CENTRAL VENOUS COLLAPSIBILITY: A NOVEL PREDICTOR OF POST- SPINAL HYPOTENSION SEVERITY

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ABSTRACT

Background: Post- spinal hypotension (PSH) is a common hemodynamic complication following spinal anesthesia and may compromise organ perfusion if not promptly identified and managed. Early prediction of patients at risk remains a key objective in perioperative care. Ultrasonographic assessment of venous collapsibility indices provides a non-invasive method for evaluating intravascular volume status. While the inferior vena cava collapsibility index (IVC CI) is widely used, its visualization may be limited in certain clinical situations. Alternative parameters such as internal jugular vein collapsibility index (IJV CI) and subclavian vein collapsibility index (SV CI) have been proposed as potential predictors.

Methods: This prospective observational study included 60 adult patients undergoing elective surgery under spinal anesthesia. Preoperative ultrasonographic measurements of IVC, IJV, and subclavian vein diameters were obtained to calculate their respective collapsibility indices. Hemodynamic parameters were recorded at baseline and at 5-minute intervals for 30 minutes following spinal anesthesia. PSH was defined as a reduction in mean arterial pressure >20% from baseline. Diagnostic performance was assessed using receiver operating characteristic (ROC) curve analysis, and correlations between indices were evaluated.

Results: IVC CI demonstrated the highest diagnostic performance, with an accuracy of 83.33% (AUC 0.91, sensitivity 76.47%, specificity 92.31%, p<0.0001). SV CI showed moderate predictive ability (accuracy 73.33%, AUC 0.74, sensitivity 76.47%, specificity 69.23%, p=0.001). In contrast, IJV CI showed poor diagnostic performance (accuracy 43.33%, AUC 0.40, sensitivity 55.88%, specificity 26.92%, p=0.194). Significant positive correlations were observed between IVC CI and IJV CI (r=0.332, p=0.009) and between IVC CI and SV CI (r=0.332, p=0.010).

Conclusion: IVC CI is a reliable and superior predictor of PSH. SV CI demonstrates moderate utility and may serve as an alternative when IVC visualization is limited, whereas IJV CI shows limited predictive value.

Keywords: Spinal anesthesia; Post-spinal hypotension; Ultrasonography; Inferior vena cava; Internal jugular vein; Subclavian vein; Hemodynamics

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INTRODUCTION

Spinal anesthesia is one of the most commonly used regional anesthetic techniques for surgeries involving the lower abdomen, pelvis, and lower limbs because it provides rapid onset of anesthesia, profound sensory blockade, and good muscle relaxation while avoiding airway manipulation associated with general anesthesia. Standard anesthesiology texts define spinal anesthesia as the injection of local anesthetic into the subarachnoid space, resulting in reversible blockade of spinal nerve conduction and sympathetic fibers. Depending on the level of blockade, this produces varying degrees of sympathetic, sensory, and motor inhibition [1].

Despite its advantages, spinal anesthesia is frequently associated with hemodynamic disturbances, most notably post-spinal hypotension (PSH). The primary physiological mechanism underlying PSH is sympathetic blockade, which causes vasodilation of both arterial and venous vessels. This leads to decreased systemic vascular resistance and pooling of blood in the venous capacitance system, resulting in reduced venous return and decreased cardiac output. As described in standard anesthetic physiology literature, blockade of sympathetic outflow from the thoracolumbar region results in reduced preload and cardiac output, ultimately causing a fall in arterial blood pressure following neuraxial blockade [2].

Post-spinal hypotension is considered one of the most common complications of spinal anesthesia. Clinically, PSH is commonly defined as a reduction in systolic blood pressure or mean arterial pressure greater than 20% from baseline values, typically occurring within the first 20–30 minutes following intrathecal injection of local anesthetic. The incidence of hypotension varies depending on patient population and surgical context, but studies have reported rates approaching 60–70% in certain groups. If not promptly recognized and managed, PSH may compromise perfusion of vital organs such as the brain, heart, and kidneys, leading to symptoms including dizziness, nausea, myocardial ischemia, or impaired renal perfusion [1,3].

