Peripheral Nerve Block Complications in Children

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KEYWORDS

• Regional anesthesia • Peripheral nerve block • Pediatric anesthesia • Complications
• Ultrasound • Local anesthetics • Intralipid • Compartment syndrome

KEY POINTS

- Peripheral nerve block (PNB) complications are rare in pediatric patients.
- PNBs are safely performed under general anesthesia.
- Ultrasound guidance lowers regional anesthesia complication rates and increases nerve block efficacy.
- When possible, anesthesia strategies incorporating PNBs should be selected over those using central/neuraxial techniques in pediatric patients.

INTRODUCTION

Acute pain management in children represents a significant challenge in the perioperative setting. Regional anesthesia is broadly applicable to multiple surgical disciplines and has proven to be reliable in providing postoperative analgesia and in reducing opioid utilization. Furthermore, the widespread implementation of regional anesthesia within hospital and ambulatory and nonhospital environments has become increasingly feasible over the past 20 years with the advent and incorporation of ultrasound guidance and point of care ultrasound (POCUS) technology. As with any interventional process, complications may occur, even among the most experienced anesthesiologists with formal training in ultrasound-guided regional anesthesia. This review assesses the occurrence of peripheral nerve block (PNB) complications and the underlying causes, as well as the treatment and consequences of these complications. Of note, this review will focus on peripheral regional anesthesia techniques and will only give cursory attention to other regional anesthesia techniques (central/neuraxial) for comparison purposes.

DEFINITIONS

Important distinctions regarding the terminology used to differentiate the various forms of regional anesthesia include the following:

- Neuraxial (central): local anesthetic medication injection/catheter placement in either the epidural space (outside "spinal sack") or subarachnoid/spinal space (inside the "spinal sack"). Epidural regions include caudal lumbar and thoracic. Epidural and spinal injections or infusions may include opioids.
- Peripheral: nonneuraxial injection or infusion of local anesthetic medication. May include upper and lower extremities, trunk (thoracic or abdominal regions), and/or face.
- Single shot PNB: injection of local anesthetic bolus once with or without medication adjuncts to increase the nerve block effect or duration.
- Catheter: insertion of a small hollow tube/line that is connected to an external port with the internal tip in or around the *(a)*

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central (epidural or subarachnoid/spinal) space or *(b)* peripheral nerve (perineural or within a fascial plane) space; the catheter is used for intermittent bolusing (syringe-bolus) OR connected to an infusion device (with continuous or intermittent bolusing, typically with an additional intermittent patient-demand bolus option). Note: when the catheter is inserted peripherally, this is referred to as a continuous PNB (CPNB) or peripheral nerve catheter (PNC)

- Local anesthetic systemic toxicity (LAST); a constellation of neurologic and cardiac signs or symptoms, ranging from the minor (confusion, perioral numbness or tingling, tinnitus, metallic taste) to the severe (seizure, arrhythmias, cardiac arrest) due to elevated plasma levels of local anesthetics
- Point of care ultrasound (POCUS); the use of real-time ultrasound guidance to facilitate the identification of relevant anatomic structures (eg, nerves, blood vessels, surrounding tissue elements) and to visualize the placement of regional anesthetic intervention (eg, needle-tip location, spread of local anesthetic)

COMPLICATIONS

Two large-scale, prospective, multisite, observational networks exist that have provided substantial data regarding the incidence of complications in pediatric regional anesthesia. The French Language Society of Pediatric Anaesthesiologists (ADARPEF) conducted 2 separate 12-month, prospective, multicenter, anonymous studies in Europe in 1994 and again in 2006 using 47 hospital sites. The Pediatric Regional Anesthesia Network (PRAN) was founded in 2007 and includes data on over 100,000 regional anesthetics from over 20 hospital sites in North America. These databases have been queried multiple times to facilitate many investigations, including the incidence of adverse events and complications from neuraxial and peripheral regional anesthesia techniques.

