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OTHER PAIN (N VADIVELU AND A KAYE, SECTION EDITORS)

Updates in Pediatric Regional Anesthesia and Its Role in the Treatment of Acute Pain in the Ambulatory Setting

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Abstract
Purpose of Review The purpose of this review is to summarize the latest advances in pediatric regional anesthesia with special emphasis on its role in the ambulatory surgical setting.
Recent Findings Undertreated pain in children following ambulatory surgery is not a rare occurrence and it is associated with increased morbidity and significant psychosocial harm. Use of regional anesthesia as part of the anesthetic approach in the ambulatory setting is safe when performed on children under general anesthesia and inclusion of certain adjuncts improves block outcomes. Ultrasonographic visualization during blockade improves safety and prolongs duration. Ambulatory continuous nerve blocks in older children are safe, efficacious, and associated with high patient and caregiver satisfaction rates.
Summary In the ever-growing field of pediatric same-day surgery, safe and efficient flow through the perioperative period necessitates use of a multimodal approach, of which regional anesthesia is but one important component. Perioperative complications are minimized with less opioid use, and yet appropriate pain management must be ensured. Pediatric regional anesthesia has been shown to be exceedingly safe under general anesthesia. Findings demonstrate that advances in ultrasound technology have contributed to safer and longer-lasting analgesia. It facilitates the development of new methods by which regional anesthesia can improve postoperative analgesia in children upon discharge and beyond.

Keywords Pediatric ambulatory anesthesia · Pediatric regional anesthesia · Pediatric analgesia · Pediatric anesthesia · Pediatric acute pain

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Introduction

This review summarizes the most recent literature published on the role of regional anesthesia (RA) in pediatric outpatient surgery, including current practice trends and evidence-based consensus opinion on several of the field's most controversial topics.

Epidemiology of Pediatric Ambulatory Surgery

Pediatric ambulatory surgery continues to grow annually. Pediatric outpatient procedures increased from 26 to 38 per 1000 children over a 10-year period [1]. The most common ambulatory surgeries are myringotomy, tonsillectomy, adenoidectomy, orthopedic and urologic procedures, and hernia repair [2]. Pediatric regional anesthesia (PRA) for outpatient procedures is also expanding, with 18% growth in a recent 10-year period [1], mostly due to increasing peripheral nerve blocks (PNBs) for orthopedic surgeries rather than neuraxial blockade [3].

Ambulatory Pediatric Pain Management

Pediatric outpatient surgical practice is ideal because risks inherent to inpatient admissions, such as iatrogenic infections and increased cost, are minimized. In children, same-day discharge reduces the stress of parental separation and disruption of routine. However, as a result, children are suffering from insufficient analgesia on subsequent postoperative days after even the most routine procedures [4••, 5]. In fact, the most common ambulatory surgeries are considered to be the most painful: tonsillectomies, appendectomies, orchidopexies, circumcisions, and orthopedic surgeries [5, 6]. An early survey by Mather et al. demonstrated that 40% of these patients experienced moderate to severe pain and 75% had suffered from inadequate analgesia [7]. Recent papers affirm those conclusions: that children's pain following ambulatory surgery is still undertreated postoperatively and at home [5, 8].

At all points of the postoperative period, studies have demonstrated that children's pain is undertreated, starting in the recovery unit. This finding is attributed to a poor comprehension of acute pain management, difficult pain assessments, and hesitancy regarding treating the very young. At home, the onus for pain control falls onto the primary caregiver with varying results. Because untreated pain has demonstrable physiological [9, 10•], psychological, and financial tolls, adequate analgesia must be ensured to minimize morbidity and health costs for successful ambulatory flow-through [11–13].

Multimodal Approach to Ambulatory Anesthesia

Implementation of RA in the ambulatory setting effectively reduces factors which delay discharge: postoperative nausea and vomiting (PONV), urinary retention, prolonged recovery, and delayed ambulation [14]. Moving away from opioid-based methodologies to utilizing a multimodal approach is fundamental to current adult and pediatric ambulatory practice. Best practice ambulatory anesthesia minimizes opioid use, uses local infiltration, incorporates safer agents, and utilizes PNBs [4••]. RA can be utilized in over 80% of pediatric surgical procedures [15]. The association between RA and decreased unplanned hospital admissions (and less cost) for adult orthopedic surgery has been established [16]. Recently in children, Hall-Burton et al. was able to show that RA-based analgesia (femoral/sciatic blocks; +/− femoral catheter) for ACL repair reduced UHA costs related to vomiting or pain [17•].

