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Effect of Different Volumes of Bupivacaine 0.25% Caudal Block on Cardiac Index Measured by Ultrasonic Cardiac Output Monitor in Children Undergoing Elective Lower Abdominal Surgery: A Double-Blind Randomized Controlled Trial

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ABSTRACT: Background: Caudal block with bupivacaine is widely used for analgesia in pediatric lower abdominal surgery, but its effects on cardiac index (CI) require further evaluation. This study assessed changes in CI following caudal bupivacaine 0.25% using non-invasive Ultrasonic Cardiac Output Monitoring (USCOM).

Methods: This double-blind randomized clinical trial included 33 children undergoing lower abdominal surgery. Participants were randomized into three groups (n=11 each): caudal bupivacaine 0.25% at 0.8 mL/kg (Group A), 1.2 mL/kg (Group B), or general anaesthesia alone (Group C). CI was measured using USCOM at baseline and serially after induction up to 30 minutes. Between-group differences were analyzed statistically.

Results: CI differed significantly among the three groups at baseline and throughout the observation period ($p < 0.05$). At baseline, mean CI was 4.53, 5.12, and 5.79 L/min/m² in Groups A, B, and C, respectively ($p = 0.022$). At 30 minutes, mean CI decreased to 3.97, 3.99, and 4.92 L/min/m² in Group A, B, and C, respectively ($p = 0.017$). CI decreased progressively over time in all groups, with lower values observed in the caudal block groups.

Conclusions: Caudal bupivacaine 0.25% was associated with a significant decrease in CI in children undergoing lower abdominal surgery. The decrease was greater with increasing bupivacaine volume, although CI remained within age-appropriate clinical ranges.

1. INTRODUCTION

Caudal block is one of the most commonly used regional anesthesia techniques in children, particularly for lower abdominal, perineal, and lower extremity procedures. It provides effective intraoperative and postoperative analgesia by interrupting

nociceptive transmission at the relevant spinal segments. Bupivacaine 0.25% is commonly used for caudal anesthesia because of its relatively prolonged duration of action. However, neuraxial blockade may also affect sympathetic nerve activity and consequently alter hemodynamics. These effects are of particular concern in children, in whom cardiovascular responses to changes in preload, afterload, and contractility differ from those of adults [1].

Cardiac output (CO) and cardiac index (CI) are important indicators of systemic circulatory function. CI, calculated by normalizing CO to body surface area, provides an assessment of cardiac performance that accounts for differences in body size. Following caudal anesthesia, sympathetic blockade and vasodilation may reduce systemic vascular resistance and venous return, potentially leading to changes in stroke volume and CO. These hemodynamic effects may be clinically relevant when larger volumes of local anesthetic are administered. Accurate assessment of CO and CI in children during anesthesia, however, remains challenging. Invasive techniques such as pulmonary artery catheterization are associated with procedural risks, whereas conventional non-invasive monitoring, including non-invasive blood pressure and electrocardiography, provides mainly indirect information regarding cardiac performance [1, 2].

The Ultrasonic Cardiac Output Monitor (USCOM) provides a non-invasive approach for assessing cardiovascular hemodynamics. Using continuous-wave Doppler technology, USCOM measures blood flow velocity across the aortic or pulmonary valve and derives stroke volume, CO, and CI. Its non-invasive nature and ability to provide real-time hemodynamic measurements make it potentially useful for evaluating dynamic cardiovascular changes during pediatric anesthesia. Previous studies have used USCOM to assess hemodynamic responses to caudal anesthesia in children, supporting its potential utility for perioperative monitoring [3, 4]. Nevertheless, quantitative data regarding the effect of caudal bupivacaine 0.25% on CI in children undergoing lower abdominal surgery remain limited. A previous randomized clinical trial reported a significant and dose-related reduction in CI following caudal bupivacaine, with more pronounced changes at higher volumes. However, the available evidence remains limited, and objective assessment using non-invasive hemodynamic monitoring may provide further information regarding the cardiovascular effects of different caudal anesthetic volumes. Therefore, this study aimed to evaluate and compare changes in CI measured using USCOM in children undergoing lower abdominal surgery who received caudal bupivacaine 0.25% at 0.8 mL/kg or 1.2 mL/kg, compared with children receiving general anesthesia without caudal block.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This study was a single-center, three-arm, parallel-group, double-blind randomized clinical trial evaluating the effect of caudal bupivacaine 0.25% on cardiac index (CI) measured by the Ultrasonic Cardiac Output Monitor (USCOM) in children undergoing lower abdominal surgery. The study was conducted in the operating room at Dr. Wahidin Sudirohusodo Hospital, Makassar, Indonesia, with recruitment conducted from April to August 2026.

