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Ultrasound-guided pericapsular nerve group block versus caudal epidural block for postoperative pain management in pediatric hip surgery: A randomized clinical trial

Samar Rafik Amin[1], Mona Ahmed Elhadad[1], Eslam Abdelshafy Tabl[2] and Zeinab Mohammed Abdelwahab[1]

Abstract

Introduction: Optimal pain control after pediatric hip surgery enhances recovery, minimizes opioid needs, and improves comfort. The pericapsular nerve group (PENG) block, a unique regional intervention, has advantages over the standard caudal epidural block (CEB). This study compares the analgesic efficacy of ultrasound-guided PENG and CEB blocks in children having hip surgery.

Methods: This study included 80 pediatric patients, aged 1 to 7 years, who received general anesthesia for hip surgery. Patients were randomly allocated to receive either a PENG block (Group P) using 0.5 mL/kg of 0.25% bupivacaine, or a CEB (Group C) using equivalent bupivacaine volume. The primary outcome was postoperative pain assessed by the FLACC scale at predefined timepoints. Secondary measured outcomes were the time until the first rescue analgesic, total morphine usage, occurrence of adverse effects, and parental satisfaction.

Results: Pain scores were generally comparable, but Group C showed significantly lower FLACC scores at 30 min (p = .047), while Group P had lower scores at 6 h (p = .024). Group P demonstrated a significantly longer time to first rescue analgesic (10.68 ± 7.03 vs 7.85 ± 4.77 h, p = .039) and lower morphine consumption (p = .047). Block performance time was greater in Group P (p < .001), but higher parental satisfaction was noted (p = .03). The safety profile was equivalent between groups, with no significant disparity in adverse effect frequency.

Conclusion: For pediatric hip surgery, ultrasound-guided PENG block provides long-lasting postoperative analgesia compared to CEB, while reducing opioid needs and enhancing parent satisfaction.

Keywords

pericapsular nerve group block, caudal block, pediatric anesthesia, hip surgery, pain, regional anesthesia

Introduction

Pediatric patients often endure severe pain following hip surgery, resulting in restlessness, emotional distress, and impaired mobility. These symptoms can elevate the risk of complications like deep vein thrombosis while contributing to psychological sequelae including anxiety, depression, and sleep disturbances—all of which exacerbate stress for both children and caregivers.[1] Approximately 20% of patients experience persistent pain 6–12 months postoperatively, leading to functional impairment and reduced quality of life.[2]

While opioids are commonly prescribed to relieve post-surgical pain, they often cause unpleasant side effects like nausea, vomiting, constipation, extreme drowsiness, and even respiratory depression.[3] Currently, regional anesthetic techniques are extensively

[1]Department of Anesthesia and Intensive care, Faculty of Medicine, Benha University, Benha, Egypt
[2]Department of Orthopedic Surgery, Benha Faculty of Medicine, Benha University, Benha, Egypt

Corresponding author:
Samar Rafik Amin, Department of Anesthesia and Intensive care, Faculty of Medicine, Benha University, 7 Ahmed Maher street, Benha 13512, Egypt.
Email: samar.rafik@gmail.com

used for pediatric surgeries because they control pain effectively while reducing the need for opioid medications and their unwanted effects.[4] The caudal epidural block (CEB) has long been a trusted pain relief method for children having lower abdominal and lower extremity surgeries.[5] Although it is effective and safe, its use may be limited by contraindications such as infection at the injection site or anatomical anomalies that necessitate alternative approaches.

The PENG block has recently gained attention as an innovative approach for hip pain management. This technique specifically blocks the accessory obturator and femoral nerve branches that supply sensation to the hip joint capsule, offering targeted pain control for the anterior hip region.[6] Although the PENG block has been extensively studied in adults, its safety and efficacy in pediatric populations remain unclear. Furthermore, no direct comparisons currently exist between ultrasound-guided PENG blocks and caudal epidural blocks for children undergoing hip surgery. This study aims to bridge this knowledge gap by evaluating whether PENG blocks provide better postoperative analgesia with reduced opioid-related side effects compared to traditional CEBs in pediatric hip surgery patients.

Patients and methods

This prospective, randomized, double-blind study was carried out at a University Hospital from August 2024 to April 2025, after receiving approval from our institutional medical ethics committee (ID: RC_30.9.2023) and obtaining signed informed consent from the children' parents. The study involved 80 children who underwent elective hip surgery. NCT06563622 is the trial's unique identifier on ClinicalTrials.gov. The full study protocol is available as Supplemental File 1. The study was conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT 2010) and the revised Declaration of Helsinki (2013).