Is Pediatric Regional Anesthesia Safe?

Efforts to draw strong conclusions from pre-existing evidence have been limited by small sample sizes and low power. The major recent advancement in the field is attributed to new high-powered databases able to outline safety and complication rates. Four seminal large-scale prospective studies (>10,000 patients/study) presents 20 years of evidence which support longstanding claims by experts that it is not only reasonable but safe to perform PRA under GA [18, 19]. Their aim was to define the safety profile and epidemiology of neuraxial and peripheral RA in the children, and none reported any instances of total paralysis or other major complications after neuraxial for anesthesia or analgesia, with an incidence (95% CI) of 0 (0–0.004%) for paralysis [20••].

The first of these studies, from the ADARPEF 1996 1-year prospective of 38 centers (~25,000 blocks, 89% under GA), revealed a complication rate of 0.9 per 1000 blocks [21]. The 2010 ADARPEF follow-up of 48 centers (~30,000 blocks with GA, 1263 without GA) reconfirmed a low 0.12% complication rate without long-term sequelae. Of note, researchers found a sixfold increase of complications with neuraxial over peripheral blockade [22]. The 2007 UK Prospective National Pediatric Epidural Audit looked at the complications associated with pediatric epidural analgesia (>10,000 epidurals, all but 1 under GA). Of the only 96 incidents reported, most were categorized as minor with 5 considered serious and 9 major (1:2000) [23].

The most recent safety literature has come from the Pediatric Anesthesia Regional Network (PRAN) database, the first internet-based continuous audit of practice trends and complication rates in children. Started in 2006 at 6 US academic centers and now with 20 participating institutions, the network has collected data on >90,000 PNBs producing valuable analyses and several publications [24••, 25, 26, 27•, 28••, 29–31]. The preliminary 2012 publication from the PRAN database covered 15,000 blocks (2007–2010) looking at the incidence and nature of complications. Polaner et al. reported no deaths or long-term (>3 months) sequelae from complications [26]. Most recently, the 2014 PRAN Report (>50,000 blocks, >95% under GA) demonstrated that PRA under GA does not increase risk of complications, early or delayed. More importantly, Taenzer et al. was able to conclude that placement of blocks under GA is as safe as placement while children are sedated or awake [24••].

Borestsky and DiNardo editorialize that highly powered internet-based data collecting, while valuable, should be interpreted with caution [32]. Authors from PRAN acknowledge limits in capturing certain detailed information regarding patient comorbidities, block efficacy, and surgical procedure. While these studies are powerful statements, there is research yet to be undertaken regarding the further safety and dosing within the field [28••].

Controversial Topics in PRA

The European Society of Regional Anaesthesia (ESRA) and Pain Therapy and the American Society of Regional

Anesthesia and Pain Medicine (ASRA) Joint Committee released the first set of two advisories to guide best PRA practice. The first practice advisory lays out an evidence-based set of recommendations covering several controversial topics where high-level evidence is lacking [20••, 33].

Regional Anesthesia Under General Anesthesia or Deep Sedation

The cumulative best evidence available with regards to RA under GA/DS in children concludes that it is safe and should be standard of care (evidence B2 and B3) [20••]. Taenzer et al. in their examination of 53,564 regional nerve blocks found that 94.5% of regional blocks were placed under GA (75% without neuromuscular blockade; 19.5% with neuromuscular blockade). The placement of blocks under GA had lower adverse outcomes than did placement of blocks in a sedated or awake patient. Awake patients were seven times more likely to experience postoperative neurologic complications [24••].

Test Dosing

Interpreting a negative LA test dose of epinephrine is difficult as children do not respond to intravascular epinephrine as do adults. Such attenuated response is attributed to choice of anesthetic agents, higher pediatric basal heart rates, and variable responsiveness of immature cardiac fibers to epinephrine. As such, the absence of hemodynamic changes (changes in heart rate, T waves, or systolic blood pressure) does not rule out intravascular injection and so the measure has been deemed discretionary (evidence B4) [20••].

