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Evaluation of Vena Cava Inferior Collapsibility Index With Ultrasonography in Children Undergoing General Anesthesia and Regional Anesthesia for Lower Abdominal and Urogenital Surgery

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Research Article

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Abstract

Background: Pediatric anesthetic management requires careful hemodynamic monitoring due to limited cardiovascular reserve and age-dependent physiological differences. Neuraxial anesthesia may affect hemodynamics differently from general anesthesia. Caudal anesthesia produces sympathetic blockade that may increase venous capacitance and alter venous return, potentially influencing intravascular volume distribution and preload. This study compared inferior vena cava (IVC) diameters and IVC distensibility (IVCDI) in children receiving general anesthesia alone versus combined general and caudal anesthesia.

Methods: In this prospective observational study, 100 children aged 1–8 years scheduled for lower abdominal or urological surgery were enrolled. Patients were allocated based on parental consent: general anesthesia with caudal anesthesia (Group I, n=50) or general anesthesia alone (Group II, n=50). Induction was with sevoflurane in patients without intravenous access and propofol in those with access, followed by laryngeal mask airway placement and controlled mechanical ventilation. In Group I, caudal anesthesia was administered with 0.2% bupivacaine (0.8 mL/kg). IVC maximum (IVC max) and minimum (IVC min) diameters were measured, and IVCDI calculated using M-mode ultrasonography via a subxiphoid approach immediately after induction (T_0) and 20 minutes later (T_1).

Results: Group I showed significant increases in IVC max and IVC min at T_1, with a non-significant trend toward increased IVCDI, without adverse hemodynamic effects. No significant changes were observed in Group II. Heart rate remained stable and comparable between groups.

Conclusion: In this study, caudal anesthesia combined with general anesthesia, at the doses used in our protocol, increased IVC diameters without significant changes in IVCDI or heart rate in mechanically ventilated children. These findings indicate increased venous capacitance without impaired preload responsiveness, supporting caudal anesthesia as a hemodynamically stable adjunct to general anesthesia in pediatric patients.

Introduction

Anesthetic management in pediatric patients requires a distinct approach due to significant anatomical, physiological, and pharmacodynamic differences compared with adults. Hemodynamic management is particularly critical in children because of their limited cardiovascular reserve, higher metabolic rate, and age-dependent variations in total body water composition (1).

Both fluid overload and insufficient fluid replacement may result in adverse outcomes, including pulmonary edema, impaired cardiac performance, tissue hypoperfusion, and organ dysfunction. Preoperative factors such as prolonged fasting, bowel preparation, vomiting, diarrhea, and environmental fluid losses may further increase the risk of hypovolemia in pediatric patients (2,3).

During anesthesia, both general and regional anesthetic techniques may influence cardiovascular function. Anesthetic agents may reduce systemic vascular resistance and myocardial contractility, whereas regional anesthesia techniques can induce hypotension secondary to sympathetic blockade. Sympathetic inhibition may lead to vasodilation, increased venous capacitance, and subsequent alterations in inferior vena cava (IVC) diameter and its dynamic indices. These physiological changes highlight the importance of reliable and sensitive hemodynamic monitoring during pediatric anesthesia (4-8).

For this reason, pediatric anesthesiologists continue to seek reliable hemodynamic monitoring methods. Conventional hemodynamic parameters, including heart rate, arterial blood pressure, and urine output, are widely used in clinical practice; however, these static variables have limited ability to accurately reflect intravascular volume status and dynamic cardiovascular changes. Consequently, dynamic parameters—such as pulse pressure variation, stroke volume variation, and pleth variability index—have gained increasing attention (4,6-8).

Among these modalities, ultrasonographic assessment has emerged as a practical, non-invasive, and repeatable bedside tool for evaluating hemodynamic status in pediatric patients. Bedside ultrasonographic evaluation of the inferior vena cava (IVC) diameter and its respiratory variations provides valuable information regarding preload conditions and cardiovascular dynamics. In mechanically ventilated patients, the IVC distensibility index (IVCDI) is commonly used (4-8). Nevertheless, interpretation of IVC measurements in children remains challenging due to age-related variability, differences in body surface area, and respiratory mechanics (6,7).

