

Ultrasound Guided Evaluation of Inferior Venacaval Collapsibility Index to Guide Fluid Management for Prediction of Hypotension after Spinal Anaesthesia

Rathod Shruti Baliram¹, Sachin Totawar², Mangesh Khadse³, Nazima Memon⁴

¹Junior Resident, Department of Anaesthesiology, Dr. SCGMC, Nanded

²Associate professor, Department of Anaesthesiology, Dr. SCGMC, Nanded

³Assistant professor, Department of Anaesthesiology, Dr. SCGMC, Nanded

⁴Associate professor, Department of Anaesthesiology, Dr. SCGMC, Nanded

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Corresponding Author: Dr. Nazima Memon

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Abstract:

Introduction: The use of ultrasound-guided inferior vena cava collapsibility index (IVCCI) has emerged as a promising noninvasive tool for predicting fluid responsiveness and optimizing hemodynamic stability in critical care settings, including spinal anaesthesia (SA). Hypotension is a common and potentially harmful complication following spinal anaesthesia, occurring in 15.3%–33% of cases. Given the risks associated with post-spinal anaesthesia hypotension (PSAH), accurate assessment of a patient's preoperative volume status is crucial for tailoring fluid management strategies to mitigate this complication. The present research aims to investigate the role of IVCCI in guiding fluid management for the prediction of PSAH in orthopedic patients scheduled for surgery under spinal anaesthesia.

Methods: The present prospective, comparative study was conducted from January 2023 to June 2024 amongst 168 patients in the Department of Anaesthesiology at a tertiary care hospital. The patients were systematically allocated to two groups: Group CI (IVCCI-measured group): 84 Patients underwent preoperative IVCCI assessment via ultrasound before receiving spinal anaesthesia. Fluid therapy was adjusted based on IVCCI values and Group NCI (Non-IVCCI-measured group): 84 Patients received standard fluid therapy without IVCCI assessment.

Results: IVCCI-guided fluid management significantly reduced the incidence of post-spinal anaesthesia hypotension (PSAH) compared to standard empirical fluid therapy ($p = 0.003$). Patients in the IVCCI group required significantly lower doses of ephedrine, indicating improved perioperative hemodynamic stability ($p = 0.006$). Systolic blood pressure at 3-, 5-, 10-, and 20-minutes post spinal block was significantly better maintained in the IVCCI group, reflecting early stabilization. IVCCI allowed for targeted preoperative fluid loading, leading to reduced total perioperative fluid use without compromising safety. Incidence of adverse effects such as bradycardia, nausea, and dizziness was similar between groups, with a trend toward lower hypoperfusion in the IVCCI group.

Conclusion: We conclude from our study that the integration of IVCCI into perioperative fluid management strategies marks a significant step toward more refined, responsive, and effective anaesthesia care. The ability to reduce PSAH, lower vasopressor dependence, and maintain hemodynamic stability through a simple ultrasound measurement underscores the value of IVCCI in modern clinical practice.

Keywords: Ultrasound, Inferior Vena Cava Collapsibility Index, Post- Spinal Anaesthesia Hypotension, Ephedrine, Hemodynamic.

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Introduction

Ultrasonography (USG) has revolutionized modern anaesthesia by improving the precision of anesthetic procedures and guiding perioperative fluid therapy. Among its many applications, the use of ultrasound-guided inferior vena cava collapsibility index (IVCCI) has emerged as a promising noninvasive tool for predicting fluid responsiveness and optimizing hemodynamic stability in critical care

settings, including spinal anaesthesia (SA). Hypotension is a common and potentially harmful complication following spinal anaesthesia, occurring in 15.3%–33% of cases, primarily due to sympathetic denervation leading to vasodilation and redistribution of central blood volume, which subsequently decreases preload and cardiac output. Given the risks associated with post-spinal

anaesthesia hypotension (PSAH), accurate assessment of a patient's preoperative volume status is crucial for tailoring fluid management strategies to mitigate this complication [1].

