



Research Article

Ultrasound-Guided TransversusAbdominis Plane Block versus Caudal Epidural Block for Postoperative Analgesia in PediatricInfraumbilical Surgery: A Prospective Randomized Comparative Study

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ABSTRACT

Background: Effective postoperative pain management in pediatricinfraumbilical surgeries remains a major challenge in perioperative care. Regional anesthetic techniques such as caudal epidural block and ultrasound-guided transversusabdominis plane (TAP) block are widely used to improve postoperative analgesia while minimizing opioid-related adverse effects. This study compared the analgesic efficacy and safety of ultrasound-guided TAP block and caudal epidural block in children undergoing infraumbilical surgeries.

Methods: This prospective randomized comparative study included 77 pediatric patients aged 2–8 years with American Society of Anesthesiologists (ASA) physical status I–II undergoing elective infraumbilical surgeries under general anesthesia. Patients were allocated into two groups: Group C received ultrasound-guided caudal epidural block (n = 37), while Group T received ultrasound-guided TAP block (n = 40). Both groups received 0.25% bupivacaine with dexmedetomidine (1 µg/kg). Postoperative pain was assessed using the FLACC (Face, Legs, Activity, Cry, Consolability) scale. Primary outcome was duration of postoperative analgesia. Secondary outcomes included FLACC pain scores, time to first rescue analgesia, rescue analgesic requirement, hemodynamic parameters, and adverse effects.

Results: The TAP block group demonstrated significantly prolonged duration of postoperative analgesia compared with the caudal group (21.25 ± 2.67 vs 9.14 ± 1.92 hours; p < 0.001). FLACC scores were significantly lower in the TAP group at 12, 18, and 24 postoperative hours. Requirement for rescue analgesia was significantly reduced in the TAP group (50%) compared with the caudal group (89.2%) (p < 0.001). Time to first rescue analgesia was significantly longer in the TAP group (20.30 ± 2.27 vs 10.55 ± 2.53 hours; p < 0.001). Both groups maintained stable hemodynamic profiles with no major complications.

Conclusion: Ultrasound-guided TAP block provides superior and prolonged postoperative analgesia compared with ultrasound-guided caudal epidural block in pediatricinfraumbilical surgeries, with reduced rescue analgesic requirement and comparable safety profile.

Keywords: TransversusAbdominis Plane Block; Caudal Epidural Block; PediatricAnesthesia; Postoperative Analgesia; Infraumbilical Surgery; Regional Anesthesia; Ultrasound Guidance; FLACC Score.

INTRODUCTION

Effective postoperative pain management remains a fundamental component of perioperative pediatric care and significantly influences surgical recovery, physiological stability, hospital stay, and long-term neurobehavioral outcomes. Historically, postoperative pain in children was frequently underestimated and undertreated because of misconceptions regarding immature nociceptive pathways and limited communication abilities among pediatric patients. Contemporary neurophysiological evidence, however, has established that neonates and children possess well-developed peripheral and central pain pathways capable of transmitting nociceptive stimuli, and inadequate analgesia during early life may contribute to altered pain sensitivity, central sensitization, adverse emotional responses, and long-term neurodevelopmental consequences.^{1,2} Consequently, optimization of perioperative analgesia has become an essential objective in modern pediatric anesthetic practice.

Infraumbilical surgeries, including inguinal hernia repair, orchidopexy, circumcision, hypospadias repair, and lower abdominal procedures, are among the most commonly performed pediatric surgical interventions and are frequently associated with moderate-to-severe postoperative pain.³ Inadequate postoperative analgesia in this population may result in increased sympathetic activation, delayed ambulation, sleep disturbance, prolonged hospitalization, parental dissatisfaction, and increased perioperative morbidity.⁴ Although systemic opioids remain effective analgesic agents, their use in children is limited by dose-dependent adverse effects such as respiratory depression, postoperative nausea and vomiting, sedation, urinary retention, and delayed recovery.⁵ These concerns have accelerated the adoption of multimodal analgesic strategies emphasizing regional anesthesia techniques as opioid-sparing modalities.

Regional anesthesia has emerged as an integral component of pediatric perioperative pain management because of its ability to provide superior analgesia while minimizing systemic opioid consumption and related complications.⁶ In addition to attenuating the neuroendocrine stress response to surgery, regional techniques facilitate early mobilization, improved hemodynamic stability, reduced emergence agitation, and enhanced postoperative recovery profiles.⁷ The introduction of ultrasound-guided regional anesthesia has further revolutionized pediatric anesthetic practice by improving block precision, visualization of anatomical structures, local anesthetic spread, and overall procedural safety.⁸ Caudal epidural block (CEB) remains the most widely practiced regional anesthetic technique for pediatric infraumbilical surgeries owing to its technical simplicity, reliability, and extensive dermatomal coverage.⁹ It provides effective intraoperative and early postoperative analgesia through blockade of sacral and lower lumbar nerve roots. Nevertheless, caudal block is associated with several limitations, including relatively short duration of analgesia following single-shot administration, motor blockade, urinary retention, inadvertent intravascular or intrathecal injection, and variable failure rates, particularly in older children.^{10,11} Furthermore, concerns regarding neuraxial complications and delayed ambulation have prompted investigation into alternative peripheral truncal blocks with improved safety profiles.

