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Paediatric Regional Anaesthesia: Current Evidence, Techniques and Evolving Standards of Care

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Abstract

Paediatric regional anaesthesia has evolved over the years with regional anaesthesia playing a vital role in perioperative pain management in children. Regional anaesthesia (RA) provides targeted analgesia in children while minimising systemic side effects and side effects associated with systemic opioid use. The Ultrasound which is now the standard of care has also revolutionised this area enabling real time visualisation of nerves and local anaesthetic spread. This enhances precision and safety reducing the incidence of complications like Local anaesthetic systemic toxicity (LAST). Common RA techniques include neuraxial blocks (e.g., caudal and epidural) and a diverse array of peripheral nerve and fascial plane blocks (e.g., TAP, ESP, and rectus sheath blocks) utilising modern, safer local anaesthetics (ropivacaine and levobupivacaine), and adjuvants (clonidine, ketamine, dexmedetomidine) to prolong analgesia. Integrating RA into Enhanced Recovery After Surgery (ERAS) protocols promotes faster recovery, and is crucial for achieving opioid-sparing analgesia. Ongoing research, including the findings of the GAS trial regarding neurodevelopmental safety, continues to support the benefits and efficacy of these techniques, cementing paediatric regional anaesthesia as a fundamental component of high-quality surgical care.

Keywords: Paediatric Regional Anaesthesia (RA), Ultrasound Guidance (USG), Local Anaesthetic Systemic Toxicity (LAST), Neuraxial and Peripheral Nerve Blocks, Opioid-sparing Analgesia.

Introduction

Paediatric regional anaesthesia involves the administration of regional nerve or neuraxial blocks specifically adapted for infants and children to provide targeted analgesia during surgical or medical procedures. Unlike general anaesthesia, this modality selectively inhibits nerve conduction in designated body regions, thereby delivering effective pain relief while minimising systemic effects. It constitutes a critical component of perioperative pain management by reducing dependence on systemic opioids and their associated adverse outcomes [1]. However, paediatric regional anaesthesia presents distinct challenges due to age-specific physiological and anatomical variations, including nerve maturation, pharmacokinetics of anaesthetic agents, and the immaturity of the nervous system, all of which necessitate meticulous selection and dosing of anaesthetics. Furthermore, psychological factors and sedation strategies differ considerably across paediatric age

groups, influencing the choice of technique and procedural planning [2].

Despite its recognised benefits, the broader implementation of paediatric regional anaesthesia has historically been not been much popular due to concerns related to anatomical variability, safety, and technical complexity, compounded by reliance on landmark-based techniques and limited imaging modalities. The advent of ultrasound guidance has markedly advanced the field by facilitating real-time visualisation of anatomical structures, thereby improving block success rates and enhancing safety [3]. Recent innovations include the development of novel peripheral nerve blocks tailored to neonates, infants, and children; the adoption of safer local anaesthetics such as levobupivacaine and ropivacaine; and the acceptance of performing regional blocks under general anaesthesia in paediatric patients - a practice traditionally contraindicated in adults but demonstrated to reduce opioid consumption and expedite recovery in children.

Current evidence establishes ultrasound-guided regional anaesthesia as the gold standard in paediatric practice, emphasising its safety, efficacy, and opioid-sparing advantages [4]. But gaps persist in the standardisation of protocols tailored to various paediatric age groups, as well as in optimising practitioner training and monitoring to mitigate complications. This review aims to integrate contemporary knowledge on paediatric regional anaesthesia techniques - including caudal, epidural, and peripheral nerve blocks - with particular emphasis on advances in ultrasound guidance. By integrating best practice recommendations and emerging evidence, this article seeks to assist clinicians in delivering age-appropriate, safe, and effective analgesic care for neonates, infants, and older children.

Anaesthesia Considerations across Adult and Paediatric age groups

The distinctions in anaesthesia between adult and paediatric populations can be categorised into anatomical, physiological, and psychological dimensions. Anatomically, paediatric patients have a smaller airway size, a larger tongue relative to the oral cavity, and a higher glottic position compared to adults. These anatomical characteristics contribute to an elevated risk of airway obstruction and present challenges in airway management during anaesthesia in paediatric patients. Also, paediatric patients possess a more compliant chest wall and a higher metabolic rate, which influence ventilation.