The study population consisted of 80 children between 1 and 6 years of age, all ASA (American Society of Anesthesiologists) physical status I or II and scheduled for elective hip surgeries under general anesthesia. While the study protocol allowed for the inclusion of children up to 7 years old, no eligible 7-year-old participants were available during the recruitment period, resulting in a final study population of children aged 1–6 years. Eligible surgical procedures included open reduction for developmental dysplasia of the hip, proximal femoral osteotomy, or acetabular reconstruction. We excluded patients whose parents declined participation or who had known hypersensitivity to local anesthetics, as well as those with bleeding disorders, pre-existing infections at the block site, or major systemic diseases affecting the cardiac, renal, or hepatic systems were also excluded. Children with neuromuscular disorders, developmental delays, or a history of previous hip surgery or trauma were also not included to ensure consistency in pain assessment and study outcomes.

Participants were randomly assigned to one of two equal groups (n = 40 each) using a computer-generated sequence created in created in IBM SPSS Statistics (version 25) by an independent biostatistician. Allocation was concealed using sequentially numbered, opaque, sealed envelopes. An independent assistant, who was uninvolved in patient's care or outcome assessment, was in charge of opening the envelopes. To maintain blinding, all blocks were performed post-induction, and the injection sites were covered with identical opaque dressings. Additionally, parents, outcomes assessors, and postoperative care providers remained unaware of group assignments' and the anesthesiologist performing the block was not involved in data collection or analysis.

The study participants were randomly assigned to two groups of equal size (40 patients each). Patients in Group P underwent ultrasound-guided PENG block administration with 0.25% bupivacaine at a dose of 0.5 mL/kg (equivalent to 1.25 mg/kg, which is well below the recommended maximum safe dose for children). Patients in Group C received ultrasound-guided CEB with an identical drug/dose to ensure safety and minimize the risk of cephalad spread and motor weakness in younger children. Both interventions occurred post-induction but before surgery end.

A sevoflurane mask was applied to the patient, and an intravenous line was established and secured. After preoxygenation, anesthesia was induced with IV fentanyl (1–2 μg/kg) and propofol (2–3 mg/kg). Endotracheal intubation was facilitated with IV atracurium (0.5 mg/kg) with the suitable sized endotracheal tube based on age and weight. Following intubation, mechanical ventilation in pressure-controlled mode was initiated. Standard monitoring included pulse oximetry (SpO_2), electrocardiography (ECG), capnography, and non-invasive blood pressure (NIBP). Sevoflurane was utilized to maintain anesthesia, and atracurium was administered as boluses every 20 min at 0.1 mg/kg to maintain neuromuscular blockade.

Sevoflurane was discontinued at the conclusion of surgery, and neuromuscular reversal was achieved with intravenous atropine (0.02 mg/kg) combined with neostigmine (0.05 mg/kg). After achieving a regular respiratory pattern and clear airway reflexes, extubation was carried out. The children were sent to the post-anesthesia care unit (PACU), where Aldrete's score was assessed and documented at 10-min intervals. Once the Aldrete score reached 9 or greater, the patient was transferred to the ward.

Group P

Patients remained supine during block administration. Using a 5–10 MHz linear ultrasound probe (LOGIQ e, GE) positioned transversely over the anterior inferior iliac spine (AIIS), we identified key anatomical structures including the iliopsoas muscle, femoral nerve, and femoral artery. The ultrasound probe was then rotated counterclockwise to align parallel with the pubic ramus, providing a longitudinal visualization of the AIIS, iliopsoas tendon eminence (IPE), femoral artery, and the groove between the psoas tendon and pubic ramus. With continuous ultrasound guidance, we inserted a 22-gauge, 5-cm needle using an in-plane technique from lateral to medial direction, carefully advancing it between the pubic ramus and psoas tendon until the needle tip contacted the IPE. After confirming negative aspiration for blood, we slowly injected 0.25% bupivacaine at a dose of 0.5 ml/kg, observing the appropriate spread of local anesthetic before finally withdrawing the needle.

Group C

Patients were positioned laterally with hips and knees flexed for the CEB. Using a 6–13 MHz linear ultrasound probe, we first identified the sacral hiatus in transverse view to measure intercornual distance and evaluate caudal space depth. The transducer was then rotated 90° to acquire a longitudinal view, allowing for measurement of bone depth and optimization of the needle insertion angle. With continuous ultrasound guidance, we inserted a 22G, 5-cm needle using an in-plane technique at the optimal angle. If the needle contacted soft tissue or bone, adjustments were made to ensure proper placement. Once the caudal space was accessed, aspiration confirmed the absence of blood or cerebrospinal fluid, and 0.25% bupivacaine at a dose of 0.5 ml/kg was injected slowly over 1 minute under ultrasound visualization.