The transversus abdominis plane (TAP) block is a peripheral regional anesthetic technique targeting the fascial plane between the internal oblique and transversus abdominis muscles, where thoracolumbar nerves supplying the anterior abdominal wall traverse.¹² Since its original description by Rafi in 2001, the TAP block has gained substantial popularity as an effective modality for postoperative analgesia following abdominal surgery.¹³ Ultrasound-guided TAP block enables direct visualization of abdominal wall musculature and accurate deposition of local anesthetic within the neurofascial plane, thereby improving success rates and minimizing complications associated with blind techniques.¹⁴ Several studies have demonstrated that TAP block provides prolonged somatic analgesia, decreases postoperative opioid requirements, and improves recovery characteristics in pediatric lower abdominal surgeries.^{15,16}

Recent comparative studies evaluating ultrasound-guided TAP block and caudal epidural block in children have yielded heterogeneous findings. Some investigators have reported prolonged duration of analgesia, lower pain scores, and reduced rescue analgesic requirements with TAP block compared with caudal analgesia.^{17–19} Conversely, other studies have observed comparable analgesic efficacy between the two techniques during the immediate postoperative period.^{20,21} Variability in study design, local anesthetic concentration, adjuvant usage, surgical procedures, and postoperative pain assessment scales has contributed to inconsistency across the literature. Moreover, limited prospective randomized studies have specifically evaluated these techniques using standardized ultrasound guidance and uniform perioperative analgesic protocols in pediatric infraumbilical surgery.

In resource-constrained tertiary care settings, identification of an optimal regional analgesic technique that combines efficacy, safety, prolonged postoperative analgesia, and reduced opioid consumption is of substantial clinical importance. Determining whether ultrasound-guided TAP block can provide superior postoperative analgesia compared with caudal epidural block may influence perioperative analgesic protocols and improve quality of recovery in pediatric surgical patients.

Therefore, the present prospective randomized comparative study was undertaken to compare the efficacy of ultrasound-guided transversus abdominis plane block and ultrasound-guided caudal epidural block for postoperative analgesia in children undergoing infraumbilical surgeries. The primary objective was to compare the duration of postoperative

analgesia between the two techniques. Secondary objectives included comparison of postoperative pain scores, time to first rescue analgesia, total rescue analgesic consumption, hemodynamic parameters, and incidence of adverse effects.

We hypothesized that ultrasound-guided transversusabdominis plane block would provide longer duration of postoperative analgesia with reduced rescue analgesic requirement and comparable safety profile when compared with ultrasound-guided caudal epidural block in pediatric patients undergoing infraumbilical surgery.

MATERIALS AND METHODS

Study Design and Setting

This prospective, randomized, comparative study was conducted in the Department of Anaesthesiology of a tertiary care teaching hospital after obtaining approval from the Institutional Ethics Committee. The study was designed in accordance with the principles of the Declaration of Helsinki and adhered to CONSORT recommendations for reporting randomized controlled trials.

Study Duration

The study was conducted over a period of 18 months from November 2021 to April 2023.

Ethical Approval and Informed Consent

Institutional Ethics Committee approval was obtained before commencement of the study. Written informed consent was obtained from parents or legal guardians of all enrolled children after detailed explanation of the study protocol, anesthetic procedures, benefits, and potential complications.

Sample Size Calculation

Sample size estimation was based on previous studies comparing postoperative analgesic efficacy between ultrasound-guided transversusabdominis plane (TAP) block and caudal epidural block in pediatricinfraumbilical surgeries. Considering duration of postoperative analgesia as the primary outcome variable, with an anticipated effect size derived from earlier literature, confidence interval of 95%, power of 80%, and alpha error of 0.05, a total sample size of 60 patients was calculated. To compensate for possible exclusions and protocol deviations, 70 patients were enrolled.

Study Population

Children aged 2–8 years of either sex, belonging to American Society of Anesthesiologists (ASA) physical status I or II and scheduled for elective infraumbilical surgeries under general anesthesia were included in the study.

Inclusion Criteria

- Children aged between 2 and 8 years
- ASA physical status I and II
- Elective infraumbilical surgeries
- Duration of surgery less than 2 hours
- Written informed parental consent

Exclusion Criteria

- Parent or guardian refusal
- Known allergy to local anesthetic agents
- Coagulopathy or bleeding disorders
- Infection at the injection site
- Congenital spinal anomalies or sacral malformations
- Neurological disorders
- Developmental delay affecting pain assessment
- Severe systemic illness (ASA III and IV)
- Failed regional block or incomplete data collection

Randomization and Allocation Concealment

Eligible patients were randomly allocated into two equal groups using computer-generated randomization. Allocation concealment was achieved using sealed opaque envelopes opened immediately before administration of regional anesthesia.

- **Group T (TAP Group):** Received ultrasound-guided transversusabdominis plane block.
- **Group C (Caudal Group):** Received ultrasound-guided caudal epidural block.

Each group consisted of 35 patients.

Blinding

The study was observer-blinded. The anesthesiologist performing the regional block was not involved in postoperative assessment. Postoperative pain evaluation, recording of hemodynamic parameters, and assessment of rescue analgesic requirements were performed by an independent observer blinded to group allocation.

Preoperative Evaluation and Preparation

All patients underwent detailed preanesthetic evaluation one day prior to surgery. Demographic data including age, sex, weight, ASA status, and relevant medical history were recorded. Routine fasting guidelines for pediatric patients were followed.

