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Ultrasound-Guided Evaluation of Volume Status: Comparing IVC Collapsibility and Caval Aorta Indices in Predicting Anesthesia-Induced Hypotension in Geriatric Surgical Patients"

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Abstract

Background: Elderly patients undergoing surgical procedures are at increased risk of perioperative hypotension due to age-related physiological changes and the effects of central neuraxial blockade (CNB). Accurate preoperative assessment of intravascular volume status is critical to predict and prevent hypotension. This study aimed to compare the efficacy of the inferior vena cava collapsibility index (IVCCI) and the IVC-to-aorta (IVC:Ao) index in predicting anesthesia-induced hypotension in geriatric surgical patients.

Materials and Methods: This prospective observational study was conducted in a tertiary care hospital from January 2021 to March 2022, including 45 elderly patients undergoing lower limb surgeries under CNB. Preoperative ultrasonographic measurements of maximum (dIVCmax) and minimum (dIVCmin) IVC diameters, abdominal aorta diameter, IVCCI, and IVC:Ao index were recorded. Hemodynamic parameters were monitored post-CNB. Hypotension was defined as systolic blood pressure (SBP) <90 mmHg, a ≥30% decrease in SBP from baseline, or mean arterial pressure (MAP) <60 mmHg. Receiver operating characteristic (ROC) curves were plotted to evaluate the predictive ability of IVCCI and IVC:Ao index.

Results:The mean preoperative d(IVC)max was significantly lower in the hypotensive group (1.15 ± 0.25 cm) compared to the normotensive group (1.32 ± 0.18 cm, $p = 0.01$). The IVC:Ao index showed a significant association with hypotension (mean: 0.49 ± 0.05 in hypotensive vs. 0.75 ± 0.03 in normotensive, $p < 0.001$) and demonstrated excellent predictive accuracy (AUC: 0.941, sensitivity: 88.9%, specificity: 81.1%). In contrast, IVCCI had limited predictive utility (AUC: 0.599, sensitivity: 55.6%, specificity: 62.2%). Other parameters, including d(Abdominal Aorta) and d(IVC)min, were not significantly associated with hypotension.

Conclusion: The IVC:Ao index is a superior predictor of anesthesia-induced hypotension in geriatric surgical patients compared to IVCCI. Its high sensitivity and specificity make it a valuable tool for preoperative risk stratification in elderly patients undergoing CNB.

Keywords- IVC collapsibility index, IVC-to-aorta index, anesthesia-induced hypotension, geriatric patients, central neuraxial blockade, ultrasonography.

INTRODUCTION

Elderly patients are at an increased risk of falls resulting in trauma to the hip and lower extremities, often requiring surgical intervention. This demographic frequently presents with comorbidities and age-related physiological and anatomical changes, posing challenges to anesthesia and surgical management. Neuraxial anesthesia is commonly preferred for these patients due to its favorable safety profile; however, perioperative hemodynamic instability, particularly hypotension, remains a significant concern. A prospective UK-based audit involving 11,085 hip surgeries identified perioperative blood pressure drops as a predictor of mortality within 5 and 30 days, irrespective of the type of anesthesia employed (1).

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Age-related factors such as occult blood loss from trauma, dehydration due to inadequate oral intake, diminished cardiac reserve, and an impaired compensatory response to hypovolemia contribute to an increased risk of hypotension in elderly surgical patients. These vulnerabilities are compounded by the effects of neuraxial blockade, which frequently induces bradycardia and hypotension, with a higher incidence in elderly individuals (2,3). Severe intraoperative hypotension has been associated with adverse postoperative outcomes, including myocardial infarction, stroke, acute kidney injury, prolonged hospital stay, and increased one-year mortality (4).