Patients received scheduled intravenous paracetamol (15 mg/kg every 6 h) for baseline analgesia; no other analgesic adjuncts such as non-steroidal anti-inflammatory drugs (NSAIDs), ketamine, or dexamethasone were administered. Pain was assessed using the age-appropriate FLACC scale,[7] evaluating five behavioral indicators: body movement, leg movement, facial expression, cry/verbalization, and consolability. Rescue analgesia (IV morphine 0.05 mg/kg) was given when the FLACC score was ≥4 for at least 10 min despite comfort measures. The attending anesthesiologist, blinded to group allocation, made all decisions regarding rescue analgesia. Patients were discharged only when standardized criteria were met: stable vital signs, tolerance of oral fluids, satisfactory pain control with oral medications, and no evidence of surgical site complications.

Study measurements. Total intraoperative fentanyl usage was recorded, with simultaneous monitoring of hemodynamic parameters (heart rate and mean arterial pressure) performed at four time points: (1) immediately post-incision, (2) 30 min after incision, (3) 1 h after incision, and (4) at surgical conclusion. Pain levels were evaluated in the recovery period using the FLACC (Face, Legs, Activity, Cry, and Consolability) scale, a validated behavioral pain assessment tool for pediatric patients. The scale yields a total score from 0 to 10, where 0 indicates a calm and relaxed state, 1–3 reflects mild discomfort, 4–6 represents moderate pain level, and 7–10 indicates severe pain or distress. Assessments occurred in the PACU and at 30 min, 1 h, 2 h, 6 h, 8 h, 12 h, and 24 h postoperatively. All measurements were obtained and recorded by a blinded anesthetist, who was uninvolved in patient care or data analysis. This assessor received standardized training in the FLACC scale prior to the study commencement to ensure consistent scoring.

Several additional parameters were recorded, including the time to perform the block (from ultrasound probe placement to completion of anesthetic injection). The time to first postoperative rescue analgesia, defined in the protocol as identical to the duration of the block, was measured as the interval between the end of surgery and the administration of the first analgesic dose in response to a FLACC score ≥4. Additionally, the total dosage of rescue analgesia required through the first 24 h post-surgery was recorded. The length of hospital stay and incidence of postoperative adverse effects (nausea, vomiting, pruritus, hematoma, bradycardia, hypotension, and limb weakness) were documented. Parental satisfaction was evaluated using a 5-point scale, where 0 indicated "very dissatisfied" and 4 indicated "very satisfied." The primary outcome of the study was the FLACC score trajectory over time (30 min, 1 h, 2 h, and 6 h postoperatively), as preregistered. The 2-h FLACC score was used for sample size calculations and is emphasized for clinical interpretation. All other measured variables were considered secondary outcomes.

Statistical analysis. Data analysis was performed using IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY). Continuous variables were first evaluated for normality using the Shapiro–Wilk test. Normally distributed data were expressed as mean ± standard deviation and compared between groups with independent t-tests, while non-normal data were reported as median (interquartile range) and analyzed with Mann–Whitney U tests. For categorical variables, we presented frequencies and percentages, using either chi-square or Fisher's exact tests for comparisons as appropriate based on the data characteristics. For the