Because of the high incidence and potential complications associated with PSH, early prediction and prevention are important goals in perioperative anesthesia practice. Conventional preventive measures include intravenous fluid loading, vasopressor administration, and continuous hemodynamic monitoring. However, these strategies may not completely prevent hypotension in all patients. Clinical guidance from anesthesia societies highlights that assessment of intravascular volume status before neuraxial blockade can help anticipate hemodynamic instability and guide individualized perioperative management [4].

Point-of-care ultrasonography has emerged as an important bedside tool for evaluating intravascular volume status and predicting fluid responsiveness. Ultrasound allows real-time visualization of large central veins and assessment of respiratory variations in venous diameter. One commonly used parameter is the inferior vena cava collapsibility index (IVC CI), which reflects respiratory changes in the diameter of the inferior vena cava and indirectly estimates central venous pressure and preload status. The collapsibility index is calculated by measuring the maximum diameter during expiration and the minimum diameter during inspiration and expressing the difference as a percentage of the maximum diameter. Greater collapsibility generally indicates lower intravascular volume and reduced venous return, which may predispose patients to hypotension following spinal anesthesia [5].

Although the inferior vena cava is commonly used to assess venous collapsibility, visualization of the IVC may be technically difficult in certain patients due to factors such as obesity, abdominal distension, bowel gas, or surgical positioning. In such situations, alternative venous structures including the internal jugular vein and subclavian vein can be assessed using ultrasound. These veins are more superficial and can be visualized easily using high-frequency linear probes, allowing measurement of their collapsibility indices as potential indicators of intravascular volume status.

Comparative evaluation of these venous collapsibility indices may therefore provide a better understanding of their usefulness in predicting post-spinal hypotension and guiding perioperative fluid management. In this context, the present study was designed to compare the diagnostic performance of internal jugular vein collapsibility index (IJV CI), subclavian vein collapsibility index (SV CI), and inferior vena cava collapsibility index (IVC CI) in predicting post-spinal hypotension. Additionally, the study also aimed to evaluate the correlation among these venous collapsibility indices to determine their relationship and potential clinical utility in patients undergoing surgery under spinal anesthesia.

Methodology

This prospective observational study was conducted over a period of 12 months at a tertiary care center in the Department of Anaesthesiology. Adult patients aged 18–65 years who were scheduled for elective surgeries under spinal anesthesia and classified as American Society of Anesthesiologists (ASA) physical status I or II were included in the study. Patients were evaluated in the supine position prior to the procedure. Individuals with contraindications to neuraxial anesthesia, failed spinal anesthesia, right ventricular dysfunction, or increased intra-abdominal pressure were excluded from the study. Preoperatively, all patients were kept nil per oral from midnight and underwent a detailed pre-anesthetic evaluation. Baseline hemodynamic parameters were recorded, including heart rate, non-invasive blood pressure, oxygen saturation using pulse oximetry, and three-lead electrocardiography (ECG).

Preoperative ultrasound assessment of venous collapsibility indices was performed using a Sonosite M-Turbo ultrasound machine. The internal jugular vein (IJV) and subclavian vein (SV) diameters were measured using a linear vascular transducer with a frequency range of 7–13 MHz, while the inferior vena cava (IVC) was assessed using a curvilinear probe with a frequency range of 1–5 MHz. For each vein, the maximum diameter during expiration and the minimum diameter during inspiration were measured over three respiratory cycles. The collapsibility index (CI) was calculated