While volume preloading may mitigate hypotension, it carries the risk of volume overload and subsequent congestive heart failure in elderly patients with compromised cardiac function (5). Hence, accurate preoperative assessment of intravascular volume status is crucial in predicting and preventing hypotension following neuraxial blockade. Current methods for volume status evaluation include heart rate variability, passive leg raise test, perfusion index, inferior vena cava (IVC) diameter (dIVC), and the IVC collapsibility index (IVCCI) (6,7). Ultrasonographic measurement of the maximum and minimum IVC diameters during the respiratory cycle provides reliable and noninvasive parameters for assessing volume status in critical care and preoperative settings (5,8,9).

Although dIVC and IVCCI have shown promise as predictors of anesthesia-induced hypotension in younger populations, their utility in elderly patients remains unexplored. Variability in IVC dimensions across individuals due to factors such as age, body mass index, and body surface area, along with the influence of intrathoracic and intraabdominal pressures, poses challenges to establishing clear reference values (7). The recently proposed IVC-to-aorta (IVC:Ao) index may address these limitations, as it normalizes IVC measurements against the more stable aortic diameter. This ratio has been demonstrated to reliably assess volume status and predict hypotension after neuraxial anesthesia in younger patients (7,10,11).

Given the paucity of data on the elderly population, this prospective observational study aims to evaluate the efficacy of IVCCI and the IVC:Ao index as predictors of hypotension following central neuraxial blockade in geriatric surgical patients.

MATERIALS AND METHODS

Study Design and Setting:

This prospective observational study was conducted in the Orthopaedic OT, EMS OT, Surgery OT, and Plastic OT of a tertiary care hospital after obtaining approval from the Institutional Ethics Committee (IEC) and written informed consent from participating patients. The study spanned from January 2021 to March 2022.

Study Population:

The study included 45 elderly patients undergoing lower limb surgeries under regional anesthesia in the form of central neuraxial block (CNB). The inclusion criteria were all elderly patients scheduled for CNB during the study period. Exclusion criteria included:

1. Refusal to provide consent.
2. Administration of peripheral nerve block before CNB.
3. Patients receiving unilateral spinal anesthesia.
4. Failed spinal anesthesia requiring conversion to general anesthesia.
5. Use of angiotensin-converting enzyme (ACE) inhibitors or angiotensin receptor blockers for hypertension.

Preoperative and Intraoperative Protocol:

All patients underwent a detailed preanesthetic evaluation and routine investigations. Fasting periods were noted, and anesthesia procedures were conducted per the discretion of the attending anesthesiologist.

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Upon arrival in the operation theater, standard monitoring equipment was applied, and intravenous access was secured if not already present. Ringer lactate solution was administered as coloading at 10 mL/kg.

Neuraxial Block Technique:
Patients were positioned supine or lateral for CNB. If combined spinal-epidural anesthesia was planned, an epidural catheter (16/18G) was inserted at the L2-L3 or L3-L4 level, followed by spinal anesthesia using a 23/25G spinal needle. The choice of local anesthetic and dosage was at the discretion of the anesthesiologist. Post-CNB, patients were positioned supine for at least 30 minutes to fix the sensory blockade level, which was assessed using the pinprick method.

Ultrasonographic Evaluation:
Ultrasonographic measurements of the inferior vena cava (IVC) and abdominal aorta were performed using a curvilinear transducer (3.5–5 MHz) with a B-mode scan. The probe was placed in the subxiphoid region for a longitudinal view of the IVC and transverse view of the aorta.

- **IVC Measurements:**
  IVC measurements were taken approximately 3–4 cm distal to the right atrium and 1 cm distal to the IVC-hepatic vein junction. Doppler waveforms were used to confirm the IVC. The maximum (dIVCmax) and minimum (dIVCmin) anteroposterior IVC diameters during expiration and inspiration were recorded over the same respiratory cycle.

- **Aorta Measurements:**
  The abdominal aorta was visualized 10 mm above the celiac trunk. The maximum internal anteroposterior diameter during systole was measured.
  To ensure accuracy, three measurements were taken for each patient, and any variation >0.2 cm in the maximum IVC or aorta diameter resulted in the exclusion of the patient.