Compartment Syndrome

The belief that peripheral nerve blockade may mask the onset of the ischemia pain from acute compartment syndrome (ACS) is a significant barrier to RA use in many clinical settings. Isolated case reports which suggest that RA leads to diagnosis or treatment delays have been reported, but otherwise is not supported by a strong evidence base. In fact, other reports suggest that the presence of breakthrough pain after placement of a well-functioning block can be an early indicator of ACS. Communication difficulties which accompany the treatment of young children are more likely to contribute to delays in ACS diagnosis, potentially prolonging its clinical time course (evidence B4). Best practice recommendations include taking measures to reduce that which may mask onset of ischemia pain. This includes the use of dilute LA concentrations in both single-shot techniques (0.1 to 0.25%) and in continuous infusions (0.1%) (evidence B4), the judicious use of adjuvants and in those surgeries with higher ACS risk, and minimization of both concentration and volumes of LA [20••].

Adjuncts and Pediatric Regional Anesthesia

Consensus regarding adjunct use in both central and peripheral blockade has not yet been reached [33]. The ideal adjunct for the ambulatory setting will augment blockade while avoiding adverse effects associated with agents such as morphine or fentanyl, i.e., PONV, hypoventilation, or prolonged recovery. Most investigational agents are not yet recommended for use in children, with exception of clonidine, morphine, and ketamine. Conclusions drawn from the adult literature should not be extrapolated onto the pediatric population due to unknown, potentially deleterious effects on the developing nervous system.

Adjuncts in Central Nerve Blockade

Clonidine has characteristics that are ideal for ambulatory surgery due to its favorable side effect profile [34]. This agent is backed by evidence which supports its augmentation of pediatric caudal analgesia. Recent meta-analysis of the existing literature was undertaken by Schnable and colleagues. Their analysis of 20 trials showed that neuraxial clonidine is associated with a significant increase in analgesia duration (3.98 h; 95% CI 2.84–5.13). The net outcome was less overall rescue medications and no increased adverse effects compared to plain local anesthetic-based epidural [35].

With regard to dexmedetomidine, the meta-analysis by Tong and colleagues suggests prolongation of postoperative analgesia with minimal adverse effect when compared to LA alone. These studies are preliminary in nature and insufficiently powered, and further research into concentration versus adverse effect is needed [36•]. Comparison of clonidine and dexmedetomidine has yet to define one agent superior to the other [37].

Recently, one study has proposed the use of magnesium in caudal analgesia, with results suggesting high-quality analgesia with brisk return of motor activity versus LA alone. Of course, further clinical investigation is required [38].

Adjuncts in Peripheral Nerve Blockade

Overall, the body of evidence regarding adjuvant use in peripheral blockade is particularly conflicting, especially with regard to clonidine. Cucchiaro et al. found that the addition of 1 mcg/kg clonidine (100 mcg, max dose) prolongs sensory and motor block duration independent of LA choice or concentration [39]. Clonidine, when added to bupivacaine-based infraorbital nerve blocks for cleft lip repair, appears to increase analgesia and decrease anesthetic requirements without adverse effects [40]. However, another smaller study found that perineural clonidine (1 mcg/kg) does not improve block quality of 0.2% ropivacaine-based axillary nerve blocks in children, but possibly does lengthen the time until rescue analgesia administration [41]. Real conclusion on the use of clonidine in PNBs in children cannot be made until more high-powered controlled studies are undertaken.

Results on dexmedetomidine in adult PNBs have been promising [42], so Lundblad and colleagues examined its feasibility in children via a prospective, randomized, double-blind trial. Dexmedetomidine 0.3 mcg/kg with 0.197% ropivacaine-based nerve block for inguinal hernia repair prolonged time to first supplemental analgesia by 88% and produced no adverse events [43]. The results are promising, but additional research is needed to verify the safety and efficacy of the perineural injection of these agents in the pediatric population.

Dexamethasone as an Adjunct

Dexamethasone has been examined as both a perineural and a systemic adjunct with confounding results. In adults and children, systemic administration is known to reduce PONV [44], and two recent meta-analyses confirm that single-dose intravenous and perineural dexamethasone administration reduces opioid requirements in adults [45]. In children, intravenous single-dose (0.5 mg/kg) administration appears to augment the intensity and duration of caudal analgesia without adverse effect [46, 47]. However, the only study directly comparing intravenous to perineural dexamethasone efficacy was in adults. Leurcharusmee and colleagues' randomized comparison study found that perineural dexamethasone (5 mg) provided 19–22% longer block duration and analgesia postoperatively compared to intravenous administration [48]. At this point, it is unclear whether analgesia augmentation is attributable to systemic or perineural administration. Future study must avoid confounding results with routine administration of dexamethasone as PONV prophylaxis.