Physiologically, children have immature organ systems that impact drug metabolism and clearance. The respiratory systems of children have reduced functional residual capacity and increased oxygen consumption, predisposing them to rapid desaturation during anaesthesia. Cardiovascular responses also differ, with children exhibiting higher heart rates and fewer myocardial reserves than adults.

Paediatric patients experience greater anxiety and fear related to separation from their parents and unfamiliar medical environments compared to adult patients. This necessitates tailored preoperative preparation, anxiety management, and sedation strategies. The immaturity of neural pathways in children affects anaesthetic effects and monitoring, requiring careful neurophysiological monitoring during anaesthesia. To summarise, paediatric anaesthesia necessitates consideration of unique anatomical airway features, developmental physiology influencing drug kinetics and respiratory function, and psychological support strategies, which distinctly differentiate it from adult anaesthesia practice [5].

Recent Advances in Paediatric Regional Anaesthesia

Recent advances in paediatric regional anaesthesia have concentrated on enhancing safety, efficacy, and recovery through the development of novel local anaesthetic formulations, improved equipment, and refined protocols. Novel local anaesthetics, such as levobupivacaine and ropivacaine, possess safer pharmacokinetic profiles compared to racemic bupivacaine, which significantly reduces the risk of cardiac toxicity [6]. Continuous peripheral nerve blocks utilising these agents have been

increasingly adopted for prolonged postoperative analgesia, particularly in infants, with an improved safety profile. Adjuvants, including dexmedetomidine and clonidine, are employed to extend block duration and enhance analgesic quality by modulating nerve signal transmission in paediatric patients.

Ultrasound guidance represents a pivotal advancement in paediatric regional anaesthesia by enabling real-time visualisation that improves the precision of local anaesthetic administration and catheter placement. This technique reduces complications and increases block success rates, allowing for lower doses of local anaesthetics while maintaining an optimal balance between safety and analgesic duration [3].

Enhanced Recovery After Surgery (ERAS) protocols increasingly incorporate regional anaesthesia as a fundamental component to minimise opioid consumption, reduce postoperative complications, and accelerate recovery [7]. Multimodal analgesic strategies that combine regional blocks with systematic postoperative care have been shown to shorten hospital stays and improve patient satisfaction in paediatric populations. For instance, in paediatric urological procedures such as hypospadias repair or nephrectomy, the transverse abdominis plane (TAP) block or ilioinguinal nerve block constitutes an integral element of multimodal analgesia. Collectively, these advancements contribute to safer and more effective paediatric regional anaesthesia, optimising perioperative pain management and recovery outcomes.

Future Trends in Paediatric Regional Anaesthesia

Emerging trends in paediatric regional anaesthesia focus on novel fascial plane blocks and continuous peripheral nerve blocks, which provide tailored and effective analgesia with enhanced nerve coverage. The widespread adoption of ultrasonographic guidance continues to improve the safety and accuracy of nerve blocks, minimising complications and prolonging analgesic effects. Advances in safety monitoring emphasise dose optimisation and real-time visualisation, thereby reducing risks, particularly in younger patients. Current research directions include expanding the application of regional anaesthesia in ambulatory settings, promoting opioid-sparing protocols, and facilitating faster recovery consistent with ERAS principles. Nevertheless, challenges remain, including the necessity for larger-scale prospective studies to better evaluate low-incidence risks, standardise techniques, and confirm long-term outcomes. Furthermore, optimising education and ethical standards for ultrasound use remains essential to ensure the safe implementation of these innovations. These trends hold promise for enhancing safety, efficacy, and patient satisfaction in paediatric regional anaesthesia [1].

Pharmacology of local anaesthetics in paediatrics

Differences in anatomy and physiology make drug dosing crucial in the paediatric population. To optimise perioperative outcomes, it is important for anaesthesiologists to understand the basic pharmacological principles behind this [8]. Children, especially neonates and infants, have immature hepatic enzyme systems and reduced plasma protein binding. Consequently, the free drug concentration is higher, resulting in a prolonged elimination half-life of amide local anaesthetics such as bupivacaine and ropivacaine [9]. Careful calculation of doses should be performed to ensure safety. The maximum recommended doses are shown in the table below.