2.2 Study Population and Sampling

The target population comprised children undergoing lower abdominal surgery for which caudal anesthesia was indicated. Eligible participants were recruited from patients scheduled for surgery at Dr. Wahidin Sudirohusodo Hospital. The sample size was calculated based on a randomized clinical trial design using an estimated standard deviation of 2.4 and a clinically meaningful difference in cardiac index (CI) of 3.0 L/min/m², with a two-sided α of 0.05 and 80% power. The minimum required sample was 10 participants per group. To account for a potential 10% dropout rate, the sample size was increased to 11 participants per group, resulting in a total of 33 participants. Participants who fulfilled the eligibility criteria and provided informed consent were randomly allocated in equal proportions to three groups: Group A, receiving general anesthesia and caudal bupivacaine 0.25% at 0.8 mL/kg; Group B, receiving general anesthesia and caudal bupivacaine 0.25% at 1.2 mL/kg; and Group C, receiving general anesthesia alone as the control group.

2.3 Eligibility Criteria

The inclusion criteria were: (1) children undergoing lower abdominal surgery for which caudal block was planned; (2) age 1–5 years and body weight ≤ 17 kg; and (3) American Society of Anesthesiologists Physical Status (ASA-PS) I–II. The exclusion criteria were: (1) coagulation abnormalities, defined as platelet count $\leq 50,000/\text{mm}^3$ and/or international normalized ratio > 1.5 ; (2) current use of vasopressor medication; (3) suspected or confirmed allergy to local anesthetics, a history of rash, or signs of infection at the injection site; (4) parental refusal to participate; and (5) planned laparoscopic surgery. Participants were

withdrawn from the study if they developed cardiopulmonary emergencies such as anaphylactic shock following general or caudal anesthesia, experienced an allergic reaction following either anaesthetic technique, or had a failed caudal block.

2.4 Randomization and Blinding

After eligibility was confirmed and written informed consent was obtained from the parents or legal guardians, participants were randomly allocated in equal proportions to one of three study groups. The study was a double-blind randomized clinical trial. We used a random number table to generate the randomization sequence, and allocation concealment was managed by personnel blinded to treatment allocation. Group assignments were prepared in sealed envelopes. Only the anesthesiologist knew the subjects' group assignments. The assignments were revealed once the study was completed and analysis was set to begin.

2.5 Data Collection and Clinical Assessment

Before anaesthesia induction, baseline demographic and clinical characteristics were recorded, including age, sex, nutritional status, and ASA-PS classification. Baseline vital signs were assessed using automated monitoring and included systolic and diastolic blood pressure, mean arterial pressure (MAP), heart rate, respiratory rate, oxygen saturation, and body temperature. Baseline hemodynamic parameters, including Cardiac Output (CO), Stroke Volume (SV), Cardiac Index (CI), and Systemic Vascular Resistance (SVR), were assessed using USCOM before induction. Following induction of general anaesthesia, the same hemodynamic parameters were serially assessed according to the predefined measurement schedule. The study protocol included a 10-minute intraoperative steady-state period without surgical stimulation during the initial hemodynamic assessment. Heart rate and MAP were continuously monitored, and potential adverse effects associated with caudal anesthesia, including bradycardia and hypotension, were assessed.