Central Neuraxial Blockade in Pediatric Regional Anesthesia

Spinal Neuraxial Anesthesia

The upside of spinal anesthesia in children—cardiopulmonary stability, less apnea and respiratory complications, and rapid recovery over GA—is on the surface ideal for ambulatory surgery. Recent evidence has supported its safe use in infants and children for subumbilical surgery [49••, 50], including recent preliminary results from the GAS Study by Davidson and colleagues. In addition to data regarding potential neurodevelopmental effects of GA, the results suggest spinals are uniformly safe in varied settings worldwide. Spinal anesthesia is the only technique to reduce incidence of postoperative apnea, and use of standard protocols (isobaric bupivacaine 0.5%, 0.2 ml/kg with 22 or 25 g spinal needle) consistently translated to 60–90 min of surgical anesthesia [49••]. Awake spinal anesthesia is a cost-saving alternative ideal for healthcare settings in economically challenged environments when used as a substitute for GA [49••, 50, 51].

Widespread implementation of spinal anesthesia in ambulatory surgery has been limited by several factors, except in certain specialized centers, despite said benefits. The block regresses rapidly, is more short-lived in the young, and carries a significant failure rate (10%) [52•]. As such, specific planning for supplemental pain control postoperatively is required for spinal anesthesia use in same-day surgery. This requisite conflicts with the aim of the multimodal approach of current pediatric ambulatory anesthesia practice [51]. Unless a special ambulatory spinal anesthesia program is initiated, spinals are best indicated in inpatient settings for those most likely to benefit, i.e., formerly premature infants and neonates with specific apneic risk [53].

Caudal Neuraxial Blockade

Caudal epidural blockade remains the gold standard of RA in children. Single-shot caudal epidurals comprise 80% of all pediatric blocks. It is easy to master and provide reliable anesthesia for subumbilical surgery [15]. Suresh et al. conclude that after prospective analysis of >18,000 caudal blocks, safety concerns should not be a barrier to its use in children, provided administered local anesthetic (LA) dosages are within the therapeutic range [28••]. It is important to note that though this technique has proven to be low risk, severe neurological complications can and do occur [54].

Advances in ultrasound (US) technology have significantly impacted recent investigation into caudal spread mechanics. Imaging studies show that LA volume (versus concentration or injection speed) positively correlates with cranial spread and time until rescue analgesia [55, 56], and yet the ultimate sensory level obtained from dispersion is not predicted by direct imaging. Unfortunately, Brenner et al. surmised that the corresponding dermatome reached by such spread was too variable for predictive clinical application [57]. Other imaging studies defined an inverse relationship between age, height, and weight with cranial extension [58]. Lastly, Lundblad et al. found that injecting high volume causes a transient increase in intracranial pressure with a concomitant decrease in cerebral blood flow as measured by transcranial doppler [59].

Recently published reports are reexamining certain contraindications and practice standards. Kako et al. report a short series of caudals placed uneventfully in children with peritonitis [60]. Keplinger et al. recently examined the feasibility of caudal blocks in larger children/adolescents (30–50 kg) and found that the technique is safe as long as LA plasma concentrations remain submaximal and ultrasonography is used [61•].

Comparison of caudal analgesia to peripheral techniques suggests the latter may win out due to a net effect of equipotent analgesia with fewer complications. Cyna and colleagues showed that upon comparison of pediatric caudals, parenteral analgesia, and dorsal penile nerve block, no difference in rescue analgesia needs or PONV was detected after circumcision [62]. More so, the caudal group experienced significantly more motor block than the others. A meta-analysis of caudal blocks versus other analgesic strategies suggests that there is no demonstrable difference in postoperative pain score or required rescue analgesia. Authors propose alternative strategies with less risk in place of neuraxial analgesia for inguinal hernia repairs [63•].