Monitoring and Data Collection:
Hemodynamic parameters, including heart rate, systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and oxygen saturation, were recorded every 2 minutes for the first 10 minutes post-CNB and then every 5 minutes for the next 30 minutes. Hypotension was defined as any of the following:

1. SBP <90 mmHg.
2. Decrease in SBP by ≥30% of baseline.
3. MAP <60 mmHg.

The anesthesiologists performing the CNB and monitoring the patients were blinded to the ultrasound measurements. Adverse events such as nausea, vomiting, discomfort, shivering, or allergic reactions were recorded and managed per protocol.

Statistical Analysis:
Data were analyzed using Microsoft Excel and SPSS software (version 27, Chicago, IL). Continuous variables were presented as mean ± standard deviation, and categorical variables were expressed as percentages. Proportions were compared using the Chi-square or Fisher's exact test. The Mann-Whitney U test was used to compare means. A p-value <0.05 was considered statistically significant.
Receiver operating characteristic (ROC) curves were plotted to determine the cutoff values for IVCCI and IVC:Ao indices, with the area under the curve (AUC) classified as follows:

- 0.9–1: Excellent predictor.
- 0.8–0.9: Good predictor.
- 0.7–0.8: Fair predictor.
- 0.6–0.7: Poor predictor.
- 0.5–0.6: Fails to predict.

Sample Size Estimation:

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The minimum sample size was estimated to be 30 patients to achieve an ROC with an AUC of 0.85, a significance level of 0.05, and a power of 95%. To enhance reliability and assess secondary objectives, the final sample size was set at 45 patients.
This methodology ensured a robust evaluation of the efficacy of IVCCI and IVC:Ao indices as predictors of anesthesia-induced hypotension in the geriatric population.

RESULTS

Patient Demographics and Baseline Characteristics

Among the 45 study participants, the majority were in the 60–69 years age group. The mean age was higher in the hypotensive group (69.89 ± 10.24 years) compared to the normotensive group (66.14 ± 5.15 years), but this difference was not statistically significant ($p = 0.061$). Gender distribution showed a higher proportion of males in the hypotensive group (66.67%) and females in the normotensive group (59.46%), with no significant association ($p = 0.690$).

Comorbidities such as diabetes mellitus (33.33%) and hypertension (33.33%) were more common among patients who developed hypotension. ASA class II and III were predominantly associated with hypotension, with 44.44% and 33.33% of patients, respectively.

Hemodynamic and Ultrasonographic Predictors of Hypotension

The mean preoperative d(IVC)max was significantly lower in the hypotensive group (1.15 ± 0.25 cm) compared to the normotensive group (1.32 ± 0.18 cm, $p = 0.01$). However, no significant difference was found in the preoperative d(IVC)min (0.65 ± 0.25 cm vs. 0.67 ± 0.15 cm, $p = 0.367$). The IVC:Ao index demonstrated a significant association with hypotension (mean: 0.49 ± 0.05 in hypotensive vs. 0.75 ± 0.03 in normotensive, $p < 0.001$), whereas the IVCCI values did not show a significant association (44.89 ± 12.56% vs. 47.92 ± 9.94%, $p = 0.22$).

Table 1: Hemodynamic and Ultrasonographic Parameters

Parameter	Hypotension (Mean ± SD)	Normotension (Mean ± SD)	p-Value
Age (years)	69.89 ± 10.24	66.14 ± 5.15	0.061
Preop d(IVC)max (cm)	1.15 ± 0.25	1.32 ± 0.18	0.01
Preop d(IVC)min (cm)	0.65 ± 0.25	0.67 ± 0.15	0.367
d(Abdominal Aorta) (cm)	1.84 ± 0.09	1.88 ± 0.13	0.223
IVCCI (%)	44.89 ± 12.56	47.92 ± 9.94	0.22
IVC:Ao Index	0.49 ± 0.05	0.75 ± 0.03	<0.001