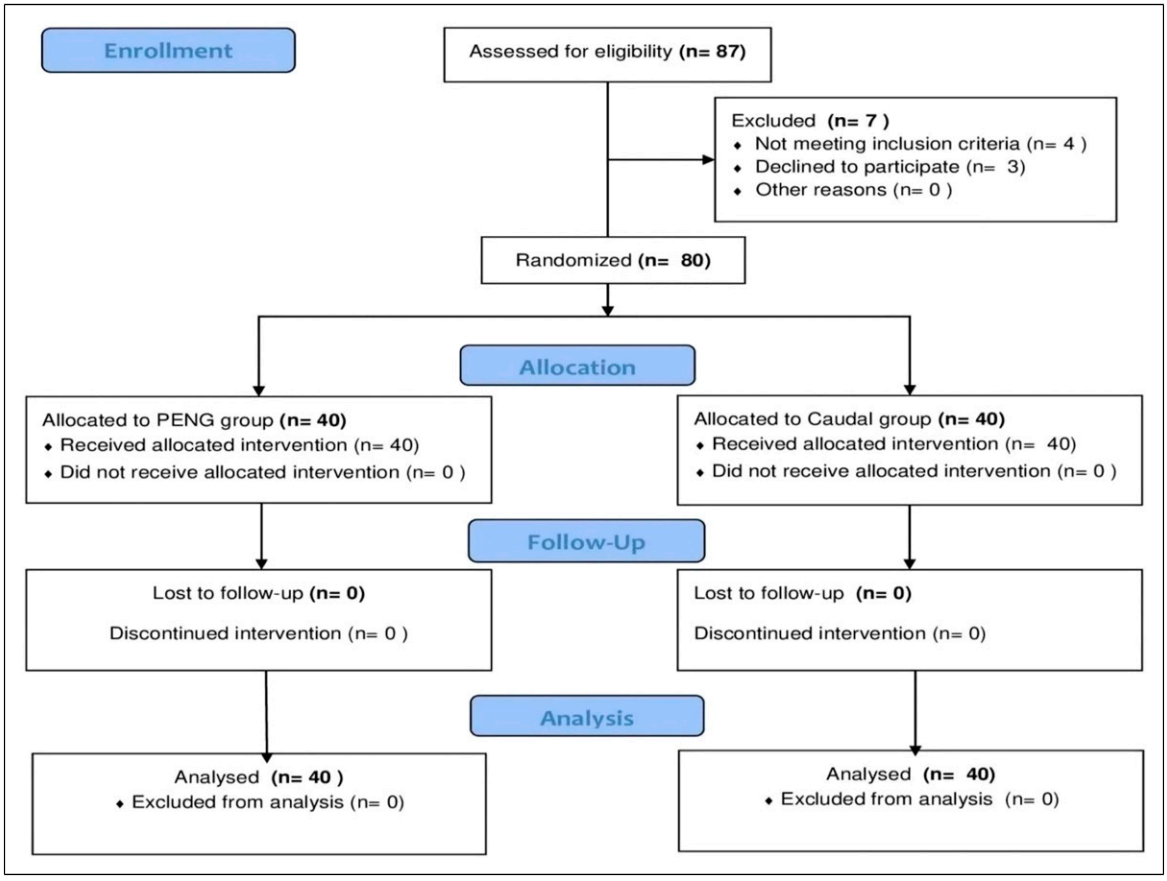

Figure 1. CONSORT flow chart of the study cases.

key dichotomous outcome (rescue analgesia within 8 h), the Number Needed to Treat and its 95% confidence interval were derived from the absolute risk difference. All analyses were conducted following the intention-to-treat principle and included all randomized patients. No data for the primary or secondary outcomes were missing; hence, no imputation methods were required.

A linear mixed-effects model was used to analyze the primary FLACC score outcome, addressing the repeated measures by including fixed factors for group, timepoint, and their interaction, plus random intercepts for individual patients. Fixed effects significance was evaluated via Satterthwaite's method, with post-hoc multiple comparisons adjusted through Tukey's procedure. Effect sizes with 95% confidence intervals (CIs) are reported for key outcomes: mean differences with 95% CIs for time to first rescue analgesia and total opioid consumption, and odds ratios (with 95% CIs) for binary adverse events. Throughout all analyses, statistical significance was defined as two-sided $p < .05$.

The required sample size was estimated based on our primary outcome measure, the FLACC pain score at 2 h postoperatively, using G*Power software (version 3.1.9.2, Universität Kiel, Germany). In a prior study,[8] the caudal group's 2-h postoperative FLACC score was 3.18 ± 0.95. In order to identify a clinically significant difference, we targeted a 20% reduction (an absolute difference of 0.64 points) in pain scores between groups. Although there is no established universal minimal clinically important difference (MCID) for the FLACC scale, a 1-point difference is frequently regarded as clinically meaningful in pediatric studies. We selected a 0.64-point difference as a conservative and practical target to balance clinical relevance and study feasibility. This corresponds to an effect size (d) of 0.674, with 80% power and a 5% alpha error; we determined a minimum sample size of 72 patients (36 per group). To accommodate potential participant attrition, we increased the total sample size to 80 patients (40 per group).

Results

Patient population

Eighty children, out of 87 eligible candidates, were randomized and completed the study. Seven patients

Table 1. Demographic and basic clinical criteria of the studied groups.