Local anaesthetic systemic toxicity (LAST) has a higher incidence in children because the safety margin is narrower. The clinical features of LAST include agitation, perioral numbness, metallic taste, seizures, arrhythmias, hypotension, and cardiac arrest. The use of ultrasound, precise calculation of the safe dose, and incremental injection with aspiration before injection can reduce the risk of LAST [10]. Every practitioner should ensure the availability of lipid emulsions and be

familiar with the management algorithms.

Table 1: Maximum recommended local anaesthetic doses in children

Drug	Maximum dose (single shot)	Maximum dose (infusion)
Bupivacaine	2–2.5 mg · kg ⁻¹	0.4–0.5 mg · kg ⁻¹ · hr ⁻¹
Ropivacaine	3 mg · kg ⁻¹	0.4 mg · kg ⁻¹ · hr ⁻¹
Lidocaine (plain)	3–5 mg · kg ⁻¹	—
Lidocaine with adrenaline	up to 7 mg · kg ⁻¹	—

Footnote: Doses are approximate and should be adjusted for age (neonate vs. older child), comorbidities, site of injection, and use of other local anaesthetics or adjuvants. Always calculate the total mg, not just volume, and use hospital protocols where available.

Adjuvants can be added to local anaesthetics to prolong analgesia and reduce the required dose of the local anaesthetic. Common adjuvants include clonidine, dexmedetomidine, ketamine, and opioids such as morphine, fentanyl, and buprenorphine; the choice depends on the block, expected duration, and side-effect profile [11].

Techniques of paediatric regional anaesthesia

Broadly, regional anaesthesia techniques in children can be divided into neuraxial and peripheral nerve blocks. Advances in ultrasound have improved the safety and precision of both the approaches [12].

Neuraxial blocks

a) Caudal epidural anaesthesia. This is the most commonly performed regional technique in children undergoing infra umbilical surgery. The child is positioned laterally and the sacral hiatus is identified between the sacral cornua and a needle advanced through the sacrococcygeal membrane. A distinct "pop" is often felt as the membrane is pierced and a local anaesthetic is injected after careful aspiration to exclude blood and CSF. A caudal block is technically straightforward, with a relatively short learning curve, and provides reliable analgesia. Single-shot caudal injections have a limited duration; adjuvants or catheter techniques may be required for prolonged postoperative pain. Ultrasound can visualise sacral anatomy and confirm needle and drug spread [13].

b) Single-shot spinal anaesthesia. Single-shot spinal anaesthesia is useful for lower abdominal and lower limb procedures in neonates and ex-premature infants, where avoiding general anaesthesia may reduce the risk of postoperative apnea and desaturation. A fine gauge (25-27 G) spinal needle is placed at L4-L5 or L5-S1 with the infant in lateral decubitus; placement of clear CSF is confirmed before injection of hyperbaric bupivacaine. A large series has demonstrated safety when appropriate monitoring and dosing are used [14].

c) Epidural anaesthesia. Epidural analgesia is valuable in major abdominal, thoracic, and orthopaedic surgeries. A midline or paramedian approach with loss of resistance (air or saline)

locates the epidural space, and a catheter may be threaded for continuous infusion. Ultrasound is useful for estimating the distance to the epidural space and reducing complications, such as inadvertent dural puncture [15].