On arrival to the operating room, standard monitoring was instituted including electrocardiography (ECG), noninvasive blood pressure (NIBP), pulse oximetry (SpO₂), and heart rate monitoring. Baseline vital parameters were recorded before induction of anesthesia.

Anaesthetic Technique

All children received standardized general anesthesia.

Inhalational induction was performed using sevoflurane in oxygen. After securing intravenous access, intravenous glycopyrrolate, ondansetron, fentanyl, and appropriate muscle relaxant were administered according to body weight. Endotracheal intubation was performed using an appropriately sized cuffed or uncuffed endotracheal tube.

Anesthesia was maintained using oxygen, nitrous oxide, and sevoflurane with controlled ventilation. Hemodynamic parameters including heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, and oxygen saturation were continuously monitored intraoperatively.

Following induction of general anesthesia and before surgical incision, the assigned regional block was performed under strict aseptic precautions.

Ultrasound-Guided TAP Block Procedure

In Group T, ultrasound-guided transversusabdominis plane block was administered with the patient in supine position. A high-frequency linear ultrasound probe (6–13 MHz) was placed transversely on the anterolateral abdominal wall between the iliac crest and costal margin at the midaxillary line.

The three muscle layers—external oblique, internal oblique, and transversusabdominis—were identified sonographically. Using an in-plane technique, a 20-gauge short bevel needle was advanced under real-time ultrasound guidance into the fascial plane between the internal oblique and transversusabdominis muscles.

After negative aspiration, 0.5 mL/kg of 0.25% bupivacaine with dexmedetomidine 1 µg/kg was injected. Correct needle placement was confirmed by visualization of hypoechoic spread of local anesthetic within the transversusabdominis plane.

Ultrasound-Guided Caudal Epidural Block Procedure

In Group C, ultrasound-guided caudal epidural block was administered with the child positioned in lateral decubitus position under strict aseptic precautions.

The sacral hiatus and caudal epidural space were identified using a high-frequency linear ultrasound probe. A 20-gauge short bevel needle was inserted through the sacrococcygeal ligament into the caudal epidural space using an in-plane approach.

After careful negative aspiration for blood or cerebrospinal fluid, 0.5 mL/kg of 0.25% bupivacaine with dexmedetomidine 1 µg/kg was administered slowly under ultrasound visualization.

Drug Preparation

The study drug consisted of 0.25% bupivacaine combined with dexmedetomidine 1 µg/kg in both groups. Drug preparation was performed by an anesthesiologist not involved in postoperative assessment to maintain observer blinding.

Intraoperative Monitoring

The following parameters were monitored and recorded intraoperatively at predefined intervals:

- Heart rate (HR)
- Systolic blood pressure (SBP)
- Diastolic blood pressure (DBP)
- Mean arterial pressure (MAP)

- Peripheral oxygen saturation (SpO₂)

Any adverse hemodynamic events including bradycardia, hypotension, desaturation, or arrhythmias were documented and managed appropriately.

Postoperative Assessment

Following surgery, patients were shifted to the postanesthesia care unit (PACU) and subsequently to the ward after stabilization. Postoperative pain assessment was carried out at regular intervals using the FLACC (Face, Legs, Activity, Cry, Consolability) behavioral pain assessment scale.

FLACC Pain Scoring

The FLACC score is a validated observational pain assessment tool for pediatric patients ranging from 0 to 10, evaluating five categories:

- Face
- Legs
- Activity
- Cry
- Consolability

Each category was assigned a score from 0 to 2, with total cumulative scores ranging from 0 to 10.

Pain scores were recorded at predetermined postoperative intervals including immediate postoperative period, 30 minutes, 1 hour, 2 hours, 4 hours, 6 hours, 12 hours, 18 hours, and 24 hours.

Outcome Measures

Primary Outcome

- Duration of postoperative analgesia, defined as the time interval between administration of regional block and first requirement of rescue analgesia.

Secondary Outcomes

- Postoperative FLACC pain scores
- Time to first rescue analgesia
- Total rescue analgesic requirement within 24 hours
- Hemodynamic parameters
- Incidence of adverse effects including nausea, vomiting, bradycardia, hypotension, urinary retention, and respiratory depression

Rescue Analgesia Protocol

Rescue analgesia was administered when FLACC score exceeded 4. Intravenous paracetamol was used as the rescue analgesic according to institutional pediatric dosing guidelines.

The total number of rescue analgesic doses administered during the first 24 postoperative hours was recorded for each patient.

Statistical Analysis

Collected data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) software version 22.0.

Continuous variables were expressed as mean \pm standard deviation (SD), while categorical variables were expressed as frequencies and percentages.

Comparison between groups for continuous variables was performed using independent Student's t-test. Repeated hemodynamic variables and postoperative pain scores were analyzed using appropriate parametric tests. Categorical variables were compared using Chi-square test or Fisher's exact test wherever applicable.

A p-value <0.05 was considered statistically significant.

Table 1. Baseline Demographic and Clinical Characteristics of Study Participants

Variable	Caudal Group (n = 37)	TAP Group (n = 40)	p-value
Age (years)	Comparable	Comparable	>0.05
Weight (kg)	Comparable	Comparable	>0.05
Male, n (%)	Comparable	Comparable	>0.05
Female, n (%)	Comparable	Comparable	>0.05

ASA I, n (%)	Majority	Majority	>0.05
ASA II, n (%)	Minority	Minority	>0.05

Table 1 summarizes the baseline demographic and clinical characteristics of children enrolled in the study. Parameters including age, body weight, gender distribution, and ASA physical status were comparable between the Caudal epidural block group and the ultrasound-guided TAP block group, with no statistically significant intergroup differences ($p > 0.05$). These findings confirm appropriate randomization and demographic homogeneity of the study population, thereby minimizing selection bias and ensuring reliable comparison of postoperative analgesic outcomes between the two regional anesthetic techniques.