Traditional methods for evaluating intravascular volume status include pulmonary artery catheterization, pulse contour analysis, passive leg raising tests, and heart rate variability indices. However, these techniques are either invasive, technically complex, or require advanced monitoring systems that may not be readily available in all perioperative settings. In contrast, IVCCI is a simple, safe, and cost-effective method that has been validated for assessing fluid responsiveness, particularly in spontaneously breathing patients. Several studies, including those, have demonstrated that an IVCCI greater than 40% can reliably identify fluid responders in patients with acute circulatory failure and cardiac arrhythmias, respectively. Additionally, research has highlighted the moderate performance of IVCCI in detecting hypotension among mechanically ventilated patients experiencing circulatory collapse [2].

The clinical consequences of PSAH are significant and may include impaired perfusion of vital organs, leading to acute kidney injury, myocardial ischemia, and cognitive dysfunction, particularly in high-risk populations such as the elderly and patients with cardiovascular comorbidities. Therefore, the ability to predict and prevent PSAH through accurate preoperative assessment is a key goal in anesthetic practice. However, excessive fluid administration carries risks of fluid overload, pulmonary edema, and hemodilution, which underscores the need for a more individualized and evidence-based approach to fluid management [3].

Recent research has also explored the application of IVCCI in spinal anaesthesia. Reported that IVCCI measurements obtained before spinal anaesthesia were reliable predictors of PSAH, with a cut-off value of >42% demonstrating significant predictive capability. In another study, they found that preoperative ultrasound evaluation of IVCCI and the caval-aorta index provided valuable insights into a patient's risk of developing PSAH, supporting the inclusion of IVCCI assessment in pre-anesthetic evaluations. Moreover, studies have indicated that IVCCI assessment, particularly in elderly patients, can enhance the accuracy of spinal-induced hypotension predictions when combined with other echocardiographic measurements [4].

The present research aims to investigate the role of IVCCI in guiding fluid management for the prediction of PSAH in orthopaedic patients scheduled for surgery under spinal anaesthesia. This study will specifically compare the incidence of PSAH in IVCCI-measured and non-measured groups, evaluate the association between IVCCI and

PSAH, and determine the intraoperative and postoperative fluid requirements in both patient groups. [5]

Material and Methods

The present quasi-experimental, prospective, comparative study was conducted to evaluate the role of Inferior Vena Cava Collapsibility Index (IVCCI) in guiding fluid management and predicting post-spinal anaesthesia hypotension (PSAH).

The study was non-randomized, with purposive sampling used to allocate patients into respective groups. IVCCI was measured preoperatively using point-of-care ultrasound (POCUS), and fluid management was adjusted accordingly. The hemodynamic parameters, including blood pressure, heart rate, and total fluid administration, were recorded at multiple time intervals. The study adhered to the principles of goal-directed fluid therapy (GDFT) to optimize hemodynamic stability while preventing fluid overload. The study was conducted in the Department of Anaesthesiology at a tertiary care hospital. All procedures were performed in standardized operating rooms, where spinal anaesthesia was administered under strict aseptic conditions by qualified anesthesiologists. The IVCCI measurements were taken in a dedicated preoperative holding area, ensuring minimal patient movement before surgery. The study adhered to the hospital's anaesthesia guidelines, infection control policies, and perioperative monitoring protocols to maintain consistency in data collection.

Inclusion Criteria: Patients scheduled for elective lower abdominal and orthopaedic lower limb surgeries under spinal anaesthesia, Age range: 18–65 years, ASA classification I & II, Body weight between 30–70 kg, Patients who provided written informed consent for participation in the study.

Exclusion Criteria: Patients who refused to participate or withdrew consent, ASA class III & IV patients, Patients undergoing emergency surgeries, where preoperative IVCCI measurement was not feasible, Patients with preexisting cardiac arrhythmias, severe valvular heart disease, or chronic heart failure, Patients with preoperative hypotension (SBP <90 mmHg) or uncontrolled hypertension (SBP >180 mmHg), Patients with coagulopathy or local skin infections at the lumbar puncture site, contraindicating spinal anaesthesia, Pregnant patients undergoing caesarean sections, due to altered hemodynamic physiology.

The study was conducted from January 2023 to June 2024 amongst 168 patients. After eligibility the patients were systematically allocated to two groups:

- Group CI (IVCCI-measured group): 84 Patients underwent preoperative IVCCI assessment via

ultrasound before receiving spinal anaesthesia. Fluid therapy was adjusted based on IVCCI values.

- Group NCI (Non-IVCCI-measured group): 84 Patients received standard fluid therapy without IVCCI assessment.

Every eligible patient was assessed preoperatively for inclusion, ensuring that selection bias was minimized. The sample size was calculated based on previous studies evaluating IVCCI-guided fluid therapy and PSAH incidence.

Study Parameters: Primary Parameter: Incidence of post-spinal anaesthesia hypotension (PSAH) (defined as SBP decrease >20% from baseline or SBP <90 mmHg).

Secondary Parameters: Total intraoperative and postoperative fluid administration (mL), Vasopressor (ephedrine/phenylephrine) requirements, Hemodynamic parameters at multiple time intervals (HR, BP, SpO₂), Incidence of adverse

effects (bradycardia, nausea, dizziness, organ hypoperfusion).

1. Preoperative Assessment: Baseline demographic data, comorbidities, and fluid status were recorded, IVCCI was measured in Group CI using a subxiphoid long-axis ultrasound approach.
2. Anaesthesia Administration: Standardized spinal anaesthesia technique was used in all patients, 0.5% hyperbaric bupivacaine (15 mg) was administered intrathecally.
3. Fluid Management: Group CI: IVCCI-guided preloading (based on IVCCI values) and Group NCI: Fixed 500 mL crystalloid preloading.
4. Intraoperative Monitoring: Continuous BP, HR, and SpO₂ monitoring. IV fluids and vasopressors administered as per patient response.
5. Postoperative Monitoring: Patients were monitored for 24 hours postoperatively for hemodynamic stability and adverse events.

Results

Table 1: Incidence of PSAH in CI and NCI Groups

PSAH Status	CI Group	NCI Group	Total
No (0)	70	53	123
Yes (1)	14	31	45
Total	84	84	168

Table no.1 shows that a significant difference was observed in the incidence of post-spinal anaesthesia hypotension (PSAH) between the IVCCI-measured (CI) and non-measured (NCI) groups. Only 14 patients (16.7%) in the CI group developed PSAH, compared to 31 patients (36.9%) in the NCI group. The Pearson Chi-Square test indicated a statistically significant association between group assignment and PSAH occurrence ($p = 0.003$). These results

strongly support the effectiveness of IVCCI-guided fluid management in reducing the risk of hypotension following spinal anaesthesia, reinforcing its clinical value in perioperative hemodynamic optimization. Significantly fewer patients developed PSAH in the IVCCI-guided group compared to standard care ($p = 0.003$, Pearson Chi-Square).

Table 2: Ephedrine Dose Administered Across CI and NCI Groups

Ephedrine Dose (mg)	CI Group	NCI Group	Total
0	70	7	77
1	3	16	19
2	2	15	17
3	1	17	18
4	3	15	18
5	5	14	19
Total	84	84	168

Table no.2 shows that there was a statistically significant difference in ephedrine dosage requirements between the IVCCI-measured (CI) and non-measured (NCI) groups ($p < 0.001$). The majority of patients in the CI group (70 out of 84) did not require any ephedrine, compared to only 7 patients in the NCI group. Conversely, the need for ephedrine across all dose levels (1–5 mg) was notably higher in the NCI group, particularly at 3 mg (17 patients) and 2 mg (15 patients), suggesting a

greater incidence and severity of hypotensive episodes. These findings indicate that IVCCI-guided fluid optimization effectively minimized vasopressor requirements by stabilizing hemodynamics preemptively, thereby reducing the severity and frequency of post-spinal anaesthesia hypotension.

Figure 5. Distribution of Ephedrine Dosage Between Study Groups Ephedrine use varied significantly

across groups, with the CI group requiring lower overall doses ($p = <0.001$, Pearson Chi-Square).

Table 3: Incidence of Bradycardia Among Study Groups

Bradycardia	CI Group	NCI Group	Total
No (0)	76	76	152
Yes (1)	8	8	16
Total	84	84	168

Table no.3 shows that Bradycardia occurred in an equal number of patients across both IVCCI-measured (CI) and non-measured (NCI) groups, with 8 cases each. The Pearson Chi-Square test yielded a p-value of 1.000, indicating no statistically significant association between bradycardia and the method of fluid management. These findings

suggest that IVCCI-guided fluid optimization did not influence the occurrence of spinal anaesthesia-related bradycardia, which may be more closely related to block height and autonomic tone rather than volume status alone. No significant difference in bradycardia incidence was observed between the CI and NCI groups ($p = 1.000$, Pearson Chi-Square).

Table 4. Incidence of Bradycardia and Nausea post operative Among Study Groups

Bradycardia	CI Group	NCI Group	Total
No (0)	76	76	152
Yes (1)	8	8	16
Nausea			
No (0)	69	74	143
Yes (1)	15	10	25
Total	84	84	168

Table no.4 shows that Bradycardia occurred in an equal number of patients across both IVCCI-measured (CI) and non-measured (NCI) groups, with 8 cases each. The Pearson Chi-Square test yielded a p-value of 1.000, indicating no statistically significant association between bradycardia and the method of fluid management. These findings suggest that IVCCI-guided fluid optimization did not influence the occurrence of spinal anaesthesia-related bradycardia, which may be more closely related to block height and autonomic tone rather than volume status alone. No significant difference in bradycardia incidence was observed between the CI and NCI groups ($p = 1.000$, Pearson Chi-Square).

Nausea was reported in 25 out of 168 participants, with slightly higher incidence in the IVCCI-measured (CI) group (17.9%) compared to the non-measured (NCI) group (11.9%). However, the difference was not statistically significant ($p = 0.278$, Pearson Chi-Square). This suggests that IVCCI-guided fluid management did not significantly affect the risk of nausea following spinal anaesthesia. Given the multifactorial etiology of nausea in the perioperative setting—ranging from hypotension to individual sensitivity—these findings indicate the need for broader prophylactic strategies irrespective of fluid optimization protocol. Nausea occurred with similar frequency in both groups, with no significant difference observed ($p = 0.278$, Pearson Chi-Square).

Table 5: Comparison of Key Perioperative Parameters Between CI and NCI Groups

Parameter	CI Group (Mean $\pm$ SD)	NCI Group (Mean $\pm$ SD)	p-value
Duration of Surgery (min)	73.75 $\pm$ 27.04	77.17 $\pm$ 26.19	0.407
Preoperative Pulse (bpm)	79.10 $\pm$ 11.01	79.23 $\pm$ 11.76	0.941
Preoperative SBP (mmHg)	118.32 $\pm$ 12.76	118.12 $\pm$ 11.42	0.914
Preoperative SpO ₂ (%)	97.17 $\pm$ 1.45	97.33 $\pm$ 1.48	0.462
IVCCI (%)	40.83 $\pm$ 11.83	—	—
Preoperative Fluid (ml)	1273.81 $\pm$ 250.36	—	<0.001
Systolic BP Drop (mmHg)	4.92 $\pm$ 11.40	11.86 $\pm$ 16.71	0.002
Total Intraoperative Fluid (ml)	1714.00 $\pm$ 474.03	1771.62 $\pm$ 410.49	0.401
Total Postoperative Fluid (ml)	1039.71 $\pm$ 295.16	1030.50 $\pm$ 289.80	0.838
Total Perioperative Fluid (ml)	998.44 $\pm$ 270.58	1009.86 $\pm$ 274.50	<0.001

Table no.5 shows that the comparison of perioperative parameters revealed several significant findings between the IVCCI-measured

(CI) and non-measured (NCI) groups. Preoperative baseline values including pulse, blood pressure, and SpO₂ were statistically similar ($p > 0.05$), indicating

homogeneity between the groups at the outset. Notably, systolic blood pressure drop was significantly lower in the CI group (mean = 4.92 mmHg) compared to the NCI group (mean = 11.86 mmHg; $p = 0.002$), confirming improved hemodynamic stability with IVCCI-guided fluid therapy. Total perioperative fluid administered was significantly less in the CI group ($p < 0.001$), supporting optimized volume management. SBP values at 3, 5, 10, and 20 minutes post-spinal anaesthesia were significantly higher in the CI group ($p < 0.05$), further reinforcing the effectiveness of IVCCI-guided preloading in preventing hypotensive shifts.

Discussion:

Baseline Demographic and Clinical Comparability: In the present study, both the IVCCI-guided (CI) and non-measured (NCI) groups were matched with respect to age distribution, sex, ASA physical status, and preoperative hemodynamic parameters, including pulse rate, systolic and diastolic blood pressure, and SpO₂ levels. None of these variables showed a statistically significant difference between the groups, affirming the internal validity of our comparative analysis.

Our findings are consistent with the design methodologies employed in several earlier studies that aimed to assess the role of IVCCI in predicting post-spinal anaesthesia hypotension (PSAH). For example, Ceruti et al. ensured comparability between groups by balancing demographic and clinical variables before analyzing the impact of IVCUS-guided fluid optimization on hypotension incidence [6]. Similarly, Ni et al. stratified participants evenly before implementing IVCCI-guided versus standard fluid administration protocols, thereby enhancing the credibility of their findings regarding reduced PSAH and fluid volume requirements [7]. However, in general surgical populations like ours, baseline homogeneity provides a strong foundation for evaluating IVCCI's predictive and preventive capabilities without confounding from population-specific physiological alterations.

Additionally, our findings align with Krishnan et al., who emphasized the importance of preoperative standardization in evaluating IVCCI thresholds. Their use of a $>50\%$ IVCCI cut-off and observation of hemodynamic responses across well-matched groups allowed for robust correlation between collapsibility and hypotension risk [8]. Likewise, Eeshwar et al. and Lal et al. employed blinding and stratification strategies to ensure group equivalence while comparing IVCCI with other ultrasound indices like the IVC: Aorta ratio [9, 10]. These methodological parallels further validate our study's approach to establishing group comparability. These results confirm that subsequent reductions in PSAH

and vasopressor use can be attributed to the use of IVCCI-guided fluid management, rather than baseline variability between study groups.

Impact of IVCCI on Incidence of Post-Spinal Anaesthesia Hypotension: Our results demonstrated a statistically significant reduction in PSAH among patients in the IVCCI-measured group (CI) compared to those receiving standard fluid therapy (NCI), with a hypotension incidence of 16.7% versus 36.9%, respectively ($p = 0.003$). This clear reduction suggests that IVCCI is a valuable tool in predicting and subsequently preventing PSAH through targeted preoperative volume optimization.

This finding aligns closely with those of Ceruti et al., who reported a 35% relative risk reduction in hypotension incidence when fluid therapy was guided by IVC ultrasound. Their results showed that the IVCUS group experienced significantly lower rates of PSAH (27.5% vs. 42.5%, $p = 0.044$), corroborating our finding that individualized, ultrasound-guided preloading offers a preventive advantage over empirical approaches [6]. Similarly, Ayyanagouda et al. found a 30% absolute reduction in hypotension (20% vs. 50%, $p = 0.002$) in their IVCUS-guided group, again demonstrating the reproducibility of our findings in different surgical populations [11].

However, the literature also presents contrasting evidence. Jaremko et al. reported that IVCCI failed to predict severe hypotension in spontaneously breathing patients undergoing knee arthroplasty. Their study found no significant differences in IVCCI values between hypotensive and non-hypotensive patients, with an ROC AUC of <0.7 [12]. In contrast, our study focused on elective general surgical patients with standard conditions, which may have allowed for more consistent IVCCI measurements and their correlation with hemodynamic outcomes.

Furthermore, studies focusing on obstetric populations such as Singh et al. and Elbadry et al. reported mixed results. While Singh et al. concluded that IVCCI was not predictive of PSAH in pregnant women undergoing cesarean sections due to physiological changes affecting IVC diameter and venous return [13], Elbadry et al. demonstrated that IVCCI offered high sensitivity (84.6%) and specificity (93.1%) in predicting hypotension in the same population, underscoring the context-dependent utility of IVCCI [14].

Ephedrine Requirement and Hemodynamic Stabilization: Our findings showed a significant reduction in both the frequency and total dose of ephedrine administered in the IVCCI-guided group (CI) compared to the standard therapy group (NCI), with a shift toward lower ephedrine dosing in the CI

group ($p = 0.006$). These results underscore the impact of IVCCI-guided fluid preloading in maintaining cardiovascular stability post spinal anaesthesia and reducing the pharmacologic intervention needed to manage hypotension.

These findings agree with previous literature. Ceruti et al. reported a significant reduction in vasoactive drug use in their IVCUS-guided group ($p = 0.015$), which paralleled the reduction in hypotension incidence [6]. The implication of their study, and ours, is that ultrasound-guided fluid management enables more precise and individualized intravascular volume optimization, reducing the need for reactive vasopressor therapy during periods of sympathetic blockade induced by spinal anaesthesia.

Similarly, Ayyanagouda et al. demonstrated that their IVCUS group not only had a lower incidence of hypotension but also required significantly fewer vasopressor interventions compared to the control group. Their findings attributed this to better volume responsiveness profiling, which led to more appropriate fluid loading prior to anaesthesia [11]. Our results resonate with this conclusion, as patients in the CI group were less likely to experience clinically significant drops in blood pressure requiring correction with ephedrine.

Contrastingly, Jaremko et al. did not find IVCCI useful in predicting or preventing hypotension in their cohort and did not observe a meaningful reduction in vasopressor requirements [12]. This may be attributed to the variability of IVC measurements in spontaneously breathing patients or to differences in intra-abdominal pressures and respiratory mechanics in the orthopaedic population studied.

Systolic Blood Pressure Trend and Early Hemodynamic Changes: One of the key observations in our study was the difference in systolic blood pressure (SBP) trends following spinal anaesthesia between the IVCCI-guided (CI) and standard therapy (NCI) groups. SBP measurements at 3-, 5-, 10-, and 20-minutes post spinal block were significantly higher in the CI group ($p < 0.05$ across all time points), indicating a more stable hemodynamic profile in patients who underwent individualized fluid resuscitation. These findings highlight the immediate benefits of preoperative IVCCI assessment in mitigating the steep drop in SBP that characteristically follows spinal anaesthesia due to sympathetic blockade and vascular pooling.

Our findings are supported by the study conducted by Ni et al., who demonstrated that IVCCI-guided fluid management led not only to a reduction in PSAH incidence but also to improved blood pressure maintenance in the early postoperative

period. Their group found that patients with IVCCI $>42\%$ were more prone to hypotension, and targeting lower collapsibility pre-spinal administration helped in maintaining more stable SBP values post induction [7]. Ceruti et al. similarly observed better intraoperative hemodynamic control in the IVCUS-guided group. [6].

Interestingly, Krishnan et al. found a robust relationship between IVCCI $>50\%$ and steep SBP drops post spinal anaesthesia. In their study, patients with higher collapsibility showed not only increased hypotension incidence but also more severe and sustained SBP reductions, thus validating our observation that early SBP trends are significantly improved when IVCCI is used to tailor fluid management [8].

Total Fluid Administration and Volume Optimization: In the IVCCI-guided group (CI), fluid therapy was tailored to the patient's collapsibility index, resulting in more targeted preoperative volume expansion. While the total intraoperative and postoperative fluid volumes did not differ significantly between the two groups ($p = 0.401$ and $p = 0.838$, respectively), the preoperative fluid volume was significantly higher in the CI group. This led to more effective volume optimization before spinal anaesthesia, reflected in improved hemodynamic stability and reduced hypotension. The total peroperative fluid administration was also significantly more efficient in the CI group ($p < 0.001$), indicating that fluid use was optimized rather than excessive.

Our findings correspond with those of Ceruti et al., who reported that the IVCUS-guided group received significantly more preoperative fluids compared to the control group, but ultimately experienced better hemodynamic outcomes, including fewer hypotensive episodes and reduced vasopressor use [6]. Their study concluded that increased pre-spinal fluid administration, when guided by real-time ultrasound, translated into clinical benefit without necessarily increasing the total fluid burden. This supports the rationale behind IVCCI-guided optimization: fluid therapy should be need-based, not empirical. Ni et al. also reported similar findings in their randomized controlled trial. [7]. In our study, while preoperative fluids were higher in the CI group due to this proactive strategy, the overall peroperative fluid profile remained balanced—indicating the prevention of fluid overload without compromising hemodynamic targets.

Ayyanagouda et al. further reinforced this approach by showing that patients in the IVCUS group who received volume correction based on ultrasound findings had a significantly lower incidence of hypotension (20% vs. 50%) despite receiving comparable or slightly higher pre-spinal fluid volumes [11]. Adverse Effects Profile:

In our study, adverse events including bradycardia, nausea, dizziness, and hypoperfusion were assessed across both the IVCCI-guided (CI) and standard therapy (NCI) groups. While the overall incidence of bradycardia, dizziness, and nausea was comparable between the groups ($p > 0.05$), there was a notable trend toward reduced hypoperfusion in the CI group, although it did not reach statistical significance ($p = 0.094$). These findings suggest that IVCCI-guided fluid optimization maintains hemodynamic stability without increasing the risk of secondary adverse events.

Our findings are supported by Ceruti et al., who, despite observing reduced hypotension in the IVCUS group, reported no significant difference in bradycardia between groups, suggesting that fluid optimization does not necessarily influence vagally mediated reflex responses [6].

In terms of nausea and dizziness, both symptoms are frequently associated with hypotension and reduced cerebral perfusion post spinal anaesthesia. The slight reduction in nausea in the NCI group (though not statistically significant) may appear paradoxical but is likely incidental given the small sample size and multi-factorial etiology of nausea. Similarly, Jaremko et al. noted that while their cohort did not benefit from IVCCI-guided therapy in terms of hypotension reduction, the incidence of minor adverse effects like nausea and dizziness did not differ between groups, further reinforcing that these symptoms may not be solely volume-related [12].

In contrast, Singh et al. and Panchal et al. in obstetric cohorts, faced inconsistent outcomes regarding secondary symptoms, likely due to altered physiological states in pregnancy affecting autonomic regulation and IVC dimensions [13, 15].

In summary, IVCCI-guided fluid therapy appears to preserve hemodynamic stability without introducing additional risks of adverse effects. The comparable rates of nausea, dizziness, and bradycardia—combined with a favorable trend in hypoperfusion—underscore the safety and tolerability of this individualized approach.

Clinical Implications and Utility of IVCCI: The clinical implications of our study highlight the transformative potential of integrating IVCCI-guided fluid optimization into routine anaesthetic practice. By enabling personalized, non-invasive assessment of a patient's intravascular volume status, IVCCI provides a practical solution to one of the most common perioperative challenges: preventing hypotension following spinal anaesthesia. Our findings—reduced incidence of PSAH, diminished need for ephedrine, and improved early systolic blood pressure (SBP) stability—demonstrate that IVCCI is more than a predictive metric; it is a tool that actively enhances

patient safety and anaesthetic outcomes when used for preemptive fluid management.

The application of IVCCI in our study was associated with reduced PSAH, echoing results from multiple clinical trials. Ceruti et al. described the successful application of IVC ultrasound in reducing PSAH incidence and vasoactive drug usage by tailoring volume resuscitation based on collapsibility indices [6]. Similarly, Ni et al. and Ayyanagouda et al. confirmed the role of IVCCI in preventing PSAH and minimizing the need for vasopressors, demonstrating consistent benefits in general surgical populations [7, 11]. These findings, taken together with our own, provide a strong argument for adopting IVCCI as a standard component of the pre-spinal anaesthesia workflow.

Clinically, IVCCI has several advantages that support its integration into perioperative protocols. It is a non-invasive, bedside assessment that takes less than two minutes to perform with minimal training. In settings where invasive monitors like central venous pressure (CVP) are not routinely indicated or feasible, IVCCI offers a practical alternative. This is particularly valuable in resource-limited environments, day-case surgeries, or among patient populations where invasive monitoring is inappropriate. In contrast to subjective assessments of hydration status, IVCCI offers a quantifiable, reproducible parameter that can guide fluid therapy with precision.

Further support for the clinical utility of IVCCI is provided by Krishnan et al., who found that IVCCI $>50\%$ was associated with a markedly higher incidence of hypotension and greater need for vasopressor therapy [8]. Their findings support our own, suggesting that specific threshold values can be operationalized as decision points for fluid bolus administration prior to spinal block. By preemptively managing fluid deficits in high-IVCCI patients, clinicians can mitigate the sudden hemodynamic shifts associated with neuraxial blockade.

In the emergency setting, Yangste et al. demonstrated that IVCCI-guided resuscitation was more effective than MAP-based resuscitation in reducing PSAH severity and adverse outcomes in patients undergoing lower limb surgeries [16]. This expands the clinical utility of IVCCI beyond elective settings into acute care scenarios where rapid and reliable volume assessment is essential.

Conclusion

We conclude from our study that the integration of IVCCI into perioperative fluid management strategies marks a significant step toward more refined, responsive, and effective anaesthesia care. The ability to reduce PSAH, lower vasopressor dependence, and maintain hemodynamic stability

through a simple ultrasound measurement underscores the value of IVCCI in modern clinical practice. With further validation and broader implementation, IVCCI has the potential to transform spinal anaesthesia management by making it safer, more efficient, and better tailored to the needs of individual patients.

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