Peripheral Nerve Blockade in Pediatric Regional Anesthesia

Clinical practice is shifting from "gold standard" caudals to peripheral techniques targeting nerves of the trunk and extremities [64]. The ADARPEF data demonstrates this very trend: central blockade has decreased from 60 to 34% of all PRA (45% of PRA in ages <3 years), with an unchanged complication rate higher than that of peripheral blockade by sixfold [25, 26]. Ultrasound use has led to the targeted delivery of anesthetics to peripheral nerves resulting in decreased dosing volumes and systemic absorption for better safety profiles and less morbidity [26]. Children with specific contraindication to neuraxial anesthesia can also benefit from peripheral techniques. They include those with coagulopathies, spinal dysraphism (meningomyelocele), bony abnormalities such as VATER/VACTERL, or postspinal fusion with instrumentation/ postlaminectomies [65].

Truncal Peripheral Nerve Blockade

Abdominal core blocks may be ideal for minor subumbilical abdominal surgeries conducted in the ambulatory setting. A caveat, all but the paravertebral core blocks, does not cover visceral pain elicited by peritoneal or spermatic cord tension [66]. The transversus abdominis plane (TAP) and illioinguinal/ illiohypogastric (IL/IH) blocks offer the most utility in ambulatory RA, and updates on these truncal blocks will be discussed.

Transversus Abdominis Plane Blockade

The use of TAP block versus caudal analgesia for a variety of pediatric urologic and abdominal surgeries is currently being explored, with little pre-existing direct comparison. Concern for high potential risks for peritoneal or liver puncture prevented accumulation of large-scale studies [25]. In adults, US-guided TAP block does substantially reduce the postoperative opioid consumption in laparoscopic cholecystectomies suggesting a potential caudal alternative [67]. In children, high-volume TAP block (0.5 ml/kg 0.25% levobupivacaine) prolongs postoperative analgesia versus wound infiltration alone in unilateral inguinal hernia repair [68]. Yet, Fredrickson et al.'s prospective randomized comparison found that ultrasound-guided IL/IH block provided superior postoperative analgesia over TAP blockade following inguinal surgery in children [69]. Further conclusions cannot be drawn while work is ongoing to define optimal application in the PRA practice [70].

The latest PRAN data reveals that complications are minor and rare with an incidence of 0.3% in children. Major events, such as peritoneal or bowel puncture and liver trauma, are possible, but less frequent upon implementation of ultrasonography [25, 71]. US guidance reliably promotes placement of LA into the proper plane, improving success rates with minimal complication. However, the site of needle insertion (subcostal, anterior, etc.) seems to influence the extent of spread and pattern of corresponding block coverage. This characteristic may prove beneficial, making the TAP block amenably flexible to surgeries at varying sights of the abdominal core [72].

Ilioinguinal/Iliohypogastric Nerve Blockade

IL/IH nerve blocks in children have been used in combination with GA for inguinal hernia repair and urologic procedures with variable success [73]. This may be due to the fact that the IL/IH nerves do not provide adequate analgesia for procedures involving the testicles which have pain fibers originating from T10, whereas the IL/IH nerves originate from the L1 nerve root [73]. Also attributable to initial low block success is that landmark-based placement has proven to be highly imprecise, with only a 61% success rate. A US study revealed that only 14% of LA administered reaches the proper plane without ultrasonographic guidance. Weintraud et al. demonstrated that IH/IL nerve blocks were placed with ultrasonographic visualization of LA deposition; the success rates jump to 94% [74–76].

Successful blocks are achieved using less volume under ultrasound with reduced risk of toxicity. Interestingly, LA deposition into the correct intramuscular plane has also been linked to increased absorption of LA overall, possibly from less diffusion, so care must be taken to keep volumes well beneath maximal doses [74]. Finally, as meta-analysis confirms, with the improvements in technique afforded by US, the IL/IH block is at least equivalent to caudal epidural in terms of duration and quality of analgesia, but, as with most peripheral techniques, benefits from fewer adverse effects [63•, 77].

Extremity Peripheral Nerve Blockade

Regional use in children has grown steadily in recent decades, from 4.4 to 8.1% of pediatric ambulatory surgery [1]. PNBs for outpatient pediatric orthopedic surgery have actually accounted for the majority of the growth trends, with an increase from 1.2 to 43% of all blocks over a 10-year period [3]. Advances in ultrasonography and heightened awareness from large-scale studies illustrating higher complication rates with neuraxial techniques have propelled these trends [28••].