using the formula:
Collapsibility Index (CI) = [(Maximum diameter − Minimum diameter) / Maximum diameter] × 100.
For measurement of the inferior vena cava collapsibility index (IVC CI), the probe was placed in the subcostal long-axis view approximately 2–3 cm distal to the right atrium. The internal jugular vein collapsibility index (IJV CI) was measured using a linear transducer positioned approximately 2 cm above the right sternoclavicular joint in the transverse plane of the neck. The subclavian vein collapsibility index (SV CI) was measured using the linear probe placed infraclavicularly to visualize the right subclavian vein.
Following ultrasound evaluation, spinal anesthesia was administered in the L2–L3 or L3–L4 intervertebral space using a 25-gauge spinal needle after confirmation of free flow of cerebrospinal fluid. A dose of 15 mg of 0.5% hyperbaric bupivacaine was injected intrathecally. Patients received co-loading with Ringer lactate solution at approximately 10–12 mL/kg over 15 minutes. Surgery was initiated after achieving a sensory block level up to T6. Hemodynamic parameters including heart rate and mean arterial pressure (MAP) were monitored every three minutes for the first 15–30 minutes following spinal anesthesia. Hypotension was defined as a decrease in MAP greater than 20% from baseline or MAP below 65 mmHg, and bradycardia was defined as a heart rate less than 60 beats per minute. Hypotension was treated with intravenous ephedrine, and bradycardia was managed with atropine according to the institutional protocol.
For statistical analysis, continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Student's t-test or Wilcoxon signed-rank test was used for comparison of paired variables where appropriate. Receiver operating characteristic (ROC) curve analysis was performed to determine the area under the curve (AUC) for each collapsibility index. Diagnostic parameters including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, and optimal cut-off values were calculated for IVC CI, IJV CI, and SV CI in predicting post-spinal hypotension.

Results:

A total of 60 patients undergoing elective surgery under spinal anesthesia were included in the study and were categorized into hypotensive (H) and non-hypotensive (NH) groups based on the occurrence of post-spinal hypotension. Demographic characteristics, hemodynamic parameters, and the diagnostic performance of venous collapsibility indices were analyzed and compared between the two groups.

S**ample demographics:**

GROUP	**H**	**NH**	**P-value**
AGE (mean ±SD)	41.97 ±15.09	42.23 ±15.55	0.948
GENDER(F/M)	15/19	12/14	0.875

Table.1 shows there is no significant age and gender difference between hypotensive and non-hypotensive groups

Key hemodynamic data: (H vs NH, mean ± SD, p-values for sample points)(Table.2):
Table.2 (Key hemodynamic data)

MAP	GROUP				P value
	H		NH		
	Mean	Standard Deviation	Mean	Standard Deviation	
Baseline	95.68	16.04	100.27	10.92	0.215
Prespinal	99.18	13.78	99.58	10.24	0.902
After 5 mins	74.88	17.39	97.85	12.07	<0.0001
After 10 mins	79.68	10.65	93.62	10.99	<0.0001
After 15 mins	88.24	10.28	97.27	10.74	0.002

After 20mins	85.94	10.76	95.62	12.20	0.002
After 25mins	87.91	9.10	98.12	10.56	<0.0001
After 30 mins	86.38	8.00	96.50	11.36	<0.0001

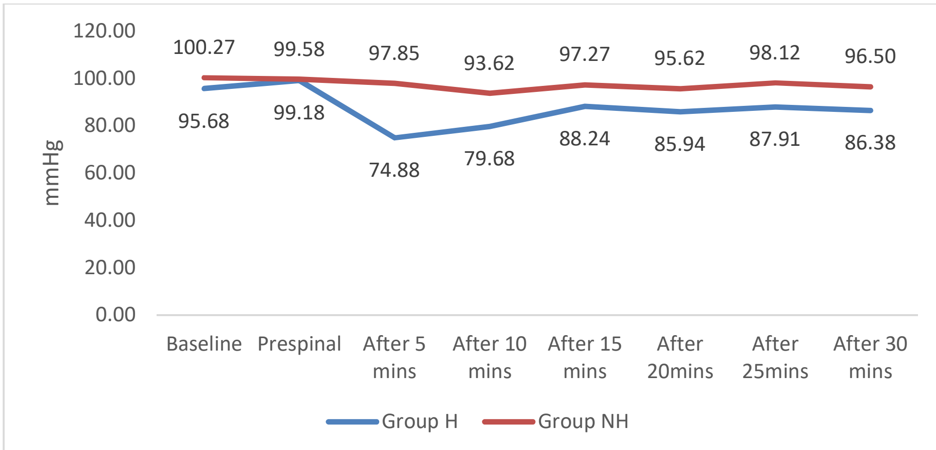

Fig.1 (MAP mmHg at various time intervals in group H and NH)