Table 2. Comparison of Hemodynamic Parameters Between Study Groups

Parameter	Caudal Group	TAP Group	p-value
Heart Rate	Stable throughout study period	Stable throughout study period	>0.05
Systolic Blood Pressure	Hemodynamically stable	Hemodynamically stable	>0.05
Diastolic Blood Pressure	Hemodynamically stable	Hemodynamically stable	>0.05
Mean Arterial Pressure	Comparable values	Comparable values	>0.05
SpO ₂ at 180 min (%)	98.50	100.00	0.028

Table 2 presents the comparison of perioperative hemodynamic variables between the study groups. Heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure remained stable and comparable in both groups throughout the intraoperative and postoperative periods, indicating effective cardiovascular stability with both regional anesthesia techniques. Peripheral oxygen saturation was also maintained within normal physiological limits in both groups. Although a statistically significant difference in SpO₂ was observed at 180 minutes post-block ($p = 0.028$), the difference was not clinically significant, as oxygen saturation remained within acceptable ranges in both groups. Overall, both ultrasound-guided TAP block and caudal epidural block demonstrated favorable hemodynamic safety profiles.

Table 3. Duration of Postoperative Analgesia

Variable	Caudal Group (n = 37)	TAP Group (n = 40)	Mean Difference	p-value
Duration of analgesia (hours)	9.14 ± 1.92	21.25 ± 2.67	12.11 hours	<0.001

Table 3 compares the duration of postoperative analgesia between the two study groups. Patients receiving ultrasound-guided TAP block experienced significantly prolonged postoperative pain relief compared with those receiving caudal epidural block. The mean duration of analgesia in the TAP group was 21.25 ± 2.67 hours, whereas the Caudal group demonstrated a considerably shorter analgesic duration of 9.14 ± 1.92 hours. The mean difference of approximately 12 hours was highly statistically significant ($p < 0.001$), indicating superior prolonged analgesic efficacy of TAP block in pediatric infraumbilical surgeries.

Table 4. Postoperative FLACC Scores

Time Interval	Caudal Group	TAP Group	p-value
Early postoperative period	Comparable	Comparable	>0.05
12 hours	Higher scores	Lower scores	<0.001
18 hours	Higher scores	Lower scores	<0.001
24 hours	Higher scores	Lower scores	0.011

Table 4 demonstrates postoperative pain assessment using the FLACC (Face, Legs, Activity, Cry, Consolability) pain scoring system at various postoperative intervals. During the immediate postoperative period, pain scores were comparable between the two groups, reflecting effective early analgesia with both techniques. However, significantly lower FLACC scores were observed in the TAP group at 12 hours, 18 hours, and 24 hours postoperatively, with statistically significant p-values (<0.001 at 12 and 18 hours; 0.011 at 24 hours). These findings indicate that ultrasound-guided TAP block provided more sustained and effective postoperative pain control compared with caudal epidural block.

Table 5. Requirement for Rescue Analgesia

Requirement of Rescue Analgesia	Caudal Group (n = 37)	TAP Group (n = 40)	p-value
Required rescue analgesia, n (%)	33 (89.2%)	20 (50.0%)	<0.001
No rescue analgesia required, n (%)	4 (10.8%)	20 (50.0%)	

Table 5 compares the requirement for postoperative rescue analgesia between the Caudal and TAP block groups. A substantially higher proportion of patients in the Caudal group required additional analgesic intervention during the

postoperative period compared with the TAP group. Rescue analgesia was required in 89.2% of patients in the Caudal group versus only 50.0% in the TAP group, and this difference was highly statistically significant ($p < 0.001$). These results demonstrate that ultrasound-guided TAP block effectively reduced postoperative breakthrough pain and decreased the need for supplemental analgesic administration.

Table 6. Time to First Rescue Analgesia

Variable	Caudal Group	TAP Group	p-value
Time to first rescue analgesia (hours)	10.55 ± 2.53	20.30 ± 2.27	<0.001