Ultrasound for Extremity Blocks

The application of ultrasonography to pediatric extremity blocks has improved efficacy and duration and lowered complication rates. The direct visualization afforded by US use facilitates the insertion of indwelling continuous catheters and provides a safer administration of nerve blocks with less local anesthetic volume [15, 78]. Duncan et al. demonstrated that while US direction and nerve stimulation had similar success rates for placement of supraclavicular blocks, the ability to visualize LA spread translated to block success achieved with less volume. [79]. Such implementation for interscalene blocks reduced volume and needle passes and resulted in better postoperative analgesia versus nerve stimulation [80••].

Upper Extremity Nerve Blocks

The PNBs for the upper extremity target specific points along the brachial plexus. Upper extremity blocks in children have enjoyed significant growth, by 64.8% in 10 years [3]. Supraclavicular, infraclavicular, and interscalene blocks comprise 74% of upper extremity blocks for pediatric traumatic orthopedic injuries, tumor removal, and repair of congenital malformations and vascular injuries [15, 26]. A summary of the most common upper extremity blocks is summarized in Table 1.

Lower Extremity Nerve Blocks

The lumbar plexus and lumbosacral plexus innervate the lower extremity, covering the anterior and posterior portions of the leg, respectively. Lower extremity blocks are more prevalent than those of the arm due to larger, more easily visualized structures and because they lack the potential respiratory complications associated with upper extremity blocks. Nerve stimulation use has declined with ultrasonography, but continues to have a role in blocking deep structures as in the lumbar plexus [26]. A summary of the most common lower extremity blocks are summarized in Table 2.

Continuous Peripheral Nerve Blocks for the Extremities

The extended analgesia afforded by continuous peripheral nerve blockade (CPNB) in children is indicated for surgeries with severe postoperative pain, painful physical therapy treatments, or treatment of complex regional pain syndrome [81, 82]. Perineural catheters significantly extend block duration beyond the 12–14 h afforded by peripheral nerve blockade alone [83]. Until recently, few had examined the feasibility and efficacy of peripheral nerve catheters (PNCs) in the pediatric ambulatory setting [82, 84, 85]. Visoiu and colleagues prospectively reviewed 403 ambulatory pediatric patients with PNCs placed. These children had lower pain scores and opioid requirements in recovery and at home relative to controls. Furthermore, patients and caregivers were highly satisfied with the extent of pain control provided by the catheters; which had a 14% complication rate (catheter leakage, 35%; failure rate, 6.9%) [86].

Adult literature has demonstrated safe use, but few studies examined the same in children. Walker et al. was able to demonstrate that use of CPNBs in children is safe, with low complication and failure rates with no reports of neurologic/infectious complications or systemic toxicity (incidence 0.04%) [27•]. The results from his PRAN database query show that use of indwelling catheters is increasing, most commonly being placed in the lower extremity of children older than 10 years of age and with near uniform utilization of ultrasonography (>90% of blocks). Of 2074 PNCs logged, only 251 reported that were mostly minor complications (incidence 12.1%) consisting of catheter malfunction/failure, infection, and vascular puncture. Of note, young children (<3 years) made up less than 5% of cohort, so results are not generalizable to this age group [27•].

Gurnaney and colleagues looked at ambulatory CPNBs in their retrospective single-center experience of 1492 catheters. They reported similar complication rates (4.2% catheter problems; 1.9% failures). In just the 5 years of review, the percentage of children being sent home with ambulatory CPNBs increased by 80% with 35% being discharged on day of surgery. Their data suggests that it is feasible to establish a pediatric ambulatory catheter program in a dedicated specialized facility [87, 88]. Even though the study included the largest cohort to date, its retrospective nature limits strong conclusions regarding risk versus benefit. As Krane and Polaner point out, prospective data collection models such as PRAN will produce evidence more conclusive and compelling overall [89].

Blocks of the Head and Neck

Children undergoing head and neck procedures, especially tonsillectomies, experience significant pain for several days post procedure [90] and benefit from multimodal regimen which incorporates regional techniques. Blocks of the head and neck are easy to place and are low-risk but underutilized; of note, no adverse events or sequelae attributed to this subset of blocks have been reported on the PRAN database [26]. Specific head and neck blocks are best indicated for the ambulatory setting which will be updated here.