Table 2: Receiver-Operating Characteristic (ROC) Curve Analysis

Parameter	Area Under Curve (AUC)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
IVC:Ao Index	0.941	88.9	81.1	53.3	96.8
Preop d(IVC)max (cm)	0.718	—	—	—	—
IVCCI (%)	0.599	55.6	62.2	26.3	85.2
Preop d(IVC)min (cm)	0.514	—	—	—	—
d(Abdominal Aorta) (cm)	0.607	—	—	—	—

The IVC:Ao index emerged as the most reliable predictor of hypotension with the highest AUC (0.941), sensitivity (88.9%), specificity (81.1%), and negative predictive value (96.8%). Preoperative d(IVC)max also demonstrated good predictive ability (AUC: 0.718). Other parameters, including IVCCI, d(Abdominal Aorta), and Preop d(IVC)min, had poor predictive value.

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DISCUSSION

This study investigated the utility of ultrasound-guided inferior vena cava collapsibility index (IVCCI) and IVC-to-aorta (IVC:Ao) index as predictors of anesthesia-induced hypotension in geriatric surgical patients undergoing central neuraxial blockade (CNB). The findings indicate that while both indices provide valuable insights into volume status, the IVC:Ao index outperformed IVCCI in predicting perioperative hypotension.

Elderly patients are particularly vulnerable to hypotension due to physiological changes such as reduced cardiac reserve, decreased adrenergic receptor sensitivity, and increased vagal tone (1,2). These changes are further exacerbated by the effects of CNB, which can induce bradycardia and vasodilation (3). Early identification of patients at risk of hypotension is crucial for optimizing perioperative management.
In this study, the IVC:Ao index demonstrated excellent predictive accuracy, with an area under the curve (AUC) of 0.941, sensitivity of 88.9%, and specificity of 81.1%. These findings are consistent with earlier research, which reported the IVC:Ao index as a reliable and non-invasive measure of volume status in younger populations (4,5). The advantage of the IVC:Ao index lies in its normalization of IVC dimensions against the aortic diameter, reducing variability caused by factors such as intrathoracic and intraabdominal pressures (6).

Conversely, the IVCCI showed limited predictive utility in this cohort, with an AUC of 0.599 and sensitivity of 55.6%. Previous studies have highlighted the IVCCI's susceptibility to variability due to individual differences in age, respiratory mechanics, and body habitus (7). These factors may explain the weaker association between IVCCI and hypotension in this geriatric population.

Preoperative d(IVC)max was significantly lower in hypotensive patients (1.15 ± 0.25 cm) compared to normotensive patients (1.32 ± 0.18 cm, $p = 0.01$), supporting its role as an additional predictor of hypotension. However, its predictive ability was inferior to the IVC:Ao index (AUC: 0.718). This aligns with findings by Salama et al., who demonstrated that preoperative IVC measurements are less reliable than combined indices in predicting anesthesia-induced hypotension (8).

While previous studies have largely focused on younger populations (9,10), the current study fills a critical gap by evaluating these indices in geriatric patients. The unique anatomical and physiological characteristics of elderly patients necessitate age-specific validation of predictive tools. However, this study's sample size of 45 patients is relatively small, and larger studies are needed to validate these findings and establish standardized thresholds for the IVC:Ao index in elderly populations.

A limitation of the IVC:Ao index is its dependency on accurate ultrasonographic measurements, which may vary based on operator experience. Training programs and standardized measurement protocols could mitigate this limitation and enhance its clinical applicability (11).

CONCLUSION

In conclusion, the IVC:Ao index is a superior predictor of anesthesia-induced hypotension compared to IVCCI in geriatric surgical patients. Its high sensitivity and specificity make it a valuable tool for preoperative risk stratification. Further large-scale studies are warranted to confirm these findings and refine the clinical use of these indices in the elderly.

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