		PENG (n = 40)	Caudal (n = 40)	*p*-value
Age (years)	Mean ± SD	4.50 ± 1.41	4.88 ± 1.26	0.215
Weight (kg)	Mean ± SD	15.38 ± 3.07	15.7 ± 2.64	0.613
Gender				
Male	n (%)	27 (67.5%)	21 (52%)	0.171
female	n (%)	13 (32.5%)	19 (48%)	
ASA				
I	n (%)	36 (90%)	35 (87.5%)	0.723
II	n (%)	4 (10%)	5 (12.5%)	
Side of surgery				
Rt	n (%)	25 (62.5%)	18 (45%)	0.116
Lt	n (%)	15 (37.5%)	22 (55%)	
Duration of surgery (min)	Mean ± SD	89.58 ± 24.14	93.23 ± 24.7	0.506

ASA: American Society of Anesthesiologists.

were excluded due to parental refusal (n = 3) or failure to meet the inclusion criteria (n = 4) (Figure 1).

Demographic data and baseline clinical variables, involving age, weight, gender distribution, ASA classification, and surgical side, were comparable across both groups, with no substantial variation observed (all *p*-values >0.05, Table 1).

Primary outcome: Postoperative pain

FLACC scale evaluations over 24 h revealed comparable pain scores between groups at most intervals. However, post-hoc analysis showed the caudal group had significantly lower pain scores at 30 min ($p = .047$), while the PENG group had significantly lower scores at 6 h ($p = .024$) (Table 2).

Secondary outcomes

Patients receiving PENG blocks (Group P) demonstrated significantly longer time to first rescue request and required 24% less total morphine over 24 h. The clinical impact was substantial, with a Number Needed to Treat (NNT) of 4 (95% CI [2 to 17]) to prevent one patient from requiring rescue analgesia within the first 8 postoperative hours. Parental satisfaction scores were also notably higher in Group P compared to Group C ($p = .03$). Block performance time was greater in Group P, while intraoperative fentanyl utilization and hospitalization duration were similar between groups (Table 3).

Hemodynamic variable remained comparable between the two groups at most intervals (all $p > .05$), but Group C exhibited significantly lower MAP at the 30-min post-incision mark ($p = .002$). No episodes of clinically significant hypotension required pharmacologic intervention in either group (Figure 2).

Safety

Procedure-associated complications were uncommon and comparably distributed between the groups. The highest incidence was for PONV, with 5% occurrence in the PENG group and 12.5% in the caudal

Table 2. Postoperative FLACC pain scores based on linear mixed-effects model.

Timepoint	PENG (mean [95% CI])	Caudal (mean [95% CI])	Mean difference (PENG - caudal)	*p*-value (post-hoc)
PACU (0)	1.38 [1.14, 1.62]	1.18 [0.94, 1.42]	+0.20	0.323
30 min	1.48 [1.24, 1.72]	1.15 [0.91, 1.39]	+0.33	0.047*
1 h	1.40 [1.16, 1.64]	1.48 [1.24, 1.72]	−0.08	0.712
2 h	1.45 [1.21, 1.69]	1.68 [1.44, 1.92]	−0.23	0.192
4 h	2.25 [2.01, 2.49]	2.28 [2.04, 2.52]	−0.03	0.897
6 h	2.45 [2.21, 2.69]	2.85 [2.61, 3.09]	−0.40	0.024*
8 h	3.35 [3.11, 3.59]	3.58 [3.34, 3.82]	−0.23	0.203
12 h	3.10 [2.86, 3.34]	3.28 [3.04, 3.52]	−0.18	0.343
24 h	3.08 [2.84, 3.32]	2.78 [2.54, 3.02]	+0.30	0.117

Values are estimated marginal means (95% confidence interval) from the linear mixed-effects model. The Group × Time interaction was significant ($p < .001$). *p*-values are from post-hoc comparisons with Tukey adjustment.*$p < .05$.

Table 3. Secondary outcomes in the studied groups.