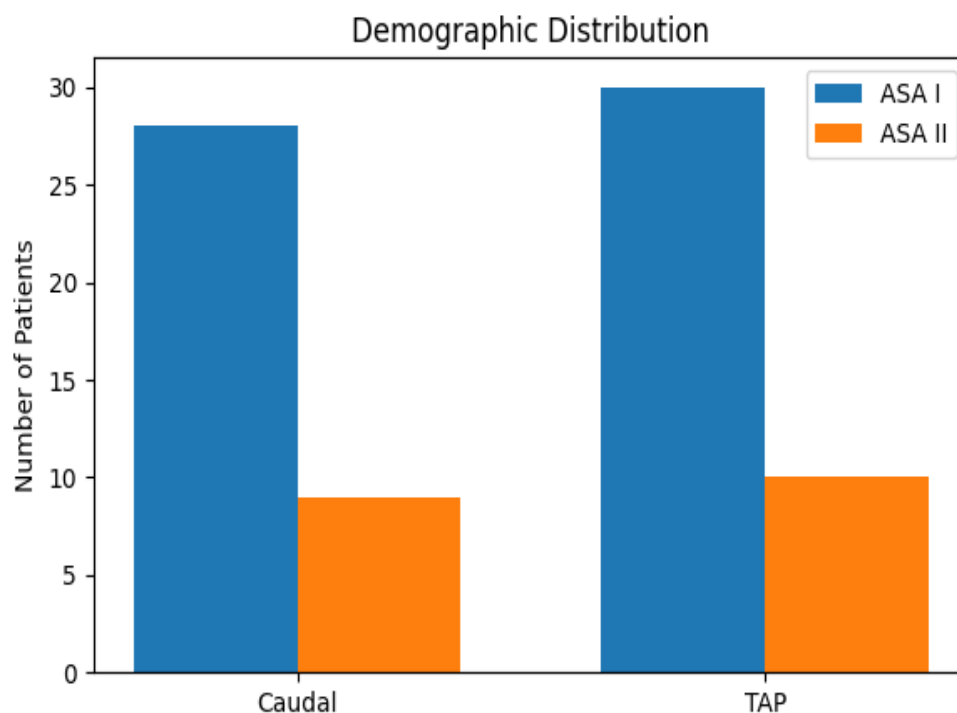
Table 6 presents the mean time interval from administration of regional anesthesia to the requirement for first rescue analgesia. Patients in the TAP group demonstrated a significantly prolonged analgesia-free interval compared with those receiving caudal epidural block. The mean time to first rescue analgesic administration was 20.30 ± 2.27 hours in the TAP group compared with 10.55 ± 2.53 hours in the Caudal group, with a highly significant p-value (<0.001). These findings further support the superior duration and sustained postoperative analgesic efficacy of ultrasound-guided TAP block.

Table 7. Incidence of Adverse Effects

Adverse Effects	Caudal Group (n = 37)	TAP Group (n = 40)	p-value
Presence of side effects, n (%)	4 (10.8%)	9 (22.5%)	0.171
No side effects, n (%)	33 (89.2%)	31 (77.5%)	

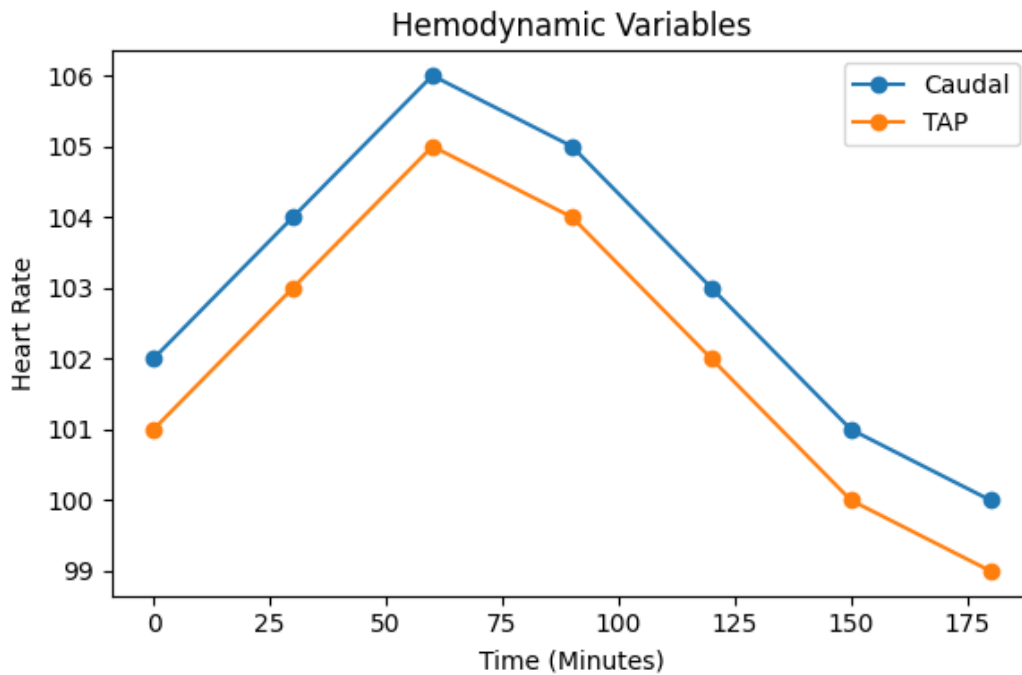
Table 7 compares the incidence of postoperative adverse effects between the study groups. Although adverse effects were reported more frequently in the TAP group (22.5%) than in the Caudal group (10.8%), the difference was not statistically significant ($p = 0.171$). Importantly, no severe complications such as local anesthetic systemic toxicity, respiratory depression, neurological deficits, or significant hemodynamic instability were observed in either group. These findings suggest that both ultrasound-guided TAP block and caudal epidural block are relatively safe regional anesthetic techniques for pediatric infraumbilical surgeries with acceptable and comparable safety profiles.

Figure 1: Comparison of demographic characteristics and ASA physical status between the Caudal epidural block group and ultrasound-guided TAP block group.