MAP: Statistically significant lower values in H group after spinal anesthesia at all time points, $p < 0.05$.(Fig.1)

Collapsibility Index Diagnostic Performance:

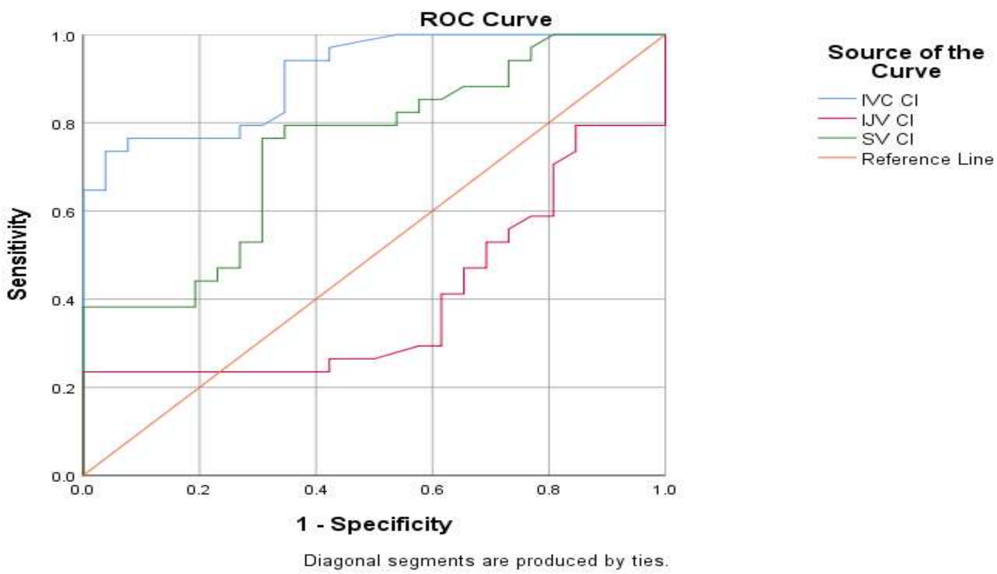

Fig.2 (Receiver operating curve)

INDEX	CUT-OFF	AUC	p-value	Sensitivity	Specificity	PPV	NPV	Accuracy
IVC CI	0.26	0.91	<0.0001	76.47%	92.31%	92.86%	75.00%	83.33%
IJV CI	0.28	0.40	0.194	55.88%	26.92%	50.00%	31.82%	43.33%

SV CI	0.24	0.74	0.001	76.47%	69.23%	76.47%	69.23%	73.33%

Table.3 (Collapsibility Index Diagnostic Performance)

IVC CI showed highest accuracy with an AUC of 0.91, sensitivity 76.47%, specificity 92.31%, and accuracy 83.33%.
SV CI had moderate diagnostic value with AUC 0.74, sensitivity 76.47%, specificity 69.23%, accuracy 73.33%.
IJV CI performed poorly with AUC 0.40 and low specificity (26.92%), sensitivity (55.88%), accuracy 43.33%.
IVC CI is the most effective predictor, SV CI is moderately useful, and IJV CI provides minimal diagnostic value for hypotension prediction(Fig.2, Table.3).

Index	Cut-off	Sensitivity	Specificity	Youden_Index
IVC CI	0.26	0.765	0.923	0.688
IJV CI	0.28	0.735	0.192	-0.073
SV CI	0.24	0.765	0.692	0.457

Table.4 (Youden index)