Table 1 Common peripheral nerve blocks of the upper extremity (brachial plexus)

Nerve block	Targets	Surgery type	Advantages	Disadvantages	Complications
Interscalene	Roots (C5–C7)	Shoulder, upper arm	Performed under GA in children as safe as placement in awake adults [35]	Ulnar sparing (C8-T1) Contraindicated in severe respiratory disease Vicinity of important nearby structures - Nerves - Vessels - Spinal cord	Unilateral diaphragmatic paralysis (phrenic nn. blockade) Horner's syndrome Hoarseness (recurrent laryngeal nn. block) Risk of intra-arterial injection (vertebral artery) Complete spinal Pneumothorax, rare
Supraclavicular	Divisions (C5-T1)	Elbow, distal upper hand to hand	Diaphragm paresis, less likely Horner's syndrome, less likely All nn. structures lateral to subclavian artery	Misses the suprascapular nn., inadequate shoulder coverage Increased risk of pneumothorax (higher rise of cervical pleura)	Pneumothorax, more likely Diaphragm paresis Horner's syndrome Intravascular injection due to proximity of subclavian artery
Suprascapular	Superior trunk (C5–C6)	Shoulder arthroscopy Chest port insertion	Pneumothorax, low risk	Most ideal for posterior approach arthroscopic surgeries	Vascular puncture, proximity of suprascapular artery
Infraclavicular	Cords (C5-T1)	Elbow, forearm and hand	Block can be performed for patients who cannot abduct arm for axillary block	Medial cord very close to axillary artery and vein so higher risk of vascular puncture than axillary block	Vascular puncture, risk of hematoma
Axillary	Branches (C5-T1) Median, ulnar, and radial nerves	Elbow to forearm and hand	Multiple nerves covered, one injection	Musculocutaneous nn. outside the neurovasc. sheath, supplemental injection Superficial structures, easily compressed vein → intravascular injection Block requires arm abduction, painful/limiting in some injuries	Intravascular injection into axillary artery Neural injury
Distal nerve blocks	Specific nerves at forearm, wrist, or digits	Surgery for individual digits or parts of the hand	Isolates individual nerves for blockade, increased motion, use of arm/forearm	Risk of nerve compression/injury Variable results, may require multiple injections Less common in the pediatric population	Nerve compression/injury

Table 2 Common peripheral nerve blocks of the lower extremity (lumbar/sacral plexus)

Nerve block	Targets	Surgery type	Advantages	Disadvantages	Complications
Lumbar Plexus	Lumbar plexus, major branches: femoral, obturator, and lateral femoral cutaneous nn.	Hip, surgeries above the knee	Multiple nerves covered, one injection	The LA must have adequate spread over the posterior surface of psoas muscle Deep block, same anticoagulation guidelines as neuraxial block apply Difficulty with compression in event vasculature puncture Deep block benefits from use of nerve stimulation and US for adequate identification High vascularity could lead to LA toxicity from absorption	Hematoma formation Nerve injury
Femoral	Femoral nerve (L2–L4)	Surgeries of anterior thigh	Technically easy block to perform with US guidance	Below knee surgery requires additional block (sciatic nn.) Femoral nerve is in close proximity to femoral artery and vein	Vessel puncture Nerve injury
Lateral femoral cutaneous nn.	Lat. fem. cut. Nn. (L2–L3)	Superficial surgery of anterolateral thigh	Easy to perform, superficial block, avoidance of other vascular structures	Always a supplement to other lower extremity blocks	Infection and hematoma, rare
Adductor Canal	Saphenous nerve (distal sensory branch of femoral nn.)	Surgery to medial aspect lower leg to ankle (not foot)	Avoids quadriceps muscle weakness associated with femoral nerve block	Usually supplemented to sciatic nn. blockade Less sensory block at knee	Infection, nerve injury and hematoma, rare
Sciatic, subgluteal	Sciatic nn. (L4-S3)	Surgeries involving lower leg	Block can be performed in multiple positions, with US guidance and/or nerve stimulation	Often combined with femoral, lateral femoral cutaneous nerve blocks	Infection, nerve injury and hematoma, rare
Sciatic, popliteal fossa	Tibial/common peroneal nn. at branch point (L4-S3)	Surgeries involving the lower leg	Can also be done in multiple positions under US guidance	Often combined with femoral, lateral femoral cutaneous nerve blocks	Hematoma formation d/t popliteal artery proximity Nerve injury, rare

The great auricular nerve, providing sensory innervation to the mastoid and the external ear, is a target for children undergoing tympanomastoid surgery. Among the most commonly placed ENT blocks [26], it has been shown to reduce PONV and opioid requirements, providing near equivalent pain control to 0.1 mg/kg of morphine sulfate [91]. Deep needle advancement runs the risk of placing LA infiltration at level of the deep cervical plexus block with potential complications including Horner's syndrome, phrenic nerve block, or unintended subarachnoid injection.

The infraorbital block is indicated for cleft lip repairs, rhinoplasties, and endoscopic sinus surgery. A 2016 Cochrane Review of infraorbital blocks in cleft lip repair in children found that the evidence (8 studies, 353 children) for postoperative pain reduction is low in quality, undersampled, and of questionable bias, but suggests that the block is superior to placebo and improves postoperative analgesia with less feeding delays [92]. The block significantly decreases the frequency and duration of sevoflurane-associated emergence agitation and with satisfactory analgesia and no delays in extubation, according to one study [93]. Use of bilateral infraorbital blocks with block of the external nasal branch of the anterior ethmoidal nerve has been recently proposed as a technique in children with nasal fractures [94].

The bilateral suprazygomatic maxillary nerve block is a novel alternative technique in children and infants undergoing palate surgery, which has been taken from a technique used to treat trigeminal neuralgia in adults [95, 96]. Sola and colleagues reported the feasibility of ultrasound-guided maxillary nerve blocks in cleft palate repair and found low technical failure rates and good success, with visualization of LA injection into the pterygopalatine fossa present in most cases [96].

The peribulbar block in children is an advanced technique utilized in eye surgery at specialized ambulatory centers such as our institution. Infants and children with congenital or acquired ophthalmologic disorders require multiple exams and surgical interventions under anesthesia. A "quiet eye" is essential for optimal surgical conditions, achievement of such requires deep anesthetic levels to suppress eye movement and activation of the oculogyric reflex, an upward and outward eye movement. The presence of this reflex is an indicator of "light" anesthesia [97, 98], and is associated with emergence delirium. In children who had received a peribulbar block under GA for vitreoretinal surgery, Subramanian et al. observed a significant decrease in hemodynamic variability, postoperative pain, oculocardiac reflex, and PONV [99]. Others documented a reduction of inhaled volatile agent concentration, maintenance of eye immobility, and early return to normal feeding and discharge [100].

To place the peribulbar block, our practice employs a short needle, 0.25 ml/kg of 0.375% ropivacaine or 0.25% bupivacaine (3 mg/kg, max dose), and an infero-temporal needle approach maintaining distance from the globe with slow incremental push to stabilize intraocular pressure (see Fig. 1).

Fig. 1 Intraoperative peribulbar block of the left eye of a 2-year-old child. An inferotemporal transconjunctival approach is illustrated using a short-beveled needle with 0.375% ropivacaine. Photo credit: Jacqueline L. Tutiven, MD; Bascom Palmer Eye Institute

Use of ultrasound for ophthalmic blockade has been described in adults [101], and ongoing studies are looking into ocular-rated probes for the placement of peribulbar blocks in adults which may avoid thermal injury and biomechanical complication risks associated with non-specialized probes [102]. However, in terms of the immature eye, there remain unanswered questions. US technology may have deleterious effects on the normal eye development, specifically with regard to the vitreous and lens. As such, future study and research are warranted before widespread application.

Conclusion

Pediatric regional anesthesia has made tremendous strides in recent years. Advances in ultrasound technology have promoted evolution of new techniques, improved block safety and efficacy, and promoted new areas of research. As ambulatory same-day surgery continues to expand, the inclusion of safe and effective measures to reduce adverse impacts must continue as standard of practice. RA remains an important component of the multimodal approach specifically benefitting pediatric patients over opioid-based analgesia. As such, further progress must be made to guarantee that children benefit from better postoperative analgesic measures. Future innovations will include methods by which analgesia can be extended for days into the postoperative period. Smooth transition from the ambulatory to home settings can ultimately be improved upon with development of longer-acting local anesthetics, increased implementation of ambulatory peripheral nerve catheters, and clarification of safe adjuvant use in nerve blockade.

Compliance with Ethical Standards

Conflict of Interest Alecia L. S. Stein, Dorothea Baumgard, Isis Del Rio, and Jacqueline Tutiven declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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