2.6 Hemodynamic Measurement by USCOM

The hemodynamic measurements were obtained using the Ultrasonic Cardiac Output Monitor (USCOM), a non-invasive continuous-wave Doppler-based monitoring device. The transducer was positioned at the suprasternal notch or pulmonary window, and its position and angle were adjusted to optimize the Doppler signal according to the visual waveform displayed on the monitor. The device provided measurements of CO, SV, CI, SVR, and other hemodynamic parameters. CI was calculated by the device from CO normalized to body surface area. For each participant, USCOM measurements of CO, SV, CI, and SVR were obtained at baseline before anaesthesia induction (T0), CI measurement was obtained every 2 minutes during the first 10 minutes after induction (CI-T1 to CI-T5), and subsequently at 15, 20, and 30 minutes after induction (CI-T15, CI-T20, and CI-T30). The primary hemodynamic outcome evaluated in this study was CI, expressed in L/min/m².

After eligibility confirmation and randomization, standard general anaesthesia was induced using intravenous propofol and fentanyl with a muscle relaxant and/or inhalational induction using sevoflurane, according to the study protocol. For participants assigned to the caudal anaesthesia groups, the child was placed in the right lateral position. A 22-gauge needle was inserted into the caudal space using a blind technique. Group A received 0.25% bupivacaine at a dose of 0.8 mL/kg, whereas Group B received 0.25% bupivacaine at a dose of 1.2 mL/kg, with the maximum administered dose limited to 2.5 mg/kg. Following injection, the patient was repositioned supine. Hemodynamic measurements were subsequently performed during a 10-minute steady-state period without surgical stimulation. Participants allocated to Group C received general anesthesia without caudal bupivacaine. All three groups underwent the same predefined hemodynamic monitoring schedule.

2.7 Statistical Analysis

Statistical analyses were performed using SPSS version 27 for Windows. Continuous variables were summarized using the mean, median, and standard deviation, as appropriate, whereas categorical variables were presented as frequencies and percentages. The Shapiro–Wilk test was used to assess the normality of continuous variables. For comparisons between two independent groups, an independent-samples t test was used for normally distributed data and the Mann–Whitney U test for non-normally distributed data. Comparisons between pre- and post-intervention measurements were performed using the paired t test for normally distributed data or the Wilcoxon signed-rank test for non-normally distributed data. For categorical variables, the chi-square test was used when the expected cell counts were adequate; Fisher's exact test was used when an expected cell count was <5.

For comparisons of CI among the three study groups, analysis of variance (ANOVA) was used when the data met parametric assumptions, whereas the Kruskal–Wallis test was used for non-normally distributed data. Statistical tests were two-sided, with a 95% confidence interval, and $p < 0.05$ was considered statistically significant.

3. RESULTS AND DISCUSSION

3.1 Baseline Characteristics

A total of 34 children were initially screened for eligibility, of whom 33 met the inclusion criteria and were enrolled in this double-blind randomized clinical trial. One subject was excluded due to parental refusal to participate. The 33 eligible subjects were randomly allocated into three groups of 11 patients each. All 33 subjects completed the study protocol and were included in the final analysis. The distribution of baseline demographic characteristics, nutritional status, and ASA physical status classification is presented in Table 1. Overall, the study population consisted of 19 males (57.6%) and 14 females (42.4%). The majority of subjects had good nutritional status ($n=25$, 75.8%), while 8 subjects (24.2%) were classified as wasted. Nearly all subjects were classified as ASA physical status II ($n=32$, 97.0%), with only one subject (3.0%) in Group B classified as ASA I. Statistical analysis using the Chi-square test revealed no significant differences between the three groups in terms of gender distribution ($p=0.883$), nutritional status ($p=0.315$), or ASA physical status ($p=0.357$), indicating that the groups were homogeneous and comparable at baseline.