Outcome measure	PENG group (n = 40)	Caudal group (n = 40	Effect size [95% CI]	P-value
Intraop. Fentanyl (μg)	9.58 ± 10.34	8.85 ± 9.23	MD: 0.73 [−2.66 to 4.11]	0.661
Time to first opioid (hr)	10.68 ± 7.03	7.85 ± 4.77	MD: 2.83 [0.14 to 5.52]	0.039*
Total morphine (mg)	2.92 ± 1.18	3.46 ± 1.21	MD: −0.54 [−1.07 to −0.01]	0.047*
Rescue analgesia (overall), n (%)	15 (37.5)	23 (57.5)	OR: 0.44 [0.18 to 1.07]	0.073
Rescue analgesia by 8h, n (%)	13 (32.5%)	23 (57.5%)	NNT: 4 [2 to 17]	0.024*
Block time (min)	10.83 ± 1.93	7.85 ± 2.28	MD: 2.98 [2.07 to 3.89]	<0.001*
LOS (days)	4.05 ± 2.15	4.20 ± 2.11	MD: −0.15 [−1.08 to 0.78]	0.754
Parent satisfaction, median (IQR)	3 (3–4)	3 (2–3)	—	0.030*

NNT: Number Needed to Treat; CI: confidence interval; MD: mean difference; OR: odds ratio; IQR: interquartile range; LOS: length of stay. Note. Data are mean ± SD unless specified. MD and OR are for PENG versus caudal. * denotes significance.

group. Only the caudal group experienced transient lower limb weakness and hypotension (both 5%). Localized hematomas were uncommon in both groups, and there were no reports of bradycardia, pruritus, or signs of local anesthetic systemic toxicity (Figure 3, Supplemental Table 1.)

Discussion

In this randomized, double-blinded trial, we investigated the analgesic efficacy of the ultrasound-guided PENG blocks with caudal epidural blocks for pediatric patients undergoing a hip surgery. The results demonstrated that The PENG block group showed superior analgesic outcomes including, reduced pain scores during critical early recovery (30 min–6 h post-op), extended duration of pain relief (10.7 vs 7.9 h), 24% lower opioid requirements, higher parental satisfaction ratings. However, it required more time to perform.

The PENG block precisely anesthetizes the anterior hip capsule through its targeted approach to the femoral and obturator nerve branches, while preserving motor function. Our results in pediatric patients validate prior adult researches,[9] filling an important knowledge void in regional anesthesia for children. This evidence establishes PENG blockade as an attractive, functionally-sparing option for perioperative pain management in pediatric hip procedures.

Although pain scores were generally comparable across most time points, the significant Group × Time interaction ($p < .001$) revealed by the linear mixed-effects model confirms distinct analgesic profiles. The caudal group revealed significant reduction in FLACC scores at 30 min postoperatively ($p = .047$), likely due to the faster onset of action typical of neuraxial techniques such as caudal epidural blocks. This observation is consistent with the pharmacological characteristics of caudal anesthesia, which allows for rapid spread of local anesthetic in the epidural space, leading to earlier onset of analgesia. Conversely, at 6 h postoperatively, the PENG group exhibited superior pain control ($p = .024$), supporting its longer-lasting analgesic effect. This

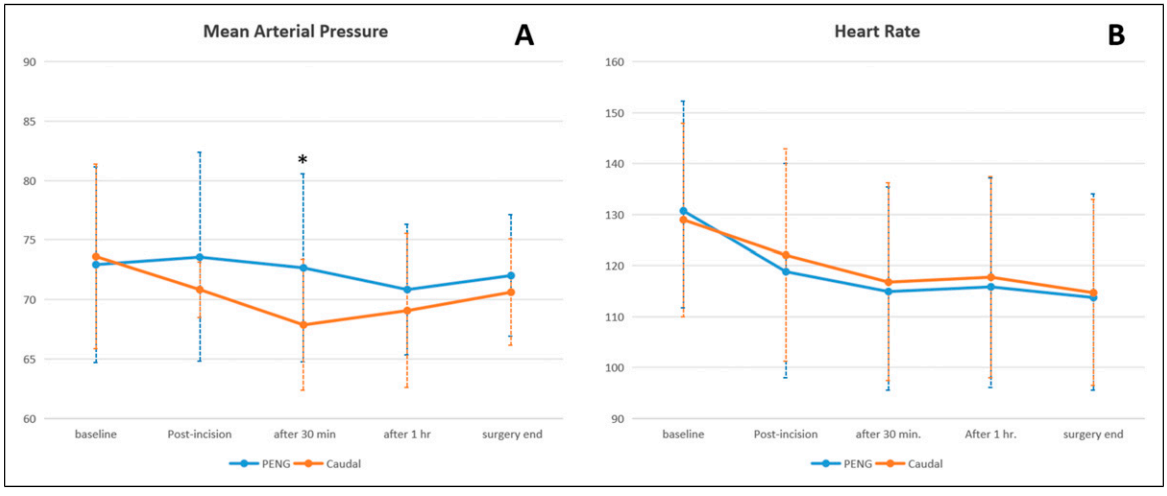

Figure 2. Perioperative hemodynamics: Mean arterial pressure (a) and heart rate (b) at predefined timepoints in the PENG and caudal groups. * Denotes for significance.