Lower abdominal and urological surgeries are frequently performed in pediatric populations, and caudal anesthesia is widely used as an adjunct to general anesthesia in these procedures (1,2). Although caudal blockade may influence hemodynamic parameters through sympathetic inhibition, its specific impact on IVC diameter and dynamic indices under controlled mechanical ventilation has not been adequately elucidated.

Although previous studies have evaluated IVC measurements as indicators of intravascular volume status in pediatric patients, data examining the influence of neuraxial anesthesia on these parameters remain limited. In particular, the effects of caudal anesthesia on IVC diameter and IVCDI under controlled mechanical ventilation have not been clearly defined. Therefore, further investigation is needed to clarify the hemodynamic implications of caudal blockade in this setting.

This prospective observational comparative study aimed to compare ultrasonographically measured IVC diameter and calculated IVCDI in pediatric patients aged 1–8 years undergoing lower abdominal surgery under general anesthesia with or without caudal anesthesia. We hypothesized that caudal anesthesia would alter IVC diameter and its dynamic indices under controlled mechanical ventilation.

Materials and Methods

This prospective observational comparative study was conducted at Gazi University Faculty of Medicine, Health Practice and Research Hospital between January 2024 and August 2024. Ethical approval was obtained from the institutional review board (Approval No: 11.12.2023–952), and written informed consent was obtained from the parents of all participants prior to enrollment.

A total of 100 pediatric patients aged 1–8 years, classified as American Society of Anesthesiologists (ASA) physical status I–II, who were scheduled to undergo elective lower abdominal or urological surgery under general anesthesia with or without caudal anesthesia, were included in the study.

Exclusion criteria included ASA physical status ≥III, chronic medication use, and parental refusal and contraindications for caudal anesthesia. Patients were additionally excluded if adequate ultrasonographic imaging could not be achieved due to poor acoustic window, or if unexpected perioperative adverse events such as allergic reactions, anaphylaxis, or anesthesia-related complications occurred.

Patients were allocated into two groups depending on parental consent for caudal anesthesia in addition to general anesthesia. Because group allocation was based on parental preference rather than randomization, the study was designed as an observational comparative study.

Group I: General anesthesia combined with caudal anesthesia

Group II: General anesthesia alone

Patients were monitored according to ASA standards, and baseline parameters were recorded before induction of anesthesia. Anesthesia induction was achieved using 3 to 6% sevoflurane via inhalation or 2–3 mg/kg IV propofol in patients with established vascular access. Following induction, a laryngeal mask airway was inserted, and mechanical ventilation was initiated with a tidal volume of 6–8 mL/kg and a respiratory rate of 14–20 breaths per minute without positive end-expiratory pressure (PEEP). Ventilation settings were maintained as consistent as possible throughout the measurement period. Remifentanil was administered at a continuous infusion rate of 0.2 μg/kg/min in both groups. Intraoperative fluid management was initiated with a standardized maintenance dose calculated according to the Holliday-Segar formula, with intravenous crystalloid administered at the calculated rate over the first 20 minutes, and subsequent fluids guided by routine hemodynamic parameters (1,2). Clinically significant tachycardia or bradycardia was defined as a ≥30% increase or decrease from baseline values. For multimodal analgesic regimen, all patients received 12.5 mg/kg paracetamol.

Ultrasonographic measurements were performed using M-mode ultrasonography (Mindray DC-N3 PRO, Shenzhen, China) by an experienced anesthesiologist blinded to the anesthesia technique. Measurements were obtained in the supine position using a subcostal longitudinal approach with a 3.5–5 MHz curvilinear probe. The IVC diameter was measured 1–2 cm distal to the IVC–right atrial junction (Figure 2) (9,10). Patients in whom the IVC could not be adequately visualized within 5 minutes due to

poor acoustic window (e.g., bowel gas or excessive adipose tissue) were excluded from analysis. Under controlled mechanical ventilation, IVC diameters were measured at inspiration and expiration, with the maximum diameter (IVC max) corresponding to inspiration and the minimum diameter (IVC min) corresponding to expiration, at two time points: immediately after induction (T_0) and 20 minutes after induction (T_1). Three consecutive measurements were obtained at each time point, and the mean values were used as IVC max and IVC min for analysis. The IVC Distensibility Index (IVCDI) was calculated as (IVC max − IVC min) / IVC min.