Nature of Complications

Estimating the prevalence of adverse events and/or the complications associated with performing PNBs in the pediatric population is not a precise undertaking because of the nature of the reported information. Complications from regional anesthesia are relatively rare and, thus, require a larger sample size to be effectively evaluated. To accomplish this, data must be collected over many years to provide reliable confidence intervals, which invariably confounds data as practice patterns and available technology change through time.

Given that only 2 databases exist, and only 1 (PRAN) is continually maintained, it must be recognized that some element of reporting bias exists in the data, leading to likely underreporting of events and ultimately an underestimation of the true prevalence. Generalizing about the safety of peripheral regional anesthesia also is difficult when individual techniques have different inherent risks and are applied to patient populations that are quite diverse (eg, neonates and infants vs children >12 years old). Last, the definition and categories of complication or adverse event are interpreted differently in the 2 databases, which further complicate estimation of the true incidence. That said, the historical complication rates based on epoch data for both ADARPEF and PRAN are still valuable for the analysis of the risks of peripheral regional anesthesia in the pediatric population.

The first ADARPEF data published in 1996 included 24,409 regional anesthetics, with 89% performed under general anesthesia. Only 4090 (16%) were true PNBs and only 5.7% involved the extremities. Twenty-five complications (0.09%) occurred, but none of the complications involved PNB techniques, leading the authors to recommend at that time that PNB be selected over central techniques.[1] The second series of ADARPEF data included 31,132 patients with 96% of procedures performed under general anesthesia and 9% catheter placements (23% lower extremity, 6% upper extremity, 15% neuraxial). PNBs represented 66% of regional anesthesia techniques in this study, with 29% of PNBs for extremities. The authors identified 41 legitimate complications and determined an overall incidence of complications in pediatric regional anesthesia (combined peripheral and central) during the study window to be 0.12% (95% confidence interval (CI): 0.09–0.17). Complications were four times more frequent in children younger than 6 months of age than in children older than 6 months and seven times higher in neuraxial than peripheral techniques. Catheter use was not associated with a higher incidence of complications. For patients over 12 years of age receiving PNBs, the complication rate for PNBs was approximately six times lower than in patients receiving neuraxial/central regional anesthesia.[2]

The PRAN data reinforce this narrative of safety, indicating complications in pediatric regional anesthesia (peripheral and central techniques) to be particularly rare and estimating the risk of severe LAST to be 0.76:10,000 cases.[3] Most of these reported LAST cases occurred in infants less than 6 months of age. This is likely due to physiologic pharmacokinetic or pharmacodynamic differences in young infants rather than supratherapeutic (toxic) dosing of local anesthetic medications. The risk of superficial or cutaneous infection after regional anesthesia is estimated to be 0.5% (53:10,000 cases). There was an incidence of transient neurologic deficit of 2.4:10,000 cases, though none resulted in permanent neurologic deficits. Further, there was no additional risk observed from performing regional anesthesia under general anesthesia.[3] Anecdotal evidence of permanent neurologic injury does exist.

Other PRAN database analyses have yielded even more reassuring conclusions. One study assessing more than 40,000 PNBs (noncatheter blocks) with 93% of the blocks placed under general anesthesia found the occurrence of LAST to be 0.005% (95% CI = 0.001–0.015%).[4] This is despite the large variability in the dosing of local anesthetic medications. The PRAN data also demonstrate a substantial increase in the utilization of ultrasound-guided regional anesthesia paired with a simultaneous decrease in neurologic PNB complications, but no change in the incidence of LAST.[3]