Peripheral nerve blocks

Peripheral nerve blocks are increasingly popular in paediatric practice as either the sole anaesthetic technique for short procedures or as part of multimodal analgesia. High-resolution ultrasound has made many blocks feasible and reproducible, even in neonates and small infants [15].

a) Upper-limb block. The supraclavicular, infraclavicular, and axillary approaches are used for surgery of the arm and hand. In the supraclavicular block, the brachial plexus is visualised as a compact bundle lateral to the subclavian artery above the first rib, and the local anaesthetic is deposited around the plexus sheath. Ultrasonography significantly reduces the risk of pneumothorax and vascular puncture. The infraclavicular approach targets the cords around the axillary artery, while axillary blocks target the terminal branches at the level of the axilla [16].

b) Lower limb block. A femoral nerve block is performed by locating the femoral nerve lateral to the femoral artery under the inguinal ligament and provides analgesia for hip, femur, and knee surgery. Sciatic nerve blocks can be performed at the subgluteal or popliteal levels depending on the surgical site; ultrasound allows the identification of the nerve and surrounding muscle planes [17].

c) Ilioinguinal - iliohypogastric (IL-IH) and TAP (transversus abdominis plane) blocks. The IL-IH block is performed under ultrasound at the level of the anterior superior iliac spine with injection between the internal oblique and transversus abdominis muscles and is highly useful for inguinal hernia repair and orchidopexy [18]. TAP blocks deposit local anaesthetic between the internal oblique and transversus abdominis muscles along mid-axillary line or between iliac crest and costal margin and provide analgesia for lower abdominal surgery [19].

d) Rectus sheath block. For midline infraumbilical incisions, the rectus sheath block places local anaesthetic in the posterior rectus sheath compartment and is beneficial for umbilical and midline procedures [19].

e) Erector spinae plane (ESP) block. The ESP block involves deposition of local anaesthetic deep to the erector spinae muscle at the transverse process level; craniocaudal spread of local anaesthetic can cover multiple dermatomes. It is a versatile option for thoracic and abdominal procedures and is regarded as safer than thoracic epidural in smaller children because it carries a minimal risk of neuraxial injury [20].

The use of peripheral nerve blocks decreases perioperative opioid requirements, thereby reducing the incidence of nausea, vomiting, and postoperative respiratory depression [18]. There is also a lower risk of emergence delirium and more stable hemodynamics, which enhance the quality of recovery [21]. Such benefits make regional techniques integral components of enhanced recovery pathways, increase parental and patient satisfaction, and are particularly beneficial in day-case surgeries [18].

Role of ultrasound guidance in paediatric regional anaesthesia

Ultrasound guidance (USG) has completely altered the approach to regional anaesthesia in children. Surface landmarks, which are unreliable even in adults, become even less dependable in paediatric patients because of partial bone ossification and diverse surface anatomy. Ultrasound overcomes this by facilitating direct, real-time visualisation of nerves, fascial planes, vessels, and the spread of local anaesthetic [15].

This approach has several practical benefits for clinicians. Success rates are better, and block consistency increases, especially in neonates and infants, where blind techniques can be unsuccessful or even dangerous [15]. Because the needle tip and local anaesthetic spread are visualised, smaller volumes can often be injected while still achieving adequate analgesia, which is an attractive safety advantage in children with a narrow margin of safety against LAST [10]. Ultrasonography also minimises inadvertent vascular puncture, pleural puncture, and intraneural injection because adjacent structures are identifiable and avoided.

Ultrasonography has also widened the range of feasible blocks in children. Fascial plane techniques (TAP, rectus sheath, ESP, and PECS blocks) are rapidly practiced after ultrasound allows reproducible placement and visual confirmation of spread. These blocks provide suitable alternatives to neuraxial techniques in many paediatric settings [12]. Catheter techniques have similar advantages; ultrasound guidance allows accurate catheter placement and better confirmation of tip location, making continuous regional analgesia more feasible and secure in children [16].

The limitations are mostly logistic and training related. High-frequency probes that provide superior resolution for superficial structures have limited depth penetration, which can be difficult for deeper blocks in neonates; additionally, ultrasound requires equipment and investment in skill acquisition. Despite this, USG is now widely regarded as the current standard of care for paediatric regional anaesthesia [15].

Safety and complications

Safety is the biggest concern for anaesthetists and families, but modern data have shown reassuring results. Large audits and registry data suggest that regional anaesthesia performed with ultrasound guidance and meticulous calculation of dosages is very safe in children [12]. The most common complication is LAST. Children are more vulnerable because of lower plasma protein binding and underdeveloped metabolic pathways. Clinical signs include agitation, tremor, perioral numbness, seizures, and final cardiovascular collapse. Prevention relies on accurate dose calculation, repeated aspiration during injection, ultrasound guidance, and accessibility to lipid emulsions for resuscitation [8].

Permanent neurological injuries are uncommon in children. Most reported neurological sequelae are transient sensory or motor disturbances that are self-limiting. Ultrasound helps reduce the risk by preventing operators from intraneural or intravascular needle placement [10]. Infection and hematoma, though rare complications of catheter techniques, pose significant clinical risks. To minimise these risks, strict adherence to aseptic protocols during catheter insertion and maintenance is essential. Routine catheter site inspections and functional checks help in early identification of potential issues, preventing progression to severe complications. Additionally, assessing for coagulopathy is critical before catheter placement, as underlying bleeding disorders can increase hematoma risk and affect management strategies [16].

Finally, regional anaesthesia decreases systemic opioid exposure and its resulting adverse effects, such as nausea, vomiting, drowsiness, and respiratory depression, which increases safety and lowers the risk of unexpected critical care admissions [13]. Overall, registry analyses show that paediatric regional techniques, when performed appropriately, have a very minimal complication rate and have advantages over systemic analgesic strategies [21].

Discussion

Paediatric regional anaesthesia has moved from being optional to being an essential part of perioperative care. The literature repeatedly shows that with ultrasound guidance, regional techniques are both beneficial and safe across age groups [8]. Compared with sole systemic analgesia, regional anaesthetic techniques reduce opioid requirement, result in fast recovery, and

decrease opioid-related adverse effects such as nausea, vomiting, pruritus, and respiratory depression, which are especially important in paediatric age groups where airway preservation and smooth emergence are of great significance.[11].

The comparison between regional and general anaesthesia is complex. For short, simple procedures, general anaesthesia remains efficient and safe. However, in specific populations, ex-premature infants susceptible to postoperative apnea or children with major comorbidities, regional techniques may be considered either as the only anaesthetic plan or as part of a combined approach [12]. Regional methods also form a cornerstone of enhanced recovery protocols, where minimisation of opioid use and early mobilisation are of utmost importance [19].

There are some areas that require additional research. The long-term safety of certain adjuvants (e.g., perineural dexmedetomidine) in infants requires more data. Concerns about anaesthesia and neurodevelopment have been answered partly by large trials such as the GAS study, which found no significant difference in neurodevelopment at two years between awake-regional and general anaesthesia in infants; however, vigilance and surveillance remain crucial [22]. Continuous catheter techniques are emerging, especially for major orthopaedic and oncologic surgeries; however, high-quality prospective paediatric trials are still relatively scarce [16].

Finally, practical barriers include differences in training and a lack of accessibility to ultrasound. Simulation, structured curricula, and clear protocols will be central to safely practicing paediatric regional anaesthesia. Multi-institutional data already shows low complication rates across tens of thousands of paediatric blocks [21]. With continued emphasis on education and vigilance, paediatric regional anaesthesia will definitely progress in terms of scope and safety.

Conclusion

Paediatric regional anaesthesia has evolved from a supplemental technique to a key component of perioperative care for infants and children. By providing targeted, effective pain relief while significantly reducing the dependence on systemic opioids, it minimises associated adverse effects such as nausea, respiratory depression, and prolonged sedation. The widespread use of ultrasound guidance for regional anaesthesia guarantees precision and safety through real time visualisation of the needle placement and local anaesthetic spread. This is particularly important given the unique anatomy of paediatric patients and their narrower margin of safety for Local Anaesthetic Systemic Toxicity (LAST).

Mounting evidence affirms the safety and efficacy of paediatric regional anaesthesia ensuring it remains vital for superior surgical care, faster recovery, better pain control, and satisfaction in this vulnerable population.

In summary, safe and successful implementation of regional anaesthesia through neuraxial techniques (such as caudal blocks) or modern fascial and peripheral nerve blocks (such as TAP or ESP) requires:

- 1) Meticulous pre-procedural planning and careful patient selection.
- 2) Accurate dose calculation adjusted for age and physiological development.
- 3) Consistent use of USG to minimise complications.

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