3 minutes later than anesthesia induction patients in Group I received a caudal epidural block using a 25G or 32G short-bevel caudal needle (Egemen Medikal Türkiye) with the patient in the lateral decubitus position. The sacral hiatus was identified, and 0.2% bupivacaine was administered at a dose of 0.8 mL/kg (maximum 20 mL) which is consistent with commonly recommended pediatric caudal dosing regimens reported in text books (11). In the non-caudal group, patients were briefly positioned as if receiving caudal anesthesia, before returning to the supine position.

Data were collected on separate proforma sheets by the USG operator and the intraoperative attending anesthetist who performed the caudal anesthesia (unaware of the IVC max and IVC min of that patient) to overcome bias.

The primary objective of the study was to evaluate time-dependent changes in heart rate and IVC-derived dynamic indices (distensibility index) in pediatric patients undergoing general anesthesia with or without caudal anesthesia. The secondary objective was to determine whether the type of anesthesia technique influenced time-related changes in IVC dynamic indices under mechanical ventilation.

Statistical analysis

An a priori sample size calculation was performed based on an anticipated 10% difference in the IVC distensibility index between groups, ensuring adequate statistical power at a significance level of 0.05. Statistical analyses were performed using SPSS for Windows version 18.0 (SPSS Inc., Chicago, IL, USA). Categorical variables were expressed as frequencies and percentages and compared using the chi-square test. The distribution of continuous variables was assessed using the Kolmogorov–Smirnov test, supported by visual inspection of histograms and probability plots. Normally distributed continuous variables were presented as mean ± standard deviation (SD) and compared using the student's t-test, while non-normally distributed variables were expressed as median with interquartile range (IQR) and compared using the Mann–Whitney U test. Within-group changes over time were analyzed using paired t-tests or Wilcoxon signed-rank tests, as appropriate. Correlations between continuous variables were evaluated using Pearson's or Spearman's correlation coefficient, depending on data distribution. A two-sided p-value < 0.05 was considered statistically significant.

Results

A total of 100 pediatric patients were analyzed, with 50 patients in Group I (general anesthesia + caudal anesthesia) and 50 patients in Group II (general anesthesia alone). Baseline demographic and surgical characteristics, including age, weight, height, ASA classification, sex, and surgical duration, were comparable between the groups (all $p > 0.05$) (Table 1). All monitored parameters remained within normal limits throughout the procedures, with no adverse hemodynamic events observed.

IVC Maximum Diameter

Post-induction (T_0) and 20-minute (T_1) IVC maximum (IVC max) diameters did not differ significantly between the groups ($p = 0.641$ and $p = 0.777$, respectively). Within Group I, a significant increase in IVC max was observed at T_1 compared to T_0 ($p = 0.006$), whereas Group II showed no significant temporal change ($p = 0.292$). Repeated measures ANOVA revealed no significant group x time interaction ($p = 0.921$) (Table 2).

IVC Minimum Diameter

IVC minimum (IVC min) diameters were similar between groups at both time points ($p > 0.05$). Group I demonstrated a significant increase at T_1 compared to T_0 ($p = 0.004$), while no significant change was observed in Group II ($p = 0.058$). The group x time interaction was not significant ($p = 0.319$) (Table 2).

Distensibility Index

No significant differences in IVC distensibility index were observed between groups at either time point ($p = 0.535$ and $p = 0.141$, respectively). Neither group showed significant temporal changes, and repeated measures ANOVA confirmed the absence of a significant time effect ($p = 0.245$) (Table 2).

Heart Rate

Heart rate was comparable between groups at post-induction and 20 minutes ($p = 0.402$ and $p = 0.986$, respectively). Both groups showed a significant decrease in heart rate at 20 minutes compared to post-induction ($p < 0.001$), with no significant group × time interaction ($p = 0.661$) (Table 2).