Regarding CPNBs, the PRAN data indicate that they are safe in pediatric patients, with adverse event rates similar to adult patients. After the review of more than 2000 CPNBs, 1 study found an incidence of serious adverse complications of 0.04% (with 0 cases of LAST), an overall catheter failure rate of 1.3%, and a catheter dislodgement rate of 7.3%.[5] With regard to CPNB use for orthopaedic-specific procedures, another study examined 339 pediatric patients and found 0 cases of LAST and determined the majority of complications related to CPNB use were minor such as dislodgement or leakage (20%), temporary motor blockade (18%), nausea/vomiting (14.7%), and transient paresthesia (6.5%), indicating a high safety profile for CPNB use in pediatric patients.[6]

A concern among providers has been the safety of performing PNB or CPNB under general anesthesia. The initial ADARPEF study from 1994 found that 89% of 24,409 regional anesthetics were performed under general anesthesia, with only 5.7% being PNB of the upper or lower extremity.[1] The follow-up ADAPREF study conducted in 2006 showed a remarkable shift in pediatric regional anesthesia use with 95.9% of 29,870 regional anesthetics performed under general anesthesia, with PNB of the upper or lower extremity comprising 19.1%. The incidence of adverse postoperative neurologic symptoms in the follow-up study was 0.17%.[2] PRAN data validate these findings and further confirm the rarity of complications and the overall safety of performing regional anesthesia under general anesthesia in pediatric patients.[3,5,7]

Patient Considerations

Evaluation of the pediatric patient for placement of a PNB or CPNB involves evaluating the proposed benefits and risks presented by the anatomic and physiologic changes that occur throughout childhood as well as an assessment of the individual patient. In no way should a pediatric patient be treated as a "small adult." Additional consideration must be made for patients who have significant comorbidities (particularly cardiac, hepatic, or renal impairments). Underlying coagulopathies or history of seizures also should be identified because these may increase the risk of complications from regional anesthesia. Anatomic considerations noted in the literature reveal that the lack of age-adapted anatomic landmark techniques is a major limitation of landmark-based regional anesthesia techniques.[8] This point further emphasizes the benefits of regional anesthesia performed with real-time ultrasound guidance in appropriately trained hands.[9]

The importance of specific physiologic differences between pediatric patient populations should be considered with local anesthetic dosing, particularly patients less than 6 months of age.[10] The major physiologic considerations in this population revolve around hepatic immaturity. Specifically, reduced local anesthetic hepatic clearance associated with immature cytochrome p450 systems and the resulting increased terminal half-life of the medications lead to increased circulating concentration of free fraction of local anesthetics.

Additionally, a reduction in alpha-1-glycoprotein from hepatic immaturity leads to an increase in the free fraction of unbound local anesthetic in the plasma. This further increases the risk of LAST even with appropriate medication dosing.

From the perspective of maturity assessment and psychological preparedness, younger pediatric patients especially have difficulty tolerating minor procedures (such as peripheral IV access) and sudden movements during PNB or CPNB

placement in very young patients could lead to patient injury. Because of these and other factors, regional anesthesia for pediatric patients typically is performed after the induction of general anesthesia. Accordingly, additional intraoperative time must be factored in when considering regional anesthesia for pediatric patients.

Patients and family should be educated regarding the relative risks and benefits of regional anesthesia. Appropriate management of expectations is important for maximizing postoperative recovery experiences. The need for additional education and reassurance should be anticipated with pediatric patients who may be distressed, particularly in the postoperative period if a limb cannot be moved independently or if transient paresthesia occurs during PNB resolution. Nonverbal patients present further difficulties postoperatively when evaluating pain, PNB efficacy assessment, and monitoring for minor signs and symptoms of LAST. With orthopedic surgery, intraoperative vital sign response and postoperative gross motor limb function evaluation are useful tools to evaluate appropriate PNB function.