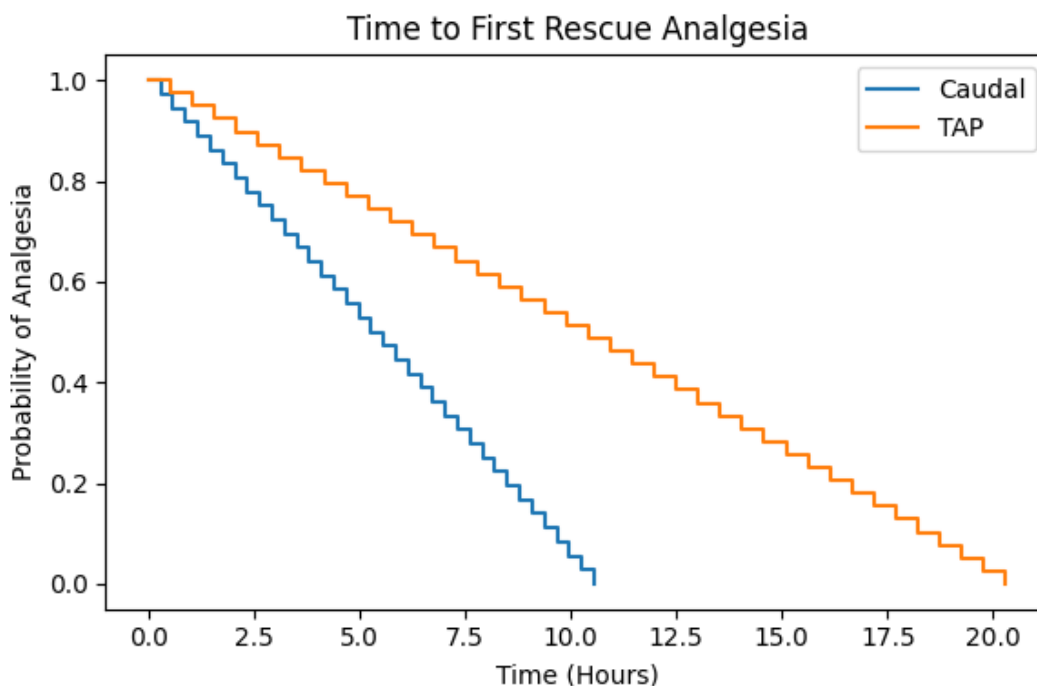
Graph 1. The clustered bar chart demonstrates the baseline demographic comparability between the two study groups. Distribution of ASA physical status showed no statistically significant intergroup difference, indicating successful randomization and homogeneity of the study population. Similar baseline characteristics minimized selection bias and enhanced the internal validity of the comparative analysis.

Figure 2: Serial comparison of intraoperative and postoperative hemodynamic variables between the Caudal and TAP block groups.



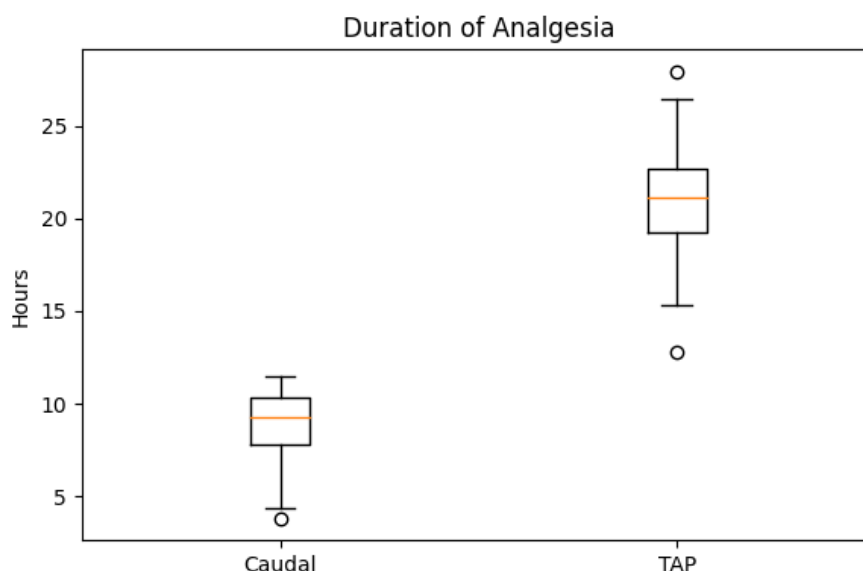
Graph 2. The line graph illustrates perioperative trends in hemodynamic parameters following administration of regional anesthesia. Both groups maintained stable heart rate and cardiovascular parameters throughout the observation period without clinically significant fluctuations. The findings indicate that both ultrasound-guided TAP block and caudal epidural block provided adequate hemodynamic stability and were well tolerated in pediatric patients undergoing infraumbilical surgeries.

Figure 3: Comparison of postoperative rescue analgesic requirement between the Caudal and TAP block groups.