Discussion

Intraoperative hemodynamic instability is an undesirable condition, particularly in the pediatric population (1-3). In this prospective observational study, we evaluated the impact of caudal anesthesia on inferior vena cava (IVC) dynamics in children undergoing lower abdominal and urological surgery under general anesthesia. Our findings demonstrate that the addition of caudal anesthesia led to a modest but significant increase in both IVC max and IVC min diameters at T_1 (20 min. post-induction) point (Group I), whereas patients receiving general anesthesia alone (Group II) did not show such changes. These changes are consistent with the physiological effects of sympathetic blockade, which include vasodilation and increased venous capacitance, ultimately affecting venous return and static intravascular volume markers (12).

Caudal anesthesia induces sympathetic blockade at the sacral and lower lumbar levels, leading to vasodilation and increased venous capacitance. Although this may redistribute blood and potentially reduce preload, compensatory mechanisms in mechanically ventilated pediatric patients, such as preserved myocardial contractility and heart rate modulation, maintain overall hemodynamic stability. Consequently, while static measures such as IVC diameter increased, dynamic indices of preload responsiveness, including the IVCDI, remained largely unchanged, reflecting the cardiovascular safety of caudal blocks. Adler et al., in a pilot study of children undergoing circumcision, evaluated the effects of caudal anesthesia on penile hemodynamics using Doppler ultrasonography, comparing arterial and venous flow velocities before and after the block. Despite the theoretical vasodilatory effects of sympathetic blockade, they observed no significant changes in penile arterial or venous blood flow following caudal anesthesia (13). These findings suggest that regional sympathetic blockade does not necessarily result in measurable alterations in regional perfusion. Consistent with this concept, our results demonstrated that although caudal anesthesia was associated with a modest increase in IVC diameters, dynamic indices reflecting preload responsiveness, such as IVC distensibility, remained largely unchanged.

Although intravenous fluid administration can influence IVC diameters and distensibility in mechanically ventilated children (14,15), in our study all patients received a standardized maintenance fluid regimen. While static measures such as IVC max and IVC min increased in the caudal group, dynamic indices such as IVCDI remained stable, suggesting that under controlled fluid administration, caudal anesthesia did not markedly affect preload responsiveness in our cohort.

Our results are consistent with prior pediatric and adult studies showing that neuraxial blocks can increase IVC diameter and venous capacitance without substantially altering dynamic preload indices (13,16-19), reinforcing the physiological principle that venous pooling after sympathetic blockade is largely compensated by intrinsic circulatory mechanisms. Crucially, our study extends this understanding to mechanically ventilated children undergoing lower abdominal or urological surgery by demonstrating that caudal anesthesia produces a modest increase in IVC diameter while preserving IVC distensibility, a key dynamic marker of preload responsiveness. These findings provide compelling evidence that caudal anesthesia delivers effective analgesia without compromising hemodynamic stability, highlighting its safety and physiological suitability in the pediatric perioperative setting.

In our study, despite observed increases in absolute inferior vena cava (IVC) diameters, the IVC distensibility index (IVCDI) did not differ significantly between groups or over time. This finding suggests that the venous dilation and increased venous capacitance associated with caudal anesthesia can be compensated without producing detectable changes in dynamic preload indices. Heart rate decreased over the 20-minute observation period in both groups, consistent with the expected physiological effects of general anesthesia and controlled mechanical ventilation, with no intergroup differences observed.

These results highlight the value of ultrasonographic IVC assessment in detecting subtle hemodynamic alterations that may not be apparent through conventional monitoring such as heart rate or arterial blood

pressure alone. This is particularly relevant in pediatric patients with limited cardiovascular reserve. Taken together, our findings support that caudal anesthesia provides effective analgesia while maintaining hemodynamic stability in children undergoing lower abdominal or urological surgery, and that IVC ultrasonography can serve as a sensitive tool for perioperative hemodynamic monitoring in this population.

Various factors may have contributed to variability in our measurements, likely reflecting differences in age, body size, and physiological status. Additionally, patients in the non-caudal group were briefly placed in lateral position to simulate caudal block timing, although all ultrasonographic measurements were consistently performed in the supine position, minimizing positional influence. The fixed caudal anesthetic dose may not capture dose-dependent hemodynamic effects, which should be explored in future studies.

Several limitations should be noted. The single-center design and relatively small sample size may limit generalizability. Group allocation was based on parental consent rather than randomization, introducing potential selection bias. The observation period was restricted to 20 minutes post-induction, preventing assessment of longer-term intraoperative or postoperative effects. All patients were assessed under controlled mechanical ventilation, which standardizes respiratory influences on IVC measurements but may limit extrapolation to spontaneously breathing children. Finally, only children aged 1–8 years undergoing elective lower abdominal or urological procedures were included, and wide age and size differences may have contributed to the observed measurement variability.

Future studies including larger cohorts, stratification by age or body size, and exploration of different caudal anesthetic doses are warranted to provide more definitive insights into the hemodynamic effects of caudal anesthesia in pediatric populations.

In conclusion, caudal anesthesia combined with general anesthesia in pediatric patients induces measurable increases in IVC diameters without significant alterations in the distensibility index or heart rate dynamics. Caudal anesthesia increases venous capacitance but does not compromise dynamic indices of preload responsiveness under controlled mechanical ventilation. IVC ultrasonography provides a practical, non-invasive bedside tool for early detection of subtle hemodynamic changes during pediatric anesthesia.

Abbreviations

ARDS: Acute Respiratory Distress Syndrome

ASA: American Society of Anesthesiologists

AVA: Aortic Valve Area

BSA: Body Surface Area

$CaCO_2$: Arterial Carbon Dioxide Content

CaO_2: Arterial Oxygen Content

CI: Collapsibility Index

cm: Centimeter

CO: Cardiac Output

CO_2: Carbon Dioxide

$CvCO_2$: Mixed Venous Carbon Dioxide Content

CvO_2: Venous Oxygen Content

CVP: Central Venous Pressure

DI: Distensibility Index

min: Minute

ECHO: Echocardiography

EVLW: Extravascular Lung Water Volume

GEDV: Global End-Diastolic Volume

HR: Heart Rate

kg: Kilogram

L: Liter

LAST: Local Anesthetic Systemic Toxicity

LiDCOplus: Lithium Dilution Cardiac Output Monitoring

LVEDP: Left Ventricular End-Diastolic Pressure

Max: Maximum

Min: Minimum

ml: Milliliter

mmHg: Millimeters of Mercury

mmol: Millimole

Na-thiopental: Sodium thiopental

PA: Pulmonary Artery

PAC: Pulmonary Artery Catheter

PAP: Pulmonary Artery Pressure

PAOP: Pulmonary Artery Occlusion Pressure

PCWP: Pulmonary Capillary Wedge Pressure

PiCCO: Pulse Contour Analysis and Transpulmonary Thermodilution

PP: Pulse Pressure

PPV: Pulse Pressure Variation

PRAM: Pressure Recording Analytical Method

PVI: Plethysmographic Variability Index

PVPI: Pulmonary Vascular Permeability Index

PVR: Pulmonary Vascular Resistance

RA: Right Atrium

RV: Right Ventricle

S: Sacral

RAP: Right Atrial Pressure

SV: Stroke Volume

SVR: Systemic Vascular Resistance

SVRI: Systemic Vascular Resistance Index

SVV: Stroke Volume Variation

T: Thoracic

TEE: Transesophageal Echocardiography

IVC: Inferior Vena Cava

VCO2: Carbon Dioxide Elimination Rate

VTI: Velocity-Time Integral

VO2: Oxygen Consumption

Declarations

AUTHOR

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ETHICS APPROVAL STATEMENT

This study was approved by the Gazi University Faculty of Medicine Institutional Review Board (Approval No: 11.12.2023–952) and conducted in accordance with the principles of the Declaration of Helsinki and International Conference on Harmonization Good Clinical Practice guidelines.

PUBLICATION PERMISSION

There is no data or images that would compromise patient privacy, and publication permission has not been granted.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

PATIENT CONSENT STATEMENT

Written informed consent was obtained from the parents or legal guardians of all participants prior to enrollment. Assent was obtained from children as appropriate according to local institutional guidelines.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author (E.A.S.) upon reasonable request.

AUTHOR CONTRIBUTIONS

B.I. conceived and designed the study, supervised all stages of the project, provided methodological guidance, and critically revised the manuscript. E.A.S conducted the experiments, collected and analyzed the data, and drafted the manuscript as part of her residency thesis under the supervision of B.I. Both authors approved the final version and are accountable for all aspects of the work.

CLINICAL STUDY NUMBER

Clinical study number: not applicable.

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Tables

Table 1

Baseline Demographic and Surgical Characteristics of the Study Groups

Characteristic	**Group I (n = 50)**	**Group II (n = 50)**	**p-value**
Age (years)	4.27 ± 2.23	4.29 ± 2.50	0.963
Weight (kg)	17.68 ± 6.12	17.60 ± 7.18	0.955
Height (cm)	107.72 ± 14.99	103.62 ± 14.78	0.172
ASA I/II (n / %)	45 (90) / 5 (10)	49 (98) / 1 (2)	0.102
Sex (F/M) (n / %)	16 (32) / 34 (68)	12 (24) / 38 (76)	0.373
Surgical duration (min)	44.28 ± 25.03	37.82 ± 12.90	0.109

Table 2

Changes in Inferior Vena Cava Diameters, Distensibility Index, and Heart Rate in Pediatric Patients Undergoing General Anesthesia with or Without Caudal Anesthesia

Parameter	**Measurement Point**	**Group I (n = 50) Mean ± SD Median (IQR)**	**Group II (n = 50) Mean ± SD Median (IQR)**	**P[a]**
IVC max (cm)	T_0	0.99 ± 0.28 0.98 (0.79–1.12)	1.02 ± 0.30 1.03 (0.80–1.23)	0.641
	T_1	1.08 ± 0.25 1.06 (0.88–1.26)	1.06 ± 0.33 1.05 (0.78–1.31)	0.777
P[b]		0.006	0.292	
P[c]				0.921
IVC min (cm)	T_0	0.68 ± 0.24 0.66 (0.51–0.86)	0.64 ± 0.26 0.64 (0.43–0.80)	0.485
	T_1	0.76 ± 0.24 0.75 (0.60–0.95)	0.70 ± 0.28 0.69 (0.47–0.90)	0.264
P[b]		0.004	0.058	
P[c]				0.319
IVCDI (%)	T_0	52.24 ± 29.17 43.84 (28.32–71.58)	55.78 ± 25.37 48.37 (38.54–74.01)	0.535
	T_1	45.79 ± 22.79 44.40 (27.52–56.79)	53.12 ± 25.08 45.72 (24.80–66.07)	0.141
P[b]		0.77	0.483	
P[c]				0.245
Heart (rate/min)	T_0	119.48 ± 12.88 121.00 (112.00–128.00)	116.92 ± 17.22 120.50 (101.75–127.25)	0.402
	T_1	105.82 ± 12.23 106.00 (99.00–116.00)	105.76 ± 20.10 106.00 (91.75–119.25)	0.986
P[b]		< 0.001	< 0.001	
P[c]				0.661

Parameter	Measurement Point	Group I (n = 50) Mean ± SD Median (IQR)	Group II (n = 50) Mean ± SD Median (IQR)	P[a]
T_0: post anesthesia induction				
T_1:20 minutes after anesthesia induction				
[a] İndependet simple t testi; [b] Paired Samples Test; [c] Repeated Measure ANOVA Test				
P^a: Between-group comparison at the same time point (T_0 or T_1).				
P^b: Within-group comparison between T_0 and T_1.				
P^c: Time × group interaction (comparison of changes over time between groups).				
Data are presented as Mean ± SD for normally distributed variables or Median (IQR) for non-normally distributed variables, as appropriate.				