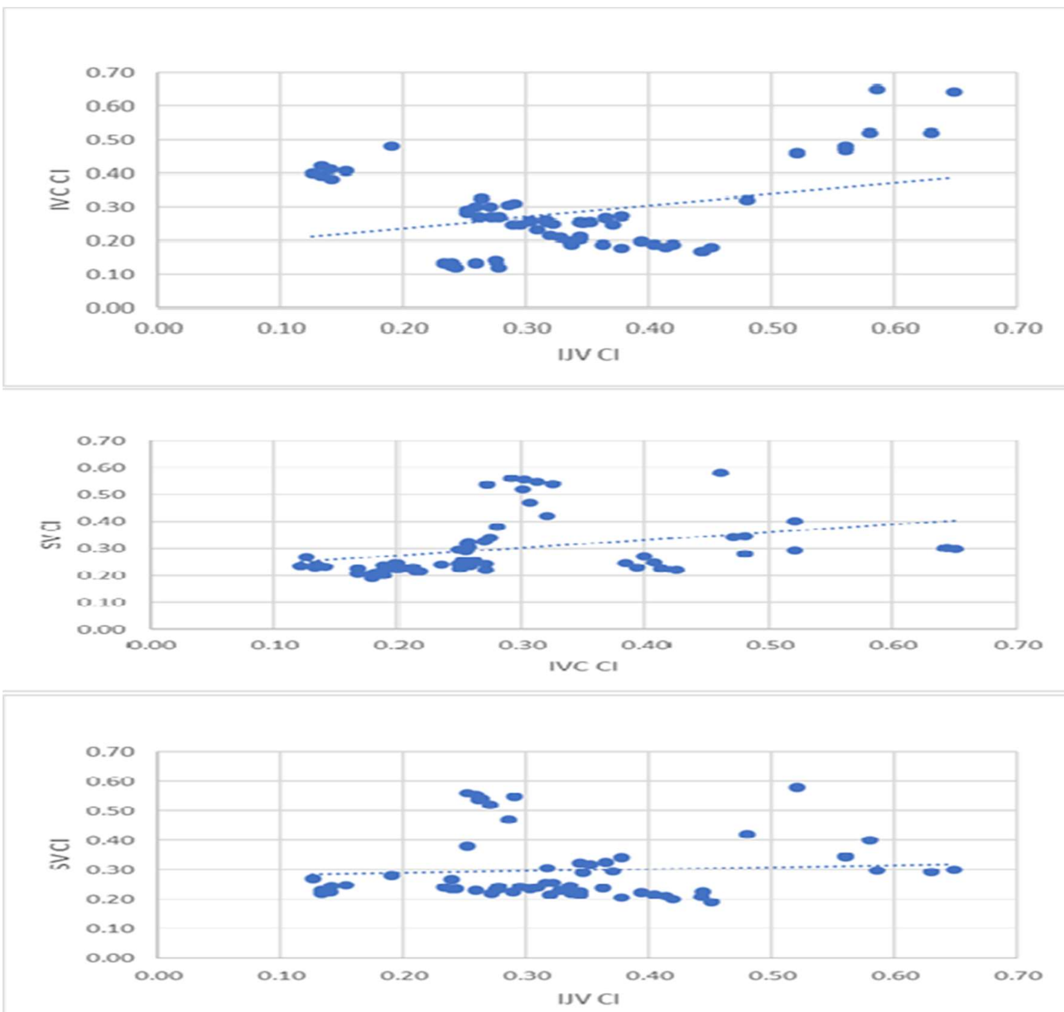

Fig.3 (scatter diagram between IJV CI and IVC CI / SV CI and IVC CI/ SV CI and IJV CI)

The scatter diagrams displayed represent the relationships between various collapsibility indices: IVC CI (Inferior Vena Cava), SV CI (Subclavian Vein), and IJV CI (Internal Jugular Vein) (Fig.3).
Stronger correlation exists between SV CI and IVC CI, and a weaker one between IJV CI and both SV CI and IVC CI.

These results suggest that IVC CI and SV CI could be more closely related physiologically, while IJV CI behaves more independently.

Correlation Analysis

		IVC CI	IJV CI	SV CI
IVC CI	Pearson Correlation	1	0.332**	0.332**
	P value		0.009	0.010
IJV CI	Pearson Correlation	0.332**	1	0.080
	P value	0.009		0.543
SV CI	Pearson Correlation	0.332**	0.080	1
	P value	0.010	0.543	
	n	60	60	60

Table 5. Correlation Analysis demonstrates that IVC CI exhibits a statistically significant weak-to-moderate positive correlation with both IJV CI ($r = 0.332$, $p = 0.009$) and SV CI ($r = 0.332$, $p = 0.010$).

In contrast, no statistically significant correlation was observed between IJV CI and SV CