Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/a1m21a91

EFFICACY OF FLUID ADMINISTRATION BY INFERIOR VENA CAVA ULTRASONOGRAPHY GUIDANCE VERSUS EMPIRICAL METHOD FOR PREVENTION OF ARTERIAL HYPOTENSION IN SPINAL ANESTHESIA PATIENTS UNDERGOING ORTHOPAEDIC SURGERIES - A RANDOMIZED CONTROLLED STUDY

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ABSTRACT

Background: Spinal anesthesia is widely used for lower-limb orthopedic surgery but is frequently complicated by arterial hypotension due to sympathetic blockade and venous pooling. Empirical fluid loading has inconsistent efficacy and risks fluid overload. Ultrasonographic assessment of the inferior vena cava (IVC) collapsibility index (IVCCI) offers a non-invasive means of predicting fluid responsiveness and guiding individualized fluid therapy.

Methods: In this single-center, randomized controlled trial, 100 ASA I–II adults aged 18–40 years scheduled for elective orthopedic surgery under spinal anesthesia were allocated to either IVC ultrasonography-guided fluid administration (Group A) or empirical fluid preloading (Group B). Group A received 500 ml Ringer Lactate boluses if IVCCI $\geq$ 36%, repeated until <36%. Group B received a fixed preload of 5 ml/kg Ringer Lactate. The primary outcome was incidence of post-spinal arterial hypotension (systolic BP <90 mmHg or diastolic BP <60 mmHg) within 30 minutes. Secondary outcomes included total crystalloid volume and vasopressor (mephentermine) requirement.

Results: Hypotension occurred in 8% of Group A versus 28% of Group B ($p = 0.019$). Group A received more total fluid (726 ± 71.6 ml) than Group B (611.1 ± 113.4 ml, $p < 0.001$), but fewer mephentermine boluses (0.12 ± 0.33 vs. 0.34 ± 0.56, $p = 0.018$). Mixed-effects models showed significantly better maintenance of systolic and mean arterial pressure in Group A ($p < 0.01$).

Conclusion: IVC ultrasonography-guided fluid therapy significantly reduced the incidence of post-spinal hypotension and vasopressor use compared with empirical preloading, supporting its use for individualized perioperative hemodynamic management in orthopedic anesthesia.

Keywords: Inferior Vena Cava, Echocardiography.

INTRODUCTION

Spinal anesthesia is commonly employed for infra-umbilical and orthopedic surgeries due to its reliable anesthetic effect and ability to reduce systemic opioid requirements, promoting faster postoperative recovery.[1] Despite these advantages, arterial hypotension remains a frequent and consequential adverse event, associated with risks such as myocardial and renal dysfunction, stroke, delirium, and extended hospitalization.[2,3] The principal mechanism behind spinal-induced hypotension is sympathetic blockade, which precipitates vasodilation, reduced systemic vascular resistance, diminished venous return, and lowered cardiac output.[4]

Patient-specific factors-including preoperative volume status, comorbidities, and intraoperative Medications-increase susceptibility to hypotension.[5]

Historically, perioperative fluid management has relied on empirical fluid loading, aiming to mitigate hypotension risk.[6] However, this approach often results in either inadequate prophylaxis or excessive fluid administration, especially in patients with cardiac comorbidities.[7] Recent focus has shifted to noninvasive hemodynamic techniques, such as transthoracic echocardiography (TTE) and bioimpedance methods, for volume responsiveness assessment,[8] yet these modalities are limited by specialized expertise requirements and equipment accessibility.[9]

Ultrasonographic measurement of the inferior vena cava collapsibility index (IVC-CI) has emerged as a rapid, noninvasive marker of intravascular volume status and fluid responsiveness.[10] The utility of IVC-CI is well-validated in critical care scenarios,[11] and its use is endorsed in echocardiographic practice guidelines.[12] Evidence suggests that IVC-CI evaluation prior to anesthesia induction can predict hypotension risk and guide optimal fluid administration.[13] IVC-CI-guided therapy has shown promise in reducing spinal-induced hypotension in various surgical populations.[14]

While promising, robust evaluation of IVC-CI's benefits in orthopedic surgical patients undergoing spinal anesthesia remains limited, despite these patients' increased risk for fluid shifts and hemodynamic instability.[15] Moreover, the integration of ultrasonography into perioperative management aligns with the growing adoption of point-of-care ultrasound (POCUS) for evidence-based, patient-centered care.[16]

The current randomized controlled trial aims to address these gaps by comparing IVC ultrasonography-guided fluid administration with traditional empirical methods in orthopedic surgery patients receiving spinal anesthesia, with the objective of establishing more effective protocols for preventing arterial hypotension and improving perioperative outcomes.[17]

MATERIALS AND METHODS

This randomized, open-label, parallel-group trial was conducted at a tertiary care teaching hospital from 2023 to 2025 to compare IVC-USG–guided fluid administration versus empirical fluid therapy in preventing arterial hypotension following spinal anesthesia in adult orthopedic surgery. After institutional ethics approval and written informed consent, 100 ASA I–II patients aged 18–40 years scheduled for elective orthopedic procedures under spinal anesthesia were enrolled. Exclusion criteria included invasive blood pressure monitoring, pre-existing hypotension (two consecutive systolic BP < 90 mmHg), failed or unilateral spinal attempts, contraindications to spinal anesthesia (local infection, coagulopathy), or refusal of consent.

Patients converted to general anesthesia were withdrawn. Sample size was calculated to be 100 patients. One hundred patients were divided equally into two groups-case group (IVC-USG guided) and control group-with 50 patients in each. Patients were randomly allocated to either group using a computer-generated random number table.

All participants fasted for solids 6 hours and clear fluids up to 2 hours preoperatively. In the preoperative area, standard ASA monitors (ECG, noninvasive BP every 3 minutes, SpO_2) were applied, and an 18 G IV cannula secured. Spinal anesthesia was performed at L3–L4 in the sitting position using a 23 G needle; 12–18 mg of 0.5% heavy bupivacaine (dose adjusted to patient constitution) was injected cranially under aseptic technique.

In the IVC group, assessment used a low-frequency linear probe (6–12 MHz) on a Sonosite Fujifilm Edge II ultrasound machine. In M-mode, three measurements of IVC diameter 2–3 cm from the right atrium were recorded as dIVCmax (end-expiration) and dIVCmin (end-inspiration). IVCCI was calculated:

$$IVCCI = ((dIVCmax - dIVCmin) / dIVCmax) \times 100\%$$

A threshold ≥ 36% indicated fluid responsiveness; such patients received 500 mL Ringer's lactate over 15 minutes, with repeated IVC reassessment until IVCCI fell below 36%, after which spinal anesthesia proceeded.

The control group received an empirical preload of 5 mL/kg Ringer's lactate immediately before spinal anesthesia without ultrasound guidance.

After the block, all patients were supine and monitored for 30 minutes. Hemodynamic parameters—SBP, DBP, MAP, and HR-were recorded immediately post-block, at every 3 minutes until 30 minutes. Significant hypotension was defined as SBP < 90 mmHg or DBP < 60mmHg. Hypotension was treated with 250 mL crystalloid boluses and IV mephentermine 6 mg increments until hemodynamic stability. Total fluid volume, cumulative vasopressor dose, and occurrence of complications (e.g., bradycardia, nausea, vomiting) were documented.

Data were coded in Microsoft Excel and analyzed using STATA 10.1. Continuous data are presented as mean ± SD and compared with unpaired or paired t-tests; categorical variables were analyzed with chi-square tests. Where appropriate, mixed-effects models, Pearson's correlation, and two-way ANOVA were applied. A p-value < 0.05 denoted statistical significance.

RESULT

All 100 patients of two groups completed the study without any exclusion. Patient demographic data that includes age, height, weight, sex and ASA grade of patients between two groups were comparable (table 1).

Measure	Stats (mean ± SD)	p-value
Age (years)	A: 31.6 ± 5.9 / B: 30.2 ± 5.0	0.221
Height (cm)	A: 164.6 ± 5.5 / B: 162.3 ± 7.2	0.077
Weight (kg)	A: 66.3 ± 8.1 / B: 65.0 ± 9.9	0.462
Sex (M/F)	M: A 40, B 36; F: A 10, B 14	0.482
ASA grade	1: A 45, B 47; 2: A 5, B 3	0.712

Table 1: Demographic distribution between the two groups

Incidence of Hypotension	Case Group (n= 50)	Control Group (n= 50)	p value
	4(8%)	14(28%)	0.019

Table 2: Comparison of hypotension in both groups

Table 2 indicates incidence of hypotension in both groups. In the case group, 4 patients out of 50 developed hypotension, whereas in the control group 14 out of 50 patients developed hypotension. The results were statistically significant.

Parameters	Case Group (n=40)	Control Group (n=40)	P value
Total IV fluids(ml)	726±71.6	611.1±113.4	0.001
vasopressors	0.12 ± 0.33	0.34 ± 0.56	0.018

Table 3: Vasopressors and IV fluids usage between the groups

Table 3 shows iv fluids used and vasopressors required in both the groups. Total iv fluid given in the case group was more as compared to the control group and results were found to be statistically significant. In the case group, only 4 patients out of 50 required vasopressors. In the control group, 14 patients out of 50 required vasopressors. The results were statistically significant.

DISCUSSION

Spinal (subarachnoid) anaesthesia is the preferred technique for lower-limb orthopaedic surgery because it provides a dense sensory–motor block with minimal airway manipulation. However, arterial hypotension-occurring in 25–40% of cases-remains a significant drawback, arising from sympathetic blockade, venous pooling, and reduced venous return. Unmanaged, it can precipitate myocardial ischaemia, cerebral hypoperfusion, and delayed recovery. Conventional prophylaxis employs empirical fluid pre-loading or reflex vasopressor administration, both of which are blunt instruments: fluid pre-loading risks overload, while vasopressors treat rather than prevent hypotension.[18–20] Thus, dynamic, patient-specific predictors of fluid responsiveness have become attractive, and point-of-care ultrasonography (POCUS) of the inferior vena cava (IVC) supplies such a predictor. In spontaneously breathing adults, the IVC collapsibility index (IVCCI) integrates intrathoracic pressure swings with venous capacitance.

Prospective trials in elective surgery, obstetrics, and critical-care settings have shown that an IVCCI > 36–42% predicts fluid responsiveness, and goal-directed fluid optimisation based on this threshold can limit post-spinal hypotension, reduce vasopressor use, and shorten recovery times.[21–23]

The present randomised controlled trial compared an ultrasound-guided fluid algorithm (Group A) with an empirical regimen (Group B) in 100 ASA I–II adults undergoing elective lower-limb orthopaedic surgery under spinal anaesthesia. Baseline demographics (age, height, weight, sex distribution, and ASA grade) were comparable between groups ($p > 0.05$ for all) (Table 1).

The primary outcome-incidence of post-spinal hypotension-was significantly lower in the IVC-guided group (8%) than in the empirical group (28%; $p = 0.019$). This finding parallels previous studies: Ni et al. reported hypotension rates of 15.3% versus 31.7% (IVC vs empirical; $p = 0.032$) [Ni et al., 2022]; Renu et al. found 15% versus 42.5% ($p = 0.029$) [Renu et al., 2023]; and Joshi et al. observed 12% versus 38% in an obstetric cohort ($p = 0.002$) [Joshi et al., 2021] (Table 2).

Secondary outcomes likewise favored the IVC-guided strategy. Group A received a larger mean fluid volume (726 ± 71.6 mL) compared to Group B (611.1 ± 113.4 mL; $p = 0.001$), yet required significantly fewer vasopressor doses (0.12 ± 0.33 vs 0.34 ± 0.56; $p = 0.018$). Ni et al. reported a median fluid volume of 330 mL in the IVC group versus 345 mL in controls ($p = 0.030$) and vasopressor requirements of 11.9% versus 27.0% ($p = 0.036$) [Ni et al., 2022]. Renu et al. documented higher fluid volumes (2062 ± 222 vs 1838 ± 203 mL; $p < 0.001$) with lower vasopressor use (15% vs 42.5%; $p = 0.002$)[Renu et al., 2023]. Joshi et al., similarly demonstrated greater fluid administration (758.5 ± 304.3 vs. 525.5 ± 265.5 mL; $p = 0.001$) and reduced vasopressor incidence (20% vs 50%; $p = 0.002$) in the IVC group [Joshi et al., 2021] (Table 3).

Although the IVC-guided group received more fluid, the lower vasopressor requirement is clinically important: it minimizes vasopressor-related side effects such as arrhythmias and tissue ischaemia. Mephentermine usage was nearly threefold higher in the empirical group, consistent with Renu et al.'s findings. These results support integrating IVC ultrasonography into perioperative fluid management protocols, particularly for spinal anaesthesia in orthopaedic surgery.

CONCLUSION

Inferior vena cava ultrasound–guided fluid management before spinal anesthesia in lower limb orthopedic surgery significantly reduced the incidence of arterial hypotension, vasopressor requirements, and fluid boluses compared with empirical fluid administration. Preoperative noninvasive assessment of intravascular volume enabled individualized, goal-directed therapy that optimized fluid use and promoted hemodynamic stability without over- or under-resuscitation. Both strategies were safe, with no intervention-related adverse events, but IVC-guided management offered superior clinical utility by improving perioperative outcomes. Integration of this approach into routine anesthesia practice requires familiarity with ultrasound protocols but promises enhanced patient safety and more efficient fluid optimization.

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