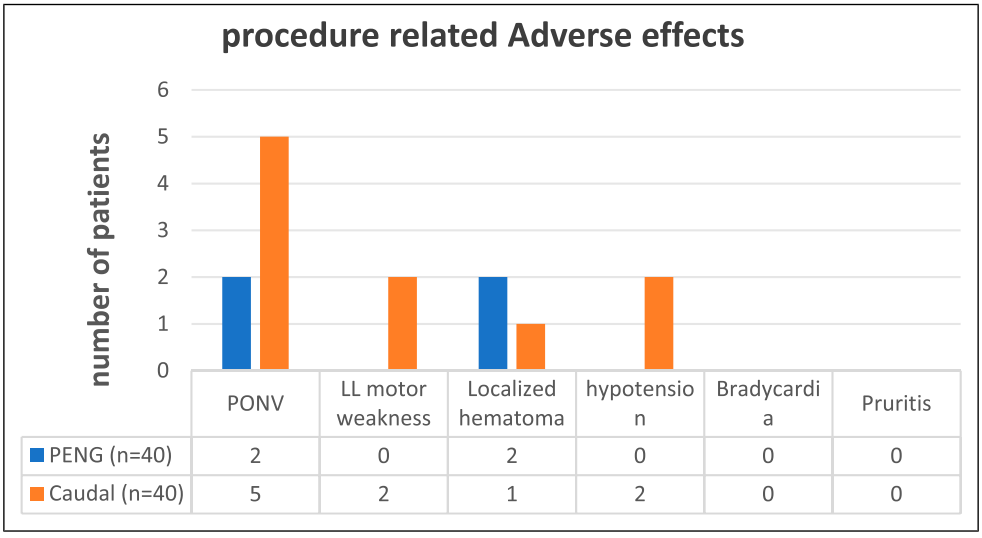

Figure 3. Adverse effects in both groups. PONV: postoperative nausea and vomiting; LL: lower limb.

delayed but prolonged action is characteristic of peripheral nerve blocks that provide targeted sensory blockades without affecting motor function. These findings corroborate the work of Guzmán and colleagues, who demonstrated that bilateral PENG blocks offer effective early postoperative analgesia in pediatric hip procedures and emphasized its potential for extended duration of analgesia without significant side effects.[10] Similarly, Domagalska et al. described prolonged postoperative comfort and reduced pain scores (the FLACC scores ranged from 0 to 3) in children under five who received PENG blocks for hip dysplasia, further highlighting its analgesic sustainability beyond the immediate recovery period.[11]

The time to first rescue analgesia demand was longer in the PENG group (10.68 ± 7.03 h) compared to the caudal group (7.85 ± 4.77 h, p = .039), indicating superior analgesic duration, indicating superior analgesic duration. This translated into lower total morphine consumption within the first 24 postoperative hours in the PENG group (p = .047), suggesting that the block not only provides sustained pain control but also reduces opioid requirements and their associated side effects. These outcomes are concordant with those reported by Bunnell and Smith, who observed that PENG block in pediatric hip surgery resulted in minimal opioid use and prolonged analgesia in all three of their pediatric cases.[12] In addition, Reysner et al.'s randomized controlled trial further established the PENG block's analgesic superiority over lumbar ESPB in pediatric hip procedures, evidenced by both prolonged time to first rescue analgesia and significantly lower postoperative opioid consumption.[13] These findings further corroborate the opioid-sparing efficacy of PENG blockade in this population.

The CEB has long been a mainstay of pediatric regional anesthesia due to its simplicity and efficacy. While high-volume caudal epidural injections can achieve broad bilateral anesthesia, their cephalad spread is unpredictable and may precipitate unintended motor block, urinary retention, or systemic spread of local anesthetics.[14] In our study, lower limb weakness and hypotension occurred only in the caudal group, although not statistically significant. The motor-sparing nature of the PENG block offers a considerable advantage in facilitating early ambulation and recovery, As highlighted in a recent narrative review by Li et al.,[15] the PENG block targets sensory branches around the hip while sparing motor function, supporting its safety and reproducibility in pediatric patients. Similarly, Elhamrawy et al.[6] reported effective analgesia without quadriceps weakness in children undergoing hip surgery. However, postoperative motor function was not formally assessed using a validated pediatric motor block scale like the modified Bromage; limb weakness was noted only through clinical observation. Therefore, our findings should be interpreted with caution.

