ORIGINAL ARTICLE

IVC Collapsibility Index (IVC-CI) Guided Preloading to Reduce Hypotension Following Spinal Block in Lower Limb Surgery

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Background: Hypotension following spinal anesthesia is a common and serious complication during lower limb surgeries. Traditional fluid preloading strategies can lead to fluid overload, especially in patients with co-morbid conditions. The inferior vena cava collapsibility index (IVC-CI) offers a non-invasive method to guide fluid management more precisely.

Objective: The primary objective was to compare the incidence of hypotension following spinal anesthesia between Group A with IVC-CI-guided fluid management, and Group B with standard fluid administration. Secondary objectives included comparisons of the total amount of fluids administered, vasopressor use, and perioperative complications between the two groups.

Materials and Methods: The present study was a prospective, comparative clinical trial involving 83 patients undergoing lower limb surgery under spinal anesthesia. Patients were randomly divided into two groups with Group A, in which ultrasound was used to measure the IVC-CI before spinal anesthesia, with an index of 36% or higher considered as responsive to fluid administration, and Group B, the standard group, which did not undergo IVC-CI assessment and received standard fluid administration.

Results: In the ultrasound-guided IVC-CI group, Group A, which included 41 patients, nine patients (21.95%) experienced hypotension, compared to eight patients (20%) in the standard care group, Group B, of 42 patients (p=0.829, 95% CI –15.77 to 19.68). There were no clinically significant differences between the groups in the total volume of fluids administered and in the use of vasopressor or inotropic drugs between the groups. Additionally, no severe postoperative complications occurred in either group.

Conclusion: The use of ultrasound to monitor IVC-CI of 36% or greater, as a guide for fluid administration prior to spinal anesthesia in patients undergoing lower limb surgery did not reduce the incidence of hypotension when compared to standard fluid administration, in patients aged 18 to 75 years without cardiovascular disease.

Keywords: Hypotension; IVC collapsibility index (IVC-CI); Spinal block

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Spinal anesthesia is widely used for lower limb and lower abdominal surgeries due to its minimal effects on the circulatory and respiratory systems[1-3] and its effectiveness in postoperative pain control. However, it may cause side effects such as hypotension in 52.6% and bradycardia in 2.5%[4], which, if not corrected or prevented, may lead to life-threatening complications such as myocardial ischemia, cardiac arrest, or cerebrovascular accident[5-10]. Risk factors for hypotension include advanced age, diabetes, hypertension, and preoperative use of antihypertensive drugs[4,11-14]. Preventive strategies include adequate fluid administration and vasopressor use[15]. However, excessive fluids may cause overload or pulmonary edema, especially in patients with comorbidities like heart disease or chronic kidney disease[16,17]. Therefore, careful and appropriate fluid management is crucial to balance the risk of hypotension and fluid overload.

Recently, ultrasound has been increasingly utilized to assess fluid status and fluid responsiveness by evaluating inferior vena cava (IVC). The diameter of the IVC changes with breathing, blood

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volume, and cardiac function, which can reflect the patient's overall fluid status[18]. Currently, ultrasound techniques are used to assess fluid status or fluid responsiveness, specifically the IVC collapsibility index (IVC-CI), while the patient breathes spontaneously[19]. This method is simple, quick, requires minimal equipment, could be performed at the patient's bedside, and is safe for the patient. It is widely used, especially in critically ill patients with hypotension due to dehydration or infection. The primary objective of the present study was to compare the incidence of hypotension, and the secondary objectives were to evaluate the amount of fluid administered, the use of vasopressor drugs, and the occurrence of complications between the IVC-CI-guided fluid management group and the standard fluid administration group in patients undergoing elective lower limb surgery.

Materials and Methods

Study population

The present study was a prospective, randomized, comparative clinical trial approved by the Human Research Ethics Committee of Srinakharinwirot University (certification number SWUEC/E/M-021/2566E) and conducted between August 2024 and May 2025. All participants received detailed information sheets and provided written informed consent. Registered with the Thai Clinical Trials Registry No. TCTR 20241116002.

The inclusion criteria were patients undergoing elective lower limb surgery at HRH Princess Maha Chakri Sirindhorn Medical Center, aged 18 to 75 years, with the American Society of Anesthesiologists (ASA) classification I to III. The exclusion criteria included patients who did not consent to participate, had contraindications to spinal anesthesia, or had underlying hypertension, as well as, those with moderate to severe cardiac conditions, such as coronary artery disease or valvular heart disease with an ejection fraction (EF) below 40% or classified as New York Heart Association (NYHA) class 3 or higher, pregnancy, body mass index (BMI) of 40 or greater, poor ultrasound visualization of major veins, known anesthetic allergies, stage 4 or higher chronic kidney disease, chronic lung disease limiting fluid administration, liver failure, or anemia with hemoglobin level of 7 mg/dL or less.

Calculation of sample size

According to the study by Ceruti et al.[19], the prevention of hypotension following spinal anesthesia can be improved by using ultrasound to assess the IVC as a guide for fluid administration, with an IVC-CI threshold of 36% or more. The study found that the incidence of hypotension was 20% in the group that used ultrasound, compared to 50% in the group that received standard fluid administration.

The sample size was calculated using the formula for comparing two proportions, with a statistical power of 80% and a significance level (alpha) of 0.05. Based on a sample size calculator, these proportions were selected from the study's range of results to ensure an adequate sample size for the present research. The research team also estimated a dropout rate of 10%, equivalent to eight participants, bringing the total sample size to 86 participants. Formula for calculation:

$$n = \left[\frac{Z_{1-\alpha/2} \cdot \sqrt{2P(1-P)} + Z_{1-\beta} \cdot \sqrt{p_1(1-p_1) + p_2(1-p_2)}}{p_1 - p_2} \right]^2$$

Patients who met the selection criteria and provided informed consent were instructed to fast according to standard protocols and received intravenous (IV) fluids. They were randomly allocated into two groups using a computer-generated block randomization sequence with 1 to 1 ratio. The sequence was prepared in advance and placed in sealed envelopes to ensure allocation concealment. Baseline blood pressure was recorded in the preoperative waiting area.

Group A: Patients in this group underwent ultrasound performed by an anesthesiologist with at least three years of experience and training in abdominal ultrasound. The procedure was conducted using the SonoSite X-Porte ultrasound machine with a curved probe. While in the supine position, the IVC diameter was measured in M-mode (motion modulation) 2 to 3 cm distal to the right atrium. The maximum diameter (dIVC max) and minimum diameters (dIVC min) of the IVC were recorded at the end of expiration and inspiration within the same respiratory cycle. The IVC-CI was calculated using the following formula: IVC-CI = (dIVC max – dIVC min) / dIVC max × 100% (Figure 1).

For patients in Group A, if the IVC-CI value before IV fluid administration was 36% or higher, fluids were administered at a rate of 3 mL/kg over 10 minutes until the IVC-CI was less than 36%, at which point fluid administration was stopped.

Group B: Patients in this group did not undergo ultrasound assessment and did not receive any IV fluid preload before spinal anesthesia. This group received an intraoperative IV fluid co-loading at

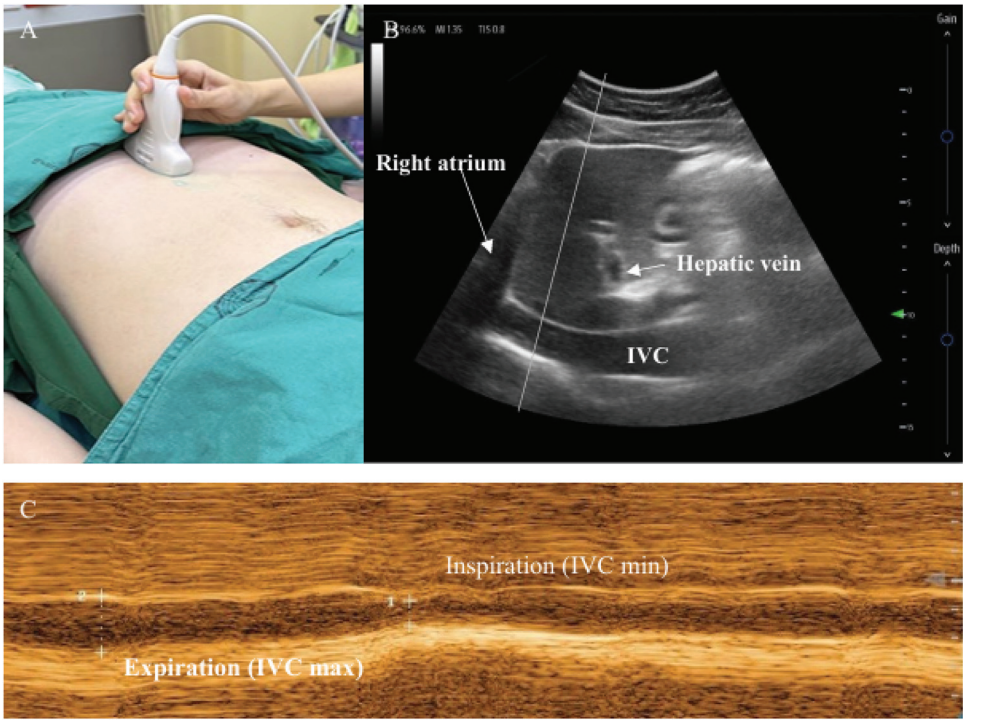

Figure 1. Positioning the ultrasound probe: use an ultrasound probe (A) to locate the appropriate area for IVC evaluation. B-mode imaging: utilize the B-mode of ultrasonography with a sub-xiphoid view (B) to visualize the IVC. M-mode imaging: apply M-mode ultrasonography to measure the IVC's maximum (IVC max) and minimum (IVC min) diameters (C).

10 mL/kg during the spinal anesthesia. When arrival in the operating room, vital signs were measured and recorded. Spinal anesthesia was administered by an anesthesiologist blinded to group allocation, using 0.5% heavy bupivacaine at a dose of 15 to 18 mg, targeting a sensory block level between T6 and T10. Data was recorded by a research assistant who was also blinded to group allocation. Hypotension was defined as a systolic blood pressure decrease of 30% or more from baseline or a mean arterial pressure (MAP) below 65 mmHg. In such cases, blood pressure was increased by administering 6 mg of ephedrine or 50 mcg of phenylephrine IV every five minutes. Ephedrine was considered the first-line agent. However, if the heart rate exceeded 100 beats per minute, phenylephrine was preferred.

Bradycardia, defined as a heart rate below 45 beats per minute, was treated with 0.6 mg of atropine IV. Data collection involved measuring blood pressure and heart rate every one minute during the first ten minutes and then every five minutes until 30 minutes after the administration of spinal anesthesia. Upon completion of the surgery, the total volume of IV fluids administered, the amount of vasopressor drugs used, positive chronotropic drugs, and any complications occurring during the perioperative anesthesia period were recorded.

In the present study, blood loss was not recorded due to the use of a tourniquet during lower limb surgeries, which minimized intraoperative bleeding and monitoring the incidence of hypotension and bradycardia within the first 30 minutes following spinal anesthesia. If any complications arose, they were recorded, and vital signs were reassessed in the recovery room immediately postoperatively and again in the ward within 24 hours.

Statistical analysis

Descriptive statistics were used for data analysis. For continuous data, the normality of variable distribution was assessed using the Kolmogorov-Smirnov test. If data were normally distributed, results were reported as mean ± standard deviation (SD) and analyzed using Independent Student's t-test. If the data were not normally distributed, non-parametric tests such as the Mann-Whitney U test for independent samples or the Wilcoxon signed-rank test for paired samples were used. Categorical variables, presented as frequencies and percentages

were analyzed using the chi-square test or Fisher's exact test, as appropriate. A p-value of less than 0.05 was considered statistically significant, with a 95% confidence interval (CI). All statistical analyses were performed using Stata Statistical Software, version 17 (StataCorp LLC, College Station, TX, USA).

Results

In the present study, 86 participants were selected and divided into Group A with 44 participants and Group B with 42 participants. In Group A, three participants were excluded due to unclear visualization of the IVC on ultrasound. In Group B, two participants were excluded due to a switch to general anesthesia as the spinal anesthesia did not achieve sufficient level of numbness for surgery. Thus, the data analysis included 41 patients in Group A and 40 in Group B (Figure 2).

From the collection of baseline data on the sample group, including age, gender, BMI, blood pressure, ASA classification, duration of surgery, fasting time, and analgesic level, it was found that there was no statistically significant difference between the two groups (Table 1).

The study was conducted on 86 patients undergoing lower extremity surgery with spinal anesthesia. Group A used ultrasound to monitor the collapse of the IVC as a guide for fluid administration before spinal anesthesia, resulting in an incidence of hypotension in nine patients (21.95%). In Group B, fluids were administered according to standard practice, with an incidence of hypotension in eight patients (20%) (risk different 1.95, 95% CI –15.77 to 19.68, p=0.829) (Table 2). In the present study, hypotension occurred exclusively within the first 30 minutes following spinal anesthesia. During the intraoperative and postoperative periods, blood pressure remained stable without hypotension.

The present study found that, for the secondary outcomes, the use of the vasopressor Ephedrine between Group A and Group B showed no statistically significant difference, both in the number of patients who received the drug, which is nine patients in Group A (21.95%), and eight patients in Group B (20%) (p=0.781) and the dosage used, which is 13.33±7.81 mg in Group A and 14.41±13.27 mg in Group B (p=0.691).

Additionally, the median fluid volume administered was equal in both groups, at 800 mL. No severe complications, such as myocardial ischemia, pulmonary edema or stroke were observed (Table 3).

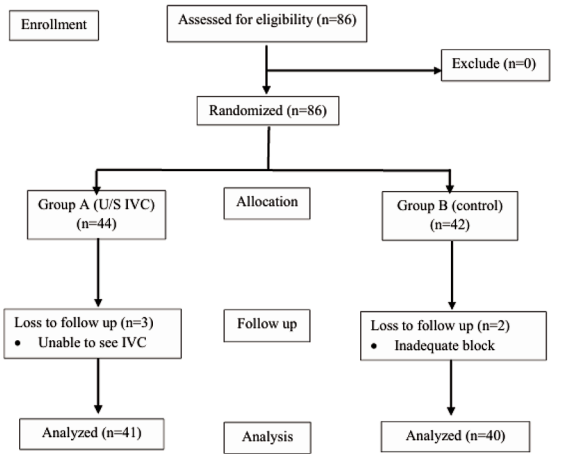

Figure 2. CONSORT flow diagram.

Table 1. Demographic data of patients underwent lower limb surgery under spinal anesthesia

Variables	Group A (n=41)	Group B (n=40)
Age (years); mean±SD	53.63±12.97	45.78±14.73
Sex; n (%)		
Male	19 (46.34)	26 (65.00)
Female	22 (53.66)	14 (35.00)
BMI (kg/m^2); mean±SD	22.85±3.83	24.43±4.68
SBP (mmHg); mean±SD	138.37±16.25	133.65±17.41
DBP (mmHg); mean±SD	80.34±9.96	81.58±11.85
MAP (mmHg); mean±SD	97.51±11.20	94.72±13.36
ASA PS; n (%)		
1	13 (31.71)	6 (15.00)
2	24 (58.54)	32 (80.00)
3	4 (9.76)	6 (15.00)
Duration of operation (hours); mean±SD	1.88±0.85	2.10±1.11
Duration of NPO (hours); mean±SD	12.34±3.50	12.02±2.63
Analgesic level; n (%)		
T6	26 (63.41)	24 (60.00)
T8	11 (26.83)	12 (30.00)
T10	4 (9.76)	4 (10.00)

BMI=body mass index; SBP=systolic blood pressure; DBP=diastolic blood pressure; MAP=mean arterial blood pressure; ASA PS=American Society of Anesthesiologists physical status; NPO=nil per os; SD=standard deviation

Discussion

In the study of 86 patients undergoing lower limb surgery with spinal anesthesia, Group A used ultrasound to monitor the collapsibility of IVC, using an IVC-CI of 36% or higher as a guide for fluid administration before administering spinal anesthesia. This was compared to Group B, which received standard fluid administration. The incidence of hypotension in Group A was 21.95%, and in Group B, it was 20%. Both groups had similar rates

Table 2. Incidence hypotension

Primary outcome	Group A (n=41); n (%)	Group B (n=40); n (%)	Risk diff.	p-value	95% CI
Hypotension	9 (21.95)	8 (20.00)	1.95	0.829	–15.77 to 19.68

CI=confidence interval

Table 3. Vasopressor and fluid use

	Group A (n=41)	Group B (n=40)	p-value
Ephedrine; n (%)	9 (21.95)	8 (20.00)	0.781
Amount of ephedrine (mg); mean±SD	13.33 (7.81)	14.41 (13.27)	0.691
Total fluid (mL); median (min-max)	800 (650 to 1,000)	800 (700 to 1,100)	0.268

SD=standard deviation

of hypotension, vasopressor use, and complications, with no statistically significant differences.

Lal et al.[18] conducted a prospective, blinded observational study assessing the predictive value of IVC-CI and the caval aorta index for hypotension after spinal anesthesia. Their findings also highlighted the utility of IVC-CI as a non-invasive marker for predicting hypotension risk, but they emphasized the limitations of relying solely on IVC indices to guide fluid therapy. The study found that while IVC-CI and caval aorta index were associated with the incidence of hypotension, fluid management based exclusively on these ultrasound parameters might not be sufficient to prevent hypotension post-spinal anesthesia.

Both studies underscore the complexity of managing spinal anesthesia-induced hypotension. The present study findings and those of Lal et al. suggest that while IVC ultrasonography can provide valuable information regarding intravascular volume status and fluid responsiveness, its use as a single parameter to guide pre-spinal fluid administration may not significantly alter hypotension outcomes. Factors such as patient comorbidities, variability in autonomic responses, and the multifactorial nature of hypotension during spinal anesthesia may contribute to this phenomenon.

These results highlight the need for a multimodal approach incorporating clinical assessment, ultrasound findings, and individualized fluid and vasopressor strategies to optimize hemodynamic stability during spinal anesthesia.

In the study by Ceruti et al.[19], 160 patients undergoing spinal anesthesia were divided into two groups with one group using ultrasound to monitor the collapse of IVC, with an IVC-CI of 36% or higher as an indicator for fluid responsiveness, while the control group did not use ultrasound to guide fluid administration. The study found that the incidence of hypotension in the ultrasound-guided IVC-CI group was 22 patients (27.5%), compared to 34 patients (42.5%), in the control group. The use of ultrasound reduced the relative risk between the groups by 35%, and the use of vasopressors was significantly lower in the ultrasound group compared to the control group. However, Ceruti et al., study included different types of surgeries, such as lower abdominal surgeries, which required higher levels of anesthesia, and patients with hypertension who were on antihypertensive medication before surgery. In contrast, the study by Critchley et al.[20] in elderly patients undergoing spinal anesthesia found that those on antihypertensive drugs had a higher incidence of hypotension than those not on antihypertensive medication. This was different from the present study, which focused on patients without hypertension and only included lower limb surgeries, leading to a lower incidence of hypotension in the present study.

Ni et al.[21] examined patients undergoing spinal anesthesia and used an IVC-CI value greater than 42% as an indicator for fluid responsiveness. They found the IVC-CI had a sensitivity of 83.9% and specificity of 76.3%, with a positive predictive value of 84%. The study revealed that using an IVC-CI greater than 42% as an indicator for fluid responsiveness resulted in a lower incidence of hypotension compared to the standard method, with rates of 15.3% and 31.7%, respectively. This differed from the present study due to the use of different cutoff values for the IVC-CI, which led to different results. The variation in cutoff values for IVC-CI across different studies can be explained by several factors. These include differences in patient populations, such as age, comorbidities such as hypertension, types of surgery such as lower limb or abdominal, and baseline intravascular volume status. These factors influence

blood circulation and fluid responsiveness, leading to different optimal IVC-CI thresholds for predicting fluid responsiveness. Respiratory patterns also play a role. Although most studies involve spontaneously breathing patients, variations in respiratory effort, tidal volume, or the use of supplemental oxygen can affect the variability of the IVC diameter, impacting the collapsibility index and the appropriate cutoff value. Differences in ultrasound techniques, timing of measurements relative to anesthesia induction, and definitions of fluid responsiveness can also affect the chosen cutoff values. Additionally, the clinical outcomes assessed vary between studies, some focus specifically on preventing hypotension, while others evaluate fluid responsiveness more broadly. This results in different emphasis on sensitivity versus specificity and consequently different cutoff thresholds.

In the present study, the researchers selected a cutoff value of 36%, based on previous literature supporting this as a balanced threshold in healthy, spontaneously breathing patients undergoing lower limb surgery. In contrast, Ni et al.[21] used a higher cutoff of 42%, which provided better sensitivity and specificity in their patient population, due to differences in patient characteristics and clinical context. These discrepancies highlight the need to tailor the IVC-CI cutoff values to specific patient groups and clinical settings rather than applying a single fixed threshold for all patients.

Multiple studies have proposed varying IVC-CI thresholds. Airapetian et al.[22] recommended IVC-CI of 42% or greater in spontaneously breathing patients, reporting very high specificity of 97% but low sensitivity of 31%. Bortolotti et al.[23] found that a threshold of 37% or greater yielded a sensitivity of 66% and specificity of 85% in spontaneously breathing patients with sepsis. Literature reviews and meta-analyses have shown a wide range of proposed thresholds, from 15% to over 40%, depending on factors such as respiratory pattern, underlying disease, and measurement technique.

Conclusion

The use of ultrasound to monitor IVC-CI of 36% or greater as a guide for fluid administration prior to spinal anesthesia in patients undergoing lower limb surgery did not reduce the incidence of hypotension when compared to standard fluid administration, in patients aged 18 to 75 years without cardiovascular disease.

What is already known about this topic?

Spinal anesthesia can lead to hypotension, particularly in patients with inadequate intravascular volume. In otherwise healthy patients undergoing lower limb surgery, using ultrasound to measure IVC-CI with a threshold of 36% or greater has been proposed as a tool to guide pre-spinal fluid administration. This approach aims to optimize fluid status and potentially reduce hypotension and fluid-related complications.

What does this study add?

However, in this study, ultrasound-guided fluid management using IVC-CI did not significantly reduce the incidence of hypotension compared to standard fluid administration. This study evaluated the effectiveness of using the IVC-CI of 36% or greater to predict fluid responsiveness in spontaneously breathing patients. The results showed no statistically significant difference in clinical outcomes compared to the group that received standard fluid management, suggesting that the selected threshold may not have been optimal for this patient population. The IVC-CI of 36% or greater was selected because it lies within the range supported by previous studies, especially those involving spontaneously breathing patients. It represents a middle-ground value, offering a balance between sensitivity and specificity, without being overly conservative or overly permissive. Based on the findings of this study, a fixed IVC-CI threshold may not be suitable for all patients, given individual variability. Therefore, assessments should consider patient-specific factors such as respiratory effort, physiological status, and clinical context to more accurately predict fluid responsiveness.

Conflicts of interest

The authors declare no conflict of interest.

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