Acute Compartment Syndrome

A recurring concern expressed regarding the use of regional anesthesia in pediatric patients (particularly trauma patients) is that of the potential to mask signs and symptoms of acute compartment syndrome (ACS). The 2018 joint publication from the American and European Societies for Regional Anesthesia and Pain Medicine (ASRA/ESRA) concluded that there is no convincing evidence that regional anesthesia complicates the diagnosis of ACS, provided patients are monitored responsibly with appropriate assessment intervals in the perioperative period[11,12] along with current best practice guidelines suggested as follows:

- Concentration of local anesthetic for a single shot in peripheral and neuraxial blocks: bupivacaine, levobupivacaine, or ropivacaine at 0.1% to 0.25% concentration. These are less likely to mask ischemic pain or to produce muscle weakness.
- Dose for continuous infusion (CPNB): bupivacaine, levobupivacaine, or ropivacaine 0.1% as the maximum permitted concentration.
- For high-risk surgery for ACS, when a sciatic nerve catheter is indicated, a restriction in ~~LA~~ local anesthetic volume and concentration is advisable
- Cautious use of ~~LA~~ local anesthetic adjuvants is recommended, as they could enhance the duration and density of the block.
- High-risk patients should be adequately evaluated by an acute pain service to allow the detection of potential, early ACS signs, and symptoms.
- If ACS is suspected, measurement of compartment pressure should be performed urgently.

Selection of Local Anesthetic Medications

In pediatric patients, proper selection and accurate dosing of local anesthetic medications are paramount to successful perioperative and postoperative management goals. Amide-class local anesthetics are preferred over ester-local anesthetics for their reduced incidence of allergic reactions, greater lipid solubility and potency, prolonged duration of action, and a greater stability to hydrolysis.[1] Ropivacaine and levobupivacaine are the drugs of choice in pediatric regional anesthesia, owing to their safer cardiac and neurotoxicity profiles (reduced risk of LAST) with ropivacaine having an increased motor-sparing effect. Dosing recommendations per ASRA/ESRA recommendations[11,12] for extremity (upper and lower) PNBs is 0.5 to 1.5 mL/kg using either ropivacaine 0.2%, levobupivacaine 0.25%, or bupivacaine 0.25%.[12]

MANAGEMENT OF COMPLICATIONS

Nonpharmacological Intervention

The rarest of circumstances with PNB/CPNB might require surgical intervention. This is largely reserved for significant malfunctions in equipment, such as a broken needle or retained catheter that must be surgically retrieved, or incision and drainage for superficial infection when conservative measures fail. Otherwise, major surgery is relegated to complications of central/neuraxial anesthesia (eg, abscess or hematoma evacuation).

As for cutaneous reactions, these are largely minor (eg, minor erythema, induration, or inflammation) and are best managed initially with conservative methods (ice application, observation). In the unlikely event of progression, escalation of care may be indicated.

Pharmacologic Intervention

In the event of a cutaneous infection resulting from a PNB or CPNB, proposed antibiotic therapy (when indicated) should be guided by resulting laboratory information. Empiric antibiotic therapy is not routinely required.

Also very uncommon, yet substantially more severe are major signs and symptoms of LAST. The method of LAST treatment depends on whether symptoms are minor or major as well as the rapidity of symptom escalation. Many of the signs and symptoms of LAST may be masked in the pediatric population by general anesthesia and the use of intraoperative muscle relaxants. Successful management of major symptoms of LAST depends entirely on close and ongoing patient evaluation and early initiation of lipid resuscitation therapy (LRT) using Intralipid 20% emulsion when the diagnosis is suspected or confirmed. Minor LAST symptomology is usually self-limited. Conservative treatment in this circumstance involves cessation of PNB local anesthetic injection or CPNB infusion (with subsequent rate or medication adjustments), supplemental oxygen, and ensuring that intravenous (IV) access and emergency equipment and supplies are available. The patient and family should be reassured, and patients should be monitored until symptoms are resolved. If minor symptoms are ongoing or escalating, benzodiazepines are appropriate to avoid neurologic symptoms such as seizures. In the event that minor symptoms represent heralding findings with progression to severe LAST and associated neuro or cardiac toxicity, initiation of LRT with Intralipid in accordance with the recommendations of the Society for Pediatric Anesthesia Checklist should be initiated:[11,13]

- Stop injecting the local anesthetic and call for help and intralipid kit.
- Confirm or establish adequate IV access.
- Maintain the airway and give 100% oxygen. Consider the placement of endotracheal tube.
- Continuously monitor electrocardiogram (ECG), blood pressure (BP), oxygen saturation by pulse oximetry (SpO2).
- If seizures develop, administer a benzodiazepine (eg, midazolam 0.05–0.1 mg/kg/min IV), watch resultant hypotension.
- Avoid routine advanced cardiac life support (ACLS) doses of epinephrine. Treat hypotension with small IV epinephrine dose (MAX: 1mcg/kg)
- *Drugs to Avoid:* propofol, vasopressin, calcium channel blockers, and beta-blockers.
- Start IV intralipid therapy as follows:
  - Initial bolus: IV 20% lipid emulsion = 1.5 mL/kg over 60 seconds
  - Maintenance infusion: IV 20% lipid emulsion = 0.25 mL/kg/min
  - Repeat IV bolus every 3 to 5 min until circulation is restored
    - MAX cumulative total bolus dosing = 4.5 mL/kg
  - If cardiovascular instability persists, double infusion rate to 0.5 mL/kg/min
    - Continue maintenance infusion for 10 mins once hemodynamic stability is restored
  - Note: total intralipid dose should not exceed 10 mL/kg
- Recognize arrhythmias and/or cardiac arrest and initiate cardiopulmonary resuscitation (CPR)/pediatric advanced life support (PALS) protocols
  - *REMEMBER:* Continue chest compressions as intralipid must circulate to be effective
    - May need prolonged compressions
- *6-min mark*: Consider alerting nearest cardiopulmonary bypass or extracorporeal membrane oxygenation (ECMO) center and intensive care unit if there is no return to spontaneous circulation to facilitate the transfer and maintenance of circulation until local anesthetic is metabolized.
- Monitor and correct acidosis, hypercarbia, and hyperkalemia as needed.

Prevention of Complications

Although the treatment of regional anesthesia complications generally is very successful, there are several processes that will limit or mitigate complications associated with peripheral regional anesthesia if used routinely. Regarding the prevention of infection or adverse cutaneous findings, the injection site should be thoroughly cleansed with a chlorhexidine or similar substance to ensure the aseptic (PNB) or sterile (CPNB) integrity of the procedure. CPNB dressings and catheter sites should be monitored routinely along with other general signs and symptoms of infection. Disconnecting or opening CPNB catheters to air should be kept to a minimum.

Preventing neurologic injury from needle trauma involves the use of real-time ultrasound guidance to avoid needle-to-nerve contact or use fascial "plane approaches" and instead favor perineural injections whenever possible. Injections of a local anesthetic should be performed with low pressure and intermittent bolusing.

As previously discussed, using precise local anesthetic dose calculations, taking into account physiologic reasons that may predispose individual patients to LAST is essential. Further, injections of local anesthetic should be incremental, and local anesthetics should be visualized with real-time ultrasound guidance for appropriate spread and followed by intermittent aspirations between boluses to ensure intravascular placement has not occurred. Finally, continuous vital-sign monitoring should occur during and after local anesthetic injections.

DISCUSSION

The use of PNB or CPNB to facilitate perioperative anesthetic and analgesic goals for pediatric patients has proliferated significantly in recent years. In many regions, data show an inversion of trends that reflect preferential selection of peripheral over central regional anesthesia techniques.[14] This trend can be attributed largely to the recognized safety and reliability of ultrasound-guided peripheral regional anesthesia in the pediatric population especially when compared with central/neuraxial techniques, new and more refined PNB approaches and techniques, and the availability of LRT/lipid emulsion 20% for the treatment of LAST.

The biggest limitation to the assessment of the safety profiles and complication rates related to PNB and CPNB in pediatric patients relate to the sources of available data. The aggregate data from the PRAN and ADARPEF studies includes both central/neuraxial and peripheral categories of regional anesthetics, and the published conclusions drawn from this aggregated data regarding complications were derived with both central and peripheral techniques in mind. These studies, however, do indicate that central regional anesthesia and minor CPNB catheter-related issues account for the vast majority of complications. This makes the true estimation of isolated peripheral nerve PNB and CPNB complication rates (prevalence and incidence) difficult to determine, although it is likely lower than the resulting published overall incidence rates for regional anesthesia complications in pediatric populations.

The ethical and practical considerations of performing PNB techniques for perioperative anesthetic and analgesic management are well defined. A postoperative course without significant pain or reliance on opioids raises the morale of the patient, parents, medical staff, and surgical team, and it is not justifiable to allow a pediatric patient to suffer pain when reliable and safe regional anesthesia techniques are available.[15] Regional anesthesia, and, in particular, PNB techniques, complement existing management strategies, and facilitate a comprehensively safer experience for the pediatric patient, but also ultimately cultivates a more satisfactory experience for all involved.

SUMMARY

Complications associated with PNB and CPNB regional anesthesia techniques include:

- Nerve block failure or incomplete nerve block coverage
- Patient anxiety/psychological traumatization
- Neurologic:
  - Minor neurologic symptoms
  - Seizures
  - Nerve damage (needle, chemical-induced)
  - Transient paresthesia
  - Prolonged motor block
- Cardiovascular:
  - Minor or major arrhythmias
  - Cardiac arrest
  - Inadvertent vascular puncture
  - Minor or major vascular injury with bleeding or hematoma formation
- Cutaneous and superficial infection (rare)
- CPNB dislodgement/disconnection or mechanical failure
- Potential to mask ACS
- Upper extremity blocks
  - Phrenic palsy (hemidiaphragm) with respiratory distress
  - Pneumothorax
  - Horner's syndrome (temporary)
- Lower extremity blocks
  - Fall Risk

CLINICAL CARE POINTS

Evidence-based pearls

- Ultrasound guidance:
  - Lowers complications[3]
  - Decreases risk of LAST[16]
  - Increases effective duration of PNB and decreases postoperative pain scores[17]
- PNB/CPNB/regional anesthesia:
  - Safe to be performed after the induction of general anesthesia[2,3]

- Placement under general anesthesia should be considered the standard technique in children[11]

- Anesthetic and analgesia strategy:
  - Strategies including PNB/CPNB use should be selected over those involving central/neuraxial regional anesthetic use in pediatric patients (when possible) due to reduced morbidity[2]
- PNBs do not mask ACS findings in the proper care settings[11]

Pitfalls relevant to the point of care

The majority of the challenges presented to the care team related to the implementation of regional anesthesia in the pediatric population, particularly PNB techniques, are related to 2 items: patient selection and management infrastructure.

- Pediatric patients are difficult to assess for both chief complaint, block efficacy, and possible signs of toxic local anesthetic dosing; this is particularly relevant in preverbal/nonverbal children
- Regimen compliance is generally more difficult to ensure (especially with variable/unpredictable support systems/guardians)
- Without adequate patient/guardian education (especially in the ambulatory care setting) and absence of routine and comprehensive follow-up with patients, adverse events and preventable complications will occur. Most important of all is the requirement to incorporate a properly trained and educated anesthesiology care team to ensure that the use of regional anesthesia and PNB techniques results in the highest quality results with consistent patient safety and satisfaction outcomes.

DISCLOSURE

B. Catalani has nothing to disclose. J. Jones has a financial relationship (Founder, Patent Holder, Major Stock Owner) with Cal Tenn Innovations Inc., a company designing a medical device for use in ultrasound imaging. He has consulted for numerous medical devices companies related to nerve block devices, but none in the past 12 months. The content of this manuscript has not been influenced by these factors or by any commercial entity.

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