The PENG block also holds practical advantages in clinical scenarios where neuraxial techniques are contraindicated, such as in children with spinal anomalies, coagulopathies, or localized infection near the sacral area. Unlike the CEB, which may be precluded in these situations, the PENG block offers a peripheral, ultrasound-guided alternative that avoids the neuraxial space entirely.[11,16] This makes it a more versatile option in patients with comorbidities or anatomical variations, expanding the range of children who can benefit from regional anesthesia for hip procedures.

In contrast to our findings, Mostafa et al. reported better analgesia with erector spinae plane block (ESPB)

than with the PENG block in pediatric hip surgery.[17] This contradiction may be due to variations in block technique, anesthetic spread, or study population. ESPB may offer broader analgesia due to craniocaudal spread, despite not directly targeting hip innervation. Our findings, however, support the PENG block's effectiveness over CEB for localized and longer-lasting pain relief. These conflicting outcomes underscore the need for further comparative research. Large-scale studies are necessary to guide optimal block selection in pediatric hip surgery.

While the PENG block required a longer time to perform (10.83 ± 1.93 min vs 7.85 ± 2.28 min, $p < .001$), this may reflect the learning curve associated with a relatively new technique and the need for precise ultrasound-guided needle placement in a deep anatomical location. This is supported by anatomical studies that highlight the challenges of identifying key landmarks such as the iliopsoas notch and femoral nerve in pediatric patients, requiring skill and experience to ensure safe and effective block administration.[15] Despite this, parental satisfaction was notably greater in the PENG group, which may be attributed to the extended duration of analgesia and reduced incidence of side effects.

Limitations

Despite these promising results, several limitations warrant consideration. First, this single-center study included a modest sample size, which may affect statistical power. Second, the potential confounding effects of general anesthesia and residual neuromuscular blockade on early postoperative FLACC scores cannot be fully excluded, potentially influencing pain assessment at the 30-min timepoint. Third, The relatively low caudal volume (0.5 mL/kg) used in this study, though selected for safety in young children, may have limited the cranial spread of local anesthetic and reduced its efficacy for higher hip dermatomes. For reliable coverage of hip innervation (up to L1-T12), volumes of 1.0–1.25 mL/kg are often recommended in this age group.[18] Our chosen regimen, while potentially suboptimal for unilateral coverage, is a widely used and safe dose that can still provide adequate analgesia when combined with general anesthesia, as supported by prior pediatric studies in hip surgery.[8] Fourth, while experienced operators performed the PENG blocks, the ultrasound-guided technique in small children may involve a learning curve that could impact block success rates and performance times. Finally, we did not assess long-term outcomes, such as persistent postoperative pain or functional recovery. Future multicenter studies with larger patient cohorts and extended follow-up periods are needed to validate the sustained efficacy and safety profile of PENG blocks in pediatric populations.

Conclusion

Ultrasound-guided PENG blocks demonstrate both safety and superior analgesic efficacy compared to CEB for pediatric postoperative pain management following hip surgery. It provides prolonged analgesia, reduces opioid requirements, and enhances parental satisfaction, despite requiring a slightly longer procedure time. It represents a safe and promising alternative, especially where neuraxial techniques are contraindicated, however, further studies involving larger sample sizes and long-term outcomes are required to validate and elaborate on these findings.

ORCID iDs

Samar Rafik Amin https://orcid.org/0000-0002-1122-6692
Mona Ahmed Elhadad https://orcid.org/0000-0001-8115-2775

Ethical considerations

The study was approved by the Institutional Ethical Committee of Benha Faculty of Medicine under the number (RC_30.9.2023).

Consent for publication

Written informed consents were obtained from parents or guardians of all pediatric patients.

Author contributions

Samar Rafik Amin and Mona Ahmed Elhadad contributed to study conception, design, anesthesia protocol, data collection, and manuscript drafting. Eslam Abdelshafy Tabl assisted with study design, surgical coordination, and critical clinical review. Zeinab Mohammed Abdelwahab contributed to data acquisition, literature review, and manuscript revision. All authors approved the final version of the manuscript.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

The de-identified dataset and statistical analysis plan generated during this study are available from the corresponding author upon reasonable request.

Clinical trial registration

The clinical trial number is NCT06563622. https://register.clinicaltrials.gov/prs/beta/studies/S000ETPK00000027/recordSummary.

Supplemental material

Supplemental material for this article is available online.

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