and parietal pleura can be visualized as they slide past each other in ‘real time’. A block needle is placed in-plane with the ultrasound probe from a lateral-to-medial approach and inserted below the lower border of the rib. The needle is advanced until the distal tip is just superficial to the pleura. A tissue plane is delineated between the internal and innermost intercostal muscles as the local anesthetic agent is injected (Fig. 6).

The duration of action of a single-shot intercostal block using bupivacaine is 8–16 h. If prolonged analgesia is required, repeated injections or the continuous administration of local anesthetic is an option. Using an 18-gauge Tuohy needle, a catheter can be advanced into the intercostal space. The catheter should not easily advance more than 3 cm beyond the needle tip or interpleural placement should be suspected. When directed medially, catheter placement may result in a paravertebral block and has been suggested as an alternative technique to paravertebral placement [65].

Complications

Pneumothorax is a commonly voiced concern with intercostal nerve blockade, although the incidence is reported at 0.073 % [66]. Lower-level intercostal nerve blocks could result in penetration of the peritoneum and abdominal viscera, although this has not been reported. Owing to the highly vascular area, the absorption of local anesthetic from the intercostal space is the highest of all peripheral blocks, with peak plasma concentrations of bupivacaine 0.5 % occurring between 5 and 15 min in children [67]. The addition of epinephrine to the local anesthetic will slow the systemic absorption. There are rare reports of total spinal anesthesia as a complication of intercostal blockade, postulated to be owing to inadvertent injection into a dural cuff extending outside the intervertebral foramen [68, 69]. Additionally, Horner syndrome has been reported following continuous intercostal nerve blockade [70].

Pediatric reports

Shelly and Park retrospectively reviewed the postoperative analgesic requirements in 14 children undergoing liver

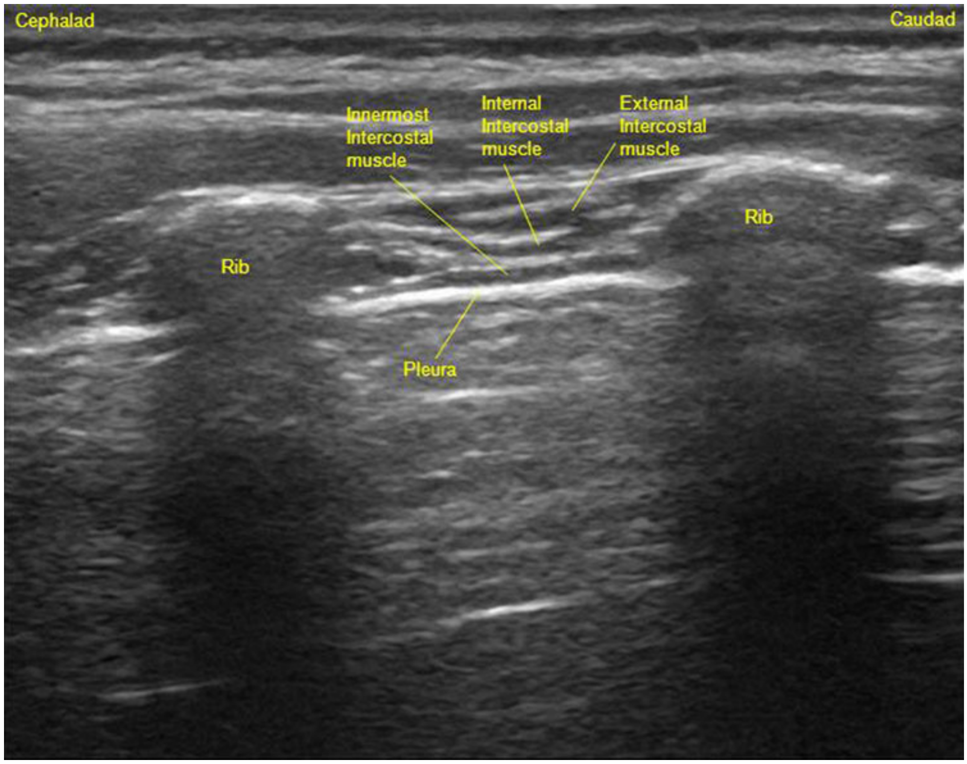

Fig. 6 Ultrasound image demonstrating the anatomy for an intercostal block. An ultrasound probe is placed at the level to be anesthetized at the posterior axillary line in the transverse plane. With the lower border of the rib in view, the needle is advanced in a lateral-to-medial approach until the potential space between the internal intercostal and innermost intercostal muscle is reached. Local anesthetic is deposited to expand the potential space

transplantation, 9 of whom received intercostal blocks and 5 of whom received intravenous opioids alone [71]. Fifty-six percent of the children receiving the intercostal block required no additional opiate analgesia, and the mean morphine equivalent doses on postoperative day 3 were 0.16 and 1.52 mg/kg in the block and non-block groups, respectively. In a prospective study of 20 children, ranging in age from 5 to 12 years, receiving general anesthesia for elective thoracotomy, there was improved postoperative analgesia in the group receiving intercostal blockade compared with those maintained on opiates alone [72]. When compared with patients receiving intravenous opioids, patients who received an intercostal block had a longer time until the first request for postoperative analgesia (8.8 $\pm$ 2.0 vs. 3.4 $\pm$ 1.3 h) and a decrease in the overall need for postoperative morphine (2.5 $\pm$ 0.52 vs. 3.4 $\pm$ 0.31 mg/kg/24 h).

Examining pharmacokinetics, Rothstein et al. [67] reported a faster absorption of bupivacaine from the intercostal space, more rapid clearance, and greater volume of distribution in children than in adults. Results indicated bupivacaine doses of 2–3 mg/kg with epinephrine 1:200,000 could be employed safely for intercostal nerve blockade in children. Bricker et al. also reported faster time to peak plasma concentration, and confirmed safety with bupivacaine at a dose of 1.5 mg/kg used for intercostal block in neonates and infants [73]. Using ropivacaine, Maurer et al. [74] reported plasma concentrations above the accepted safety level after an initial bolus of 1 mg/kg followed by a continuous infusion at 0.4–0.6 mg/kg/h. Therefore, typically, a bolus dose of 0.5 mL/kg should be used for appropriate analgesia with a lower risk of local anesthetic toxicity.

Regarding continuous intercostal nerve blocks in children, Downs and Cooper [75] reported their experience with nine children, who ranged in age from 1 to 12 years, following thoracotomy. Using a surgically placed extra-pleural catheter, the dosing regimen included an infusion of 0.3 mg/kg/h of bupivacaine after an intraoperative loading dose of 0.75–1.5 mg/kg. They reported adequate analgesia, minimal need for supplemental morphine, and no adverse effects.

Summary

Overall, the utility of intercostal nerve blockade in the pediatric population may be invaluable for thoracotomies. If there are contraindications to a neuraxial technique or if the risk of an asleep thoracic epidural outweighs the benefits, an intercostal block should be considered.

Overall summary

Peripheral nerve blocks offer the pediatric patient excellent postoperative analgesia with the potential for reducing intra- and postoperative opioid consumption and hence opioid-related adverse effects. Additionally, selected studies have demonstrated improved analgesia when comparing regional anesthetic techniques with intravenous opioids. In the truncal region, a spectrum of regional anesthetic techniques is available to provide analgesia for thoracic, abdominal, and inguinal surgical procedures, as well as major orthopedic procedures of the hip and femur. Currently, with the exception of ilioinguinal/iliohypogastric nerve blockade, regional blocks of the trunk are used relatively infrequently in children compared with adults. However, with increasing literature demonstrating improved technique and safety in children, as well as the increased use of ultrasound, there is increasing interest in using these techniques in the pediatric population. Ultrasound guidance has been shown to increase the accuracy and efficacy of these techniques, decrease the incidence of complications, and minimize the volume of local anesthetic needed. Given this information, it is generally recommended that ultrasound be used in the performance of trunk blocks in the pediatric population. Overall, pediatric regional anesthesia is a vital tool to obtain optimal pain control and anesthetic care. The future of pediatric regional anesthesia seems promising owing to the use of safer techniques and their wider acceptance.

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Conflict of interest None.

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