Table 1. Characteristics of Study Subjects

Characteristic	Group A (n=11)	Group B (n=11)	Group C (n=11)	Total (n=33)	p-value
Gender, n (%)					0.883
Male	6 (54.5)	6 (54.5)	7 (63.6)	19 (57.6)	
Female	5 (45.5)	5 (45.5)	4 (36.4)	14 (42.4)	
Nutritional Status, n (%)					0.315
Wasted	3 (27.3)	1 (9.1)	4 (36.4)	8 (24.2)	
Good	8 (72.7)	10 (90.9)	7 (63.6)	25 (75.8)	
ASA-PS, n (%)					0.357
ASA I	0 (0.0)	1 (9.1)	0 (0.0)	1 (3.0)	
ASA II	11 (100.0)	10 (90.9)	11 (100.0)	32 (97.0)	

Data presented as n (%) unless otherwise specified. ASA-PS: American Society of Anesthesiologists Physical Status. Chi-square test

Baseline hemodynamic parameters measured using USCOM are summarized in Table 2. Significant differences were observed between groups for several demographic and anthropometric variables. Heart rate demonstrated significant variation between groups ($p=0.017$), with Group B showing the highest mean HR (108.91 ± 13.03 bpm), followed by Group A (108.27 ± 3.82 bpm), and Group C (97.27 ± 9.76 bpm). Mean arterial pressure was significantly different among groups ($p < 0.001$), increasing with age: Group A (74.27 ± 4.13 mmHg), Group B (75.64 ± 6.34 mmHg), and Group C (84.27 ± 4.94 mmHg). Cardiac index demonstrated significant intergroup differences ($p=0.022$), with Group C exhibiting the highest mean CI (5.79 ± 1.04 L/min/m²), followed by Group B (5.12 ± 1.15 L/min/m²), and Group A (4.53 ± 0.77 L/min/m²).

3.2 Comparison of Cardiac Index During Perioperative Period (CI-T0 to CI-T30)

Serial measurements of cardiac index were performed at baseline (CI-T0), every 2 minutes during the first 10 minutes after induction (CI-T1 to CI-T5), and at 15, 20, and 30 minutes post-induction (CI-T15, CI-T20, CI-T30). All time points demonstrated statistically significant differences between the three groups ($p < 0.05$ for all measurements). In Group A, mean

CI-T0 was 4.53 ± 0.77 L/min/m², which showed a gradual decline to 4.10 ± 0.70 L/min/m² at T5, and further decreased to 3.97 ± 0.66 L/min/m² at T30. The decline was relatively modest and stabilized after T5, with minimal fluctuations throughout the observation period. Group B demonstrated a more pronounced decrease in CI. Starting from a baseline of 5.12 ± 1.15 L/min/m² at T0, CI decreased to 4.32 ± 1.05 L/min/m² at T5, and continued to decline progressively, reaching 3.99 ± 0.96 L/min/m² at T30. This group exhibited the steepest and most progressive decline among the three groups. Group C maintained the highest CI values throughout the observation period. Baseline CI was 5.79 ± 1.04 L/min/m² at T0, decreasing gradually to 5.19 ± 0.77 L/min/m² at T5, and reaching 4.92 ± 0.75 L/min/m² at T30. The decline in this group was more gradual and consistent compared to the caudal block groups. All groups demonstrated a decreasing trend in CI following anesthetic induction; however, the magnitude and pattern of decline differed significantly between groups, with Group C consistently maintaining higher CI values at all time points.

Comparative analysis revealed statistically significant differences in cardiac index between the three study groups at all measurement time points. At baseline (CI-T0), Group C demonstrated significantly higher mean CI (5.79 ± 1.04 L/min/m²) compared to Group B (5.12 ± 1.15 L/min/m²) and Group A (4.53 ± 0.77 L/min/m²) ($p=0.022$). At CI-T1 (2 minutes post-induction), the pattern persisted with Group C showing the highest CI (5.69 ± 1.03 L/min/m²), followed by Group B (4.98 ± 1.10 L/min/m²), and Group A (4.53 ± 0.75 L/min/m²) ($p=0.028$). By T5 (10 minutes post-induction), CI values were: Group C (5.19 ± 0.77 L/min/m²), Group B (4.32 ± 1.05 L/min/m²), and Group A (4.10 ± 0.70 L/min/m²) ($p=0.016$). At the final measurement point (T30, 30 minutes post-induction), Group C maintained significantly higher CI (4.92 ± 0.75 L/min/m²) compared to Group A (3.97 ± 0.66 L/min/m²) and Group B (3.99 ± 0.96 L/min/m²) ($p=0.017$). Notably, Groups A and B demonstrated converging CI values at T30, despite starting from different baselines. The percentage decrease in CI from baseline to T30 was most pronounced in Group B, followed by Group A, and least in Group C, demonstrating a dose-dependent effect of caudal bupivacaine on cardiac index. Despite statistically significant decreases, all CI values remained within clinically acceptable ranges for the respective age groups according to USCOM reference values.

Table 2. Baseline Hemodynamic Parameters and Demographic Characteristics

Parameter	Group A	Group B	Group C	p-value
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
Age (years)	1.33 ± 0.28	2.42 ± 1.32	3.65 ± 1.18	0.002**
Weight (kg)	8.45 ± 0.94	10.63 ± 2.14	12.49 ± 2.61	<0.001*
Height (cm)	75.59 ± 5.95	83.65 ± 15.64	95.09 ± 11.09	0.002*
BSA (m ²)	0.42 ± 0.04	0.49 ± 0.08	0.57 ± 0.09	<0.001**
HR (bpm)	108.27 ± 3.82	108.91 ± 13.03	97.27 ± 9.76	0.017**
MAP (mmHg)	74.27 ± 4.13	75.64 ± 6.34	84.27 ± 4.94	<0.001*
CO (L/min)	1.80 ± 0.32	2.52 ± 0.80	3.44 ± 0.86	<0.001*
SV (mL)	16.70 ± 3.17	24.22 ± 10.28	35.79 ± 9.61	<0.001**
SVR (dyn·s/cm ⁵)	1983.45 ± 230.07	1822.73 ± 292.18	1477.09 ± 211.60	<0.001**
CI-T0 (L/min/m ²)	4.53 ± 0.77	5.12 ± 1.15	5.79 ± 1.04	0.022**
CI-T1 (L/min/m ²)	4.53 ± 0.75	4.98 ± 1.10	5.69 ± 1.03	0.028*
CI-T2 (L/min/m ²)	4.35 ± 0.70	4.83 ± 1.04	5.55 ± 0.98	0.017*

CI-T3 (L/min/m ²)	4.31 ± 0.68	4.63 ± 1.06	5.42 ± 0.93	0.021*
CI-T4 (L/min/m ²)	4.21 ± 0.71	4.50 ± 1.05	5.31 ± 0.83	0.025**
CI-T5 (L/min/m ²)	4.10 ± 0.70	4.32 ± 1.05	5.19 ± 0.77	0.016**
CI-T15 (L/min/m ²)	4.10 ± 0.75	4.22 ± 1.07	5.09 ± 0.80	0.044**
CI-T20 (L/min/m ²)	4.08 ± 0.77	4.12 ± 0.98	4.99 ± 0.78	0.031**

BSA: Body Surface Area; HR: Heart Rate; MAP: Mean Arterial Pressure; CO: Cardiac Output; CI: Cardiac Index; SV: Stroke Volume; SVR: Systemic Vascular Resistance.

*One-way ANOVA **Kruskal-Wallis test

3.3 Incidence of Side Effects and Complications

No adverse events or complications were observed in any of the study groups throughout the perioperative period. Specifically, there were no instances of hypotension, bradycardia, allergic reactions, or requirement for vasopressor support. Additionally, no cases of caudal block failure were encountered.

3.4 Discussion

This double-blind randomized clinical trial demonstrated that caudal block with bupivacaine 0.25% produced significant but clinically acceptable decreases in Cardiac Index (CI) in children undergoing lower abdominal surgery. The magnitude of CI reduction was dose-dependent, with the higher volume (1.2 mL/kg) producing more pronounced hemodynamic changes compared to the lower volume (0.8 mL/kg) and general anaesthesia alone. Figure 1 shows the changes in mean Cardiac Index (CI) values measured using USCOM across the three study groups during the observation period from T0 (preoperative) to T30 (30 minutes after anaesthesia induction), while Figure 2, the boxplot graph shows the distribution and dynamics of Cardiac Index (CI) values in the three research groups (Group A, Group B, and Group C) during nine monitoring time points, starting from baseline (T0) to T30.

The principal finding of this study is that caudal block administration resulted in statistically significant decreases in CI across all measurement time points (CI-T0 to CI-T30), with all values remaining within age-appropriate normal ranges according to USCOM reference values. Group C (general anaesthesia only) consistently maintained the highest CI values throughout the observation period, while Group B (1.2 mL/kg) exhibited the steepest and most progressive decline. Group A (0.8 mL/kg) demonstrated the most stable hemodynamic profile with minimal fluctuations.

These findings are consistent with the study by Sarhan et al., which reported significant dose-dependent decreases in CI following caudal block in children aged 1-8 years [1]. In their randomized controlled trial involving 96 children, they found that the percentage decrease in CI at 10 minutes post-block was significantly greater in the 0.8 mL/kg group (-11.4%) and 1.2 mL/kg group (-17.1%) compared to the control group (-0.7%) [1]. Our findings similarly demonstrated progressive CI reduction, with Group B showing more pronounced decreases than Group A, supporting the dose-response relationship of bupivacaine on cardiac function.

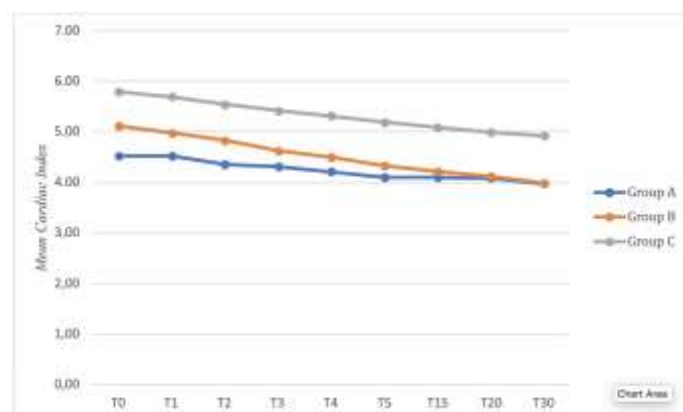


Figure 1. Changes in Mean Cardiac Index Measured by USCOM in Children Who Received Different Doses of 0.25% Bupivacaine Caudal Block (Groups A, B, and C)

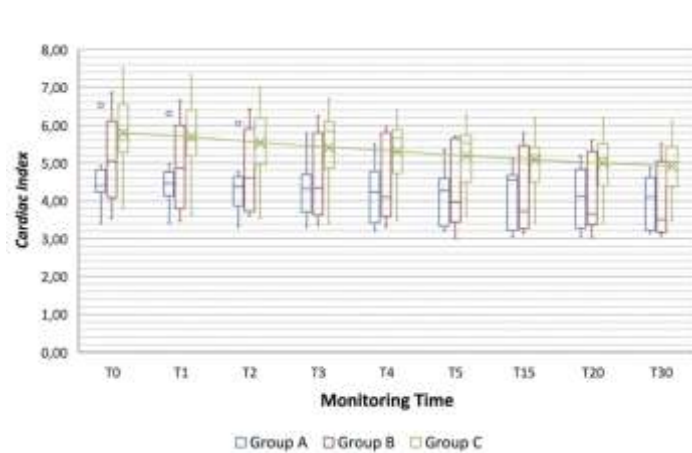


Figure 2. Cardiac Index Distribution Graph (Boxplot) in the Study Groups

The observed decreases in CI following caudal block can be attributed to several interconnected mechanisms. Caudal anaesthesia produces sympathetic blockade, leading to venous and arterial vasodilation, decreased systemic vascular resistance (SVR), and reduced venous return (preload) [2, 3]. In pediatric patients, whose cardiac output is predominantly heart rate-dependent due to relatively fixed stroke volume, these changes can significantly impact CI [4, 5].

Our findings showed significant differences in SVR between groups ($p < 0.001$), with Group A demonstrating the highest SVR ($1983.45 \pm 230.07 \text{ dyn}\cdot\text{s}/\text{cm}^5$), followed by Group B ($1822.73 \pm 292.18 \text{ dyn}\cdot\text{s}/\text{cm}^5$), and Group C ($1477.09 \pm 211.60 \text{ dyn}\cdot\text{s}/\text{cm}^5$). This pattern suggests that the sympathetic blockade from caudal anaesthesia produced dose-dependent vasodilation. However, contrary to expectations, SVR did not uniformly decrease following caudal block in all groups.

These findings align with Siriboon et al., who reported no evidence of SVR decrease following caudal block in children under 8 years of age, and even observed increased SVR in older children (3-8 years) [3]. They proposed that this paradoxical increase may reflect immature sympathetic nervous system development in pediatric patients, or compensatory vasoconstriction in upper body vasculature counteracting lower extremity vasodilation [3]. The increase in SVR may also represent a compensatory mechanism responding to decreased CO, as SVR is inversely related to CO [3].

An important finding in our study was the significant baseline differences in age between groups (Group A: 1.33 ± 0.28 years, Group B: 2.42 ± 1.32 years, Group C: 3.65 ± 1.18 years; $p = 0.002$), which inevitably influenced baseline hemodynamic parameters. This age distribution resulted in corresponding differences in weight, height, BSA, heart rate, and mean arterial pressure at baseline.

These age-related variations are well-documented in pediatric hemodynamics. Neonates and infants have myocardium with near-maximal contractility, limited preload reserve, and are highly dependent on heart rate to maintain cardiac output [4, 6]. As children mature, myocardial mass increases, ventricular volume expands, and contractile efficiency improves, allowing for greater stroke volume and enhanced cardiac reserve [5, 7]. The higher baseline CI observed in Group C (5.79 ± 1.04 L/min/m²) compared to Groups A (4.53 ± 0.77 L/min/m²) and B (5.12 ± 1.15 L/min/m²) likely reflects this age-dependent maturation of cardiovascular function [8]. Despite normalization to body surface area, CI still demonstrates age-related variation due to differences in autonomic nervous system maturity and cardiovascular response to anesthetic agents [9].

Our results corroborate findings from multiple studies investigating hemodynamic effects of caudal anaesthesia in pediatric patients. Benka et al. demonstrated that combining caudal block with general anaesthesia provided greater hemodynamic stability compared to general anaesthesia alone in children undergoing herniorrhaphy [10]. They reported that the caudal block group showed less heart rate and systolic blood pressure elevation during surgical stimulation, suggesting better attenuation of stress response [10]. The study by Liu et al. investigated the effects of adding epinephrine to caudal anaesthesia and found significantly increased stroke volume and cardiac output in the epinephrine group compared to plain local anesthetic [11]. This finding supports the theory that hemodynamic effects of caudal block are mediated through autonomic nervous system modulation, as epinephrine's systemic absorption produces direct beta-receptor-mediated inotropic effects [11]. The absence of epinephrine in our study protocol may explain the more pronounced CI decreases observed.

Regarding the safety profile, our finding of no adverse events (hypotension, bradycardia, or requirement for vasopressors) contrasts with Sarhan et al., who reported significantly higher incidence of intraoperative hypotension in the 1.2 mL/kg group (62.5%) compared to the 0.8 mL/kg group (33.3%) and control group (18.8%) [1]. This discrepancy may be attributed to several factors: (1) our study included only ASA I-II patients without cardiovascular comorbidities, (2) optimal preoperative fasting was ensured, (3) we used a more conservative definition of hypotension, and (4) the smaller sample size may have reduced our ability to detect infrequent adverse events.

The use of USCOM as a non-invasive cardiac output monitoring tool represents both a strength and limitation of this study. USCOM utilizes continuous-wave Doppler technology to measure blood flow velocity through the aortic or pulmonary valve, providing real-time, non-invasive assessment of hemodynamic parameters [12, 13].

Validation studies have demonstrated good correlation between USCOM and pulmonary artery catheter thermodilution in pediatric patients. Beltramo et al. reported a bias of 0.2 L/min with percentage error of 11% in 31 children undergoing cardiac catheterization, which improved to 0.1 L/min bias and 8% error after excluding one outlier [12]. This supports USCOM's reliability as a bedside monitoring tool in pediatric populations.

However, some studies have shown variable results. Fraga et al. found that USCOM did not always reliably represent absolute CO values compared to thermodilution, particularly in patients with complex cardiac anatomy [13]. Therefore, CI values from USCOM should be interpreted within the clinical context and patient characteristics. Despite these limitations, USCOM remains a valuable alternative to invasive monitoring, especially in pediatric patients where pulmonary artery catheterization is technically challenging and carries significant risks [14, 15].

A significant strengths of this study were double blind RCT method and the serial measurement of hemodynamic parameters at multiple time. This comprehensive temporal mapping allowed us to characterize the time-dependent effects of caudal block on CI. This pattern of hemodynamic change has important implications for clinical monitoring. Several limitations of this study should be acknowledged. First, the observation period was limited to 30 minutes post-induction, which precludes evaluation of long-term hemodynamic stability, recovery phase effects, or postoperative outcomes. Second, the inclusion criteria restricted enrollment to ASA I-II patients without cardiovascular comorbidities. While this enhances internal validity and patient safety, it limits the generalizability of findings to children with compromised cardiovascular status who may be more vulnerable to hemodynamic disturbances and precisely the population most in need of careful monitoring. Finally, USCOM measurements were not validated against the gold standard pulmonary artery catheter thermodilution method in this study. While USCOM has demonstrated acceptable accuracy in validation studies [12-14], the absence of simultaneous gold standard measurements in our protocol means that absolute CI values should be interpreted with appropriate caution.

4. CONCLUSION

Caudal block with bupivacaine 0.25% produces dose-dependent decreases in Cardiac Index in children undergoing lower abdominal surgery, with all values remaining within clinically acceptable ranges. The 0.8 mL/kg dose demonstrates a more favorable hemodynamic profile compared to 1.2 mL/kg, with less pronounced and more stable CI values. Despite statistically significant decreases, caudal block remains a safe technique when performed in appropriately selected ASA I-II patients with careful hemodynamic monitoring. The use of non-invasive cardiac output monitoring with USCOM enables real-time assessment of hemodynamic status and early detection of cardiovascular changes that may not be apparent from blood pressure monitoring alone.

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Author Contributions

ARP contributed to the study conception and design, conducted data collection, performed data analysis, and prepared the original manuscript draft. SKA and NSW contributed to the methodology, investigation, formal analysis, and critical revision of the manuscript. SHH, MR, and HN contributed to the study supervision, critical revision of the manuscript, and final approval of the submitted version. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

This research adhered to the ethical guidelines outlined in the Declaration of Helsinki. Approval for the study was granted by the Health Research Ethics Committee at Hasanuddin University, Makassar, Indonesia (Approval No. 458/UN4.6.4.5.31/PP36/2026; approved on 31 March 2026). Prior to participants being enrolled, written informed consent was obtained from their parents or legal guardians.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request

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