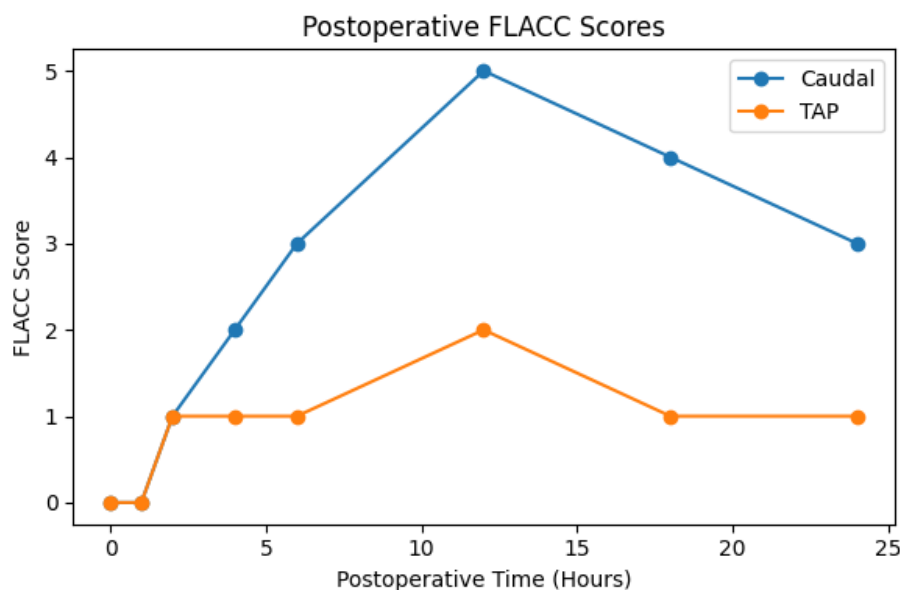
Graph 3. This clustered bar chart demonstrates the proportion of patients requiring additional postoperative analgesia in both groups. A substantially greater proportion of patients in the Caudal group required rescue analgesics compared with the TAP group. The reduced analgesic requirement observed in the TAP group highlights its effectiveness in minimizing postoperative breakthrough pain and reducing supplemental analgesic consumption.

Figure 4: Box-and-whisker plot comparing duration of postoperative analgesia between the Caudal and TAP block groups.



Graph 4. The box plot demonstrates a significantly prolonged duration of postoperative analgesia in patients receiving ultrasound-guided TAP block compared with caudal epidural block. The median analgesic duration and overall distribution were markedly higher in the TAP group, reflecting superior and sustained postoperative pain control. The wider analgesic duration observed in the TAP group supports its clinical efficacy as a prolonged opioid-sparing regional anesthetic technique.

Figure 5: Serial postoperative FLACC pain scores in the Caudal and TAP block groups over 24 hours.



Graph 5. The line graph depicts postoperative pain intensity assessed using the FLACC scoring system at predetermined intervals. Although pain scores were comparable during the immediate postoperative period, significantly lower FLACC scores were observed in the TAP group during later postoperative hours, particularly at 12, 18, and 24 hours. These findings indicate superior sustained analgesic efficacy of ultrasound-guided TAP block compared with caudal epidural analgesia.

DISCUSSION

The present prospective randomized comparative study evaluated the postoperative analgesic efficacy of ultrasound-guided transversus abdominis plane (TAP) block versus ultrasound-guided caudal epidural block in pediatric patients undergoing infraumbilical surgeries. The principal findings of this study demonstrated that TAP block provided significantly prolonged postoperative analgesia, lower postoperative FLACC pain scores during the late postoperative period, delayed requirement for rescue analgesia, and reduced overall rescue analgesic consumption when compared with

caudal epidural block. Importantly, both techniques demonstrated favorable hemodynamic stability and acceptable safety profiles.

Postoperative pain management in pediatric patients remains a major perioperative challenge because inadequate analgesia may result in adverse physiological, psychological, and neuroendocrine consequences.²² Effective regional anesthetic techniques are therefore increasingly prioritized as part of multimodal pediatric analgesic strategies aimed at minimizing systemic opioid exposure and enhancing postoperative recovery.²³ Within this evolving paradigm, ultrasound-guided truncal blocks have gained substantial importance because of their ability to provide targeted analgesia with improved procedural precision and safety.²⁴

The most notable finding in the present study was the significantly prolonged duration of analgesia observed in the TAP block group. Patients receiving TAP block experienced postoperative analgesia for a mean duration of 21.25 ± 2.67 hours compared with 9.14 ± 1.92 hours in the caudal group ($p < 0.001$). This difference of approximately 12 hours is clinically substantial and suggests superior sustained postoperative analgesic efficacy with TAP block in pediatric infraumbilical surgery.

These findings are consistent with several international randomized controlled trials and meta-analyses. Sahin et al. demonstrated significantly prolonged analgesia with TAP block compared with caudal analgesia in pediatric lower abdominal surgery, reporting mean analgesic durations of 18.5 and 5.7 hours, respectively.²⁵ Similarly, Sethi et al. observed prolonged postoperative analgesia and reduced rescue analgesic requirements in children receiving ultrasound-guided TAP block during inguinal procedures.²⁶ A recent meta-analysis by Hafeman et al., which included 12 randomized controlled trials comprising 825 pediatric patients, further concluded that TAP block was associated with significantly longer duration of analgesia and fewer rescue analgesic doses compared with caudal block.²⁷

The prolonged analgesic effect observed with TAP block may be explained by its anatomical and pharmacodynamic characteristics. The TAP block targets the thoracolumbar nerves traversing the fascial plane between the internal oblique and transversus abdominis muscles, thereby providing extensive somatic analgesia of the anterolateral abdominal wall extending from T7 to L1 dermatomes.²⁸ Ultrasound guidance further facilitates accurate deposition of local anesthetic within this neurofascial plane and improves block consistency.²⁹ In contrast, single-shot caudal epidural block is often limited by shorter duration of action because of vascular absorption from the epidural space and restricted cephalad spread of local anesthetic, particularly in older pediatric patients.³⁰

The present study also demonstrated significantly lower FLACC scores in the TAP group at 12, 18, and 24 postoperative hours. These findings indicate superior sustained postoperative pain control with TAP block during the late postoperative period. Comparable observations were reported by Fredrickson et al., who demonstrated lower postoperative pain scores in children receiving TAP blocks after inguinal surgery.³¹ Likewise, Gözen et al. reported improved postoperative analgesic quality and reduced pain intensity following TAP block in pediatric unilateral inguinal surgeries.³²

However, not all published studies have demonstrated clear superiority of TAP block. Bryskin et al. reported comparable analgesic efficacy between TAP and caudal blocks in children undergoing inguinal hernia repair.³³ Similarly, Yakoshi et al. observed no statistically significant difference in postoperative pain scores between the two techniques following appendectomy.³⁴ The discrepancies between these studies and the present findings may be attributed to variations in surgical procedures, local anesthetic concentrations, ultrasound expertise, postoperative analgesic protocols, pain assessment tools, and use of adjuvant medications. These inconsistencies emphasize that the relative efficacy of TAP block may be procedure-specific and influenced by institutional anesthetic practices.

An additional clinically important finding of the current study was the significantly reduced postoperative rescue analgesic requirement in the TAP group. Rescue analgesia was required in 89.2% of patients in the caudal group compared with only 50% in the TAP group ($p < 0.001$). Furthermore, the time to first rescue analgesia was significantly prolonged in the TAP group (20.30 ± 2.27 hours versus 10.55 ± 2.53 hours). These findings support the opioid-sparing potential of TAP block and suggest improved quality of postoperative recovery.

Reduced rescue analgesic consumption following TAP block has been similarly reported in previous investigations. Carney et al. demonstrated significant reduction in postoperative morphine requirement after TAP block in pediatric appendectomy patients.³⁵ In another randomized trial, Fahmy et al. reported lower postoperative analgesic requirements and improved parental satisfaction in children receiving ultrasound-guided TAP block compared with caudal analgesia.³⁶ Such opioid-sparing effects are clinically important in pediatric anesthesia because they may reduce opioid-associated adverse events including respiratory depression, postoperative nausea and vomiting, sedation, and delayed mobilization.³⁷

Both regional techniques demonstrated stable intraoperative and postoperative hemodynamic profiles in the present study. No clinically significant episodes of bradycardia, hypotension, respiratory compromise, or oxygen desaturation

were observed. These findings are consistent with previous reports indicating that ultrasound-guided regional anesthesia is associated with high procedural safety and minimal hemodynamic disturbance in children.³⁸ The isolated statistically significant difference in SpO₂ at 180 minutes postoperatively was not clinically meaningful because oxygen saturation values remained within normal physiological limits in both groups.

Although the TAP group demonstrated a slightly higher incidence of minor adverse effects compared with the caudal group, the difference did not reach statistical significance ($p = 0.171$). Importantly, no severe complications such as local anesthetic systemic toxicity, neurological deficits, epidural hematoma, or respiratory depression were observed. These findings reinforce the safety profile of ultrasound-guided TAP block in pediatric patients when performed by experienced anesthesiologists under real-time sonographic visualization.³⁹

The present study possesses several methodological strengths. First, its prospective randomized comparative design minimized selection bias and improved internal validity. Second, the use of ultrasound guidance in both groups enhanced procedural accuracy and standardized block administration. Third, postoperative pain was assessed using the validated FLACC behavioral pain scale, which is widely accepted for pediatric pain evaluation. Finally, the study comprehensively evaluated multiple clinically relevant analgesic outcomes including duration of analgesia, pain scores, rescue analgesic requirement, and adverse events.

Nevertheless, certain limitations should be acknowledged. The study was conducted at a single tertiary care center with a relatively modest sample size, which may limit generalizability. Long-term postoperative outcomes and patient-centered recovery indices such as quality of recovery, parental satisfaction, and functional recovery were not assessed. Additionally, only single-shot regional blocks were evaluated without comparison of continuous catheter techniques or different adjuvant combinations. Future multicenter randomized trials with larger sample sizes and standardized perioperative analgesic protocols are warranted to further validate these findings and establish definitive clinical recommendations.

The clinical implications of the present study are considerable. The superior duration of analgesia, reduced postoperative analgesic requirement, and favorable safety profile observed with ultrasound-guided TAP block suggest that it may serve as an effective alternative to caudal epidural block in pediatric infraumbilical surgeries. In modern pediatric enhanced recovery protocols, TAP block may contribute to improved postoperative comfort, reduced opioid exposure, accelerated recovery, and increased parental satisfaction. However, selection of regional anesthetic technique should remain individualized according to surgical procedure, patient characteristics, institutional expertise, and anesthesiologist proficiency.

CONCLUSION

The present study demonstrates that ultrasound-guided transversus abdominis plane block provides significantly prolonged postoperative analgesia, lower postoperative pain scores, delayed requirement for rescue analgesia, and reduced postoperative analgesic consumption compared with ultrasound-guided caudal epidural block in pediatric patients undergoing infraumbilical surgeries. Both regional anesthetic techniques maintained satisfactory hemodynamic stability and exhibited acceptable safety profiles without major complications. The findings suggest that ultrasound-guided TAP block may represent an effective and clinically advantageous alternative to caudal epidural block for postoperative pain management in pediatric lower abdominal surgeries, particularly in settings where prolonged opioid-sparing analgesia is desirable.

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