Figures

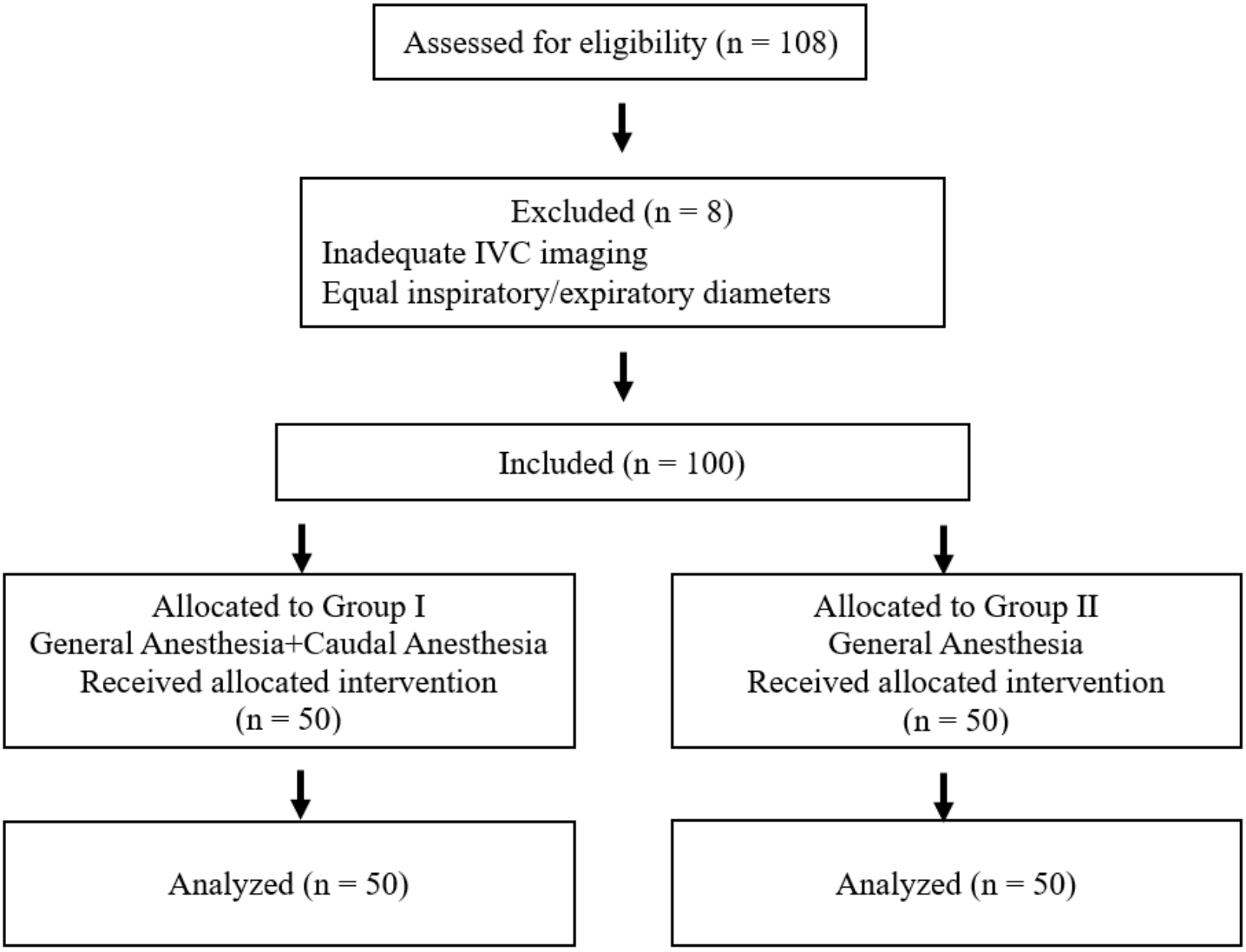


Figure 1

Subxiphoid longitudinal view of the inferior vena cava (IVC). The anteroposterior diameter was measured 1–2 cm distal to the right atrial junction (10).



Figure 2

STROBE flow diagram of patient enrollment, allocation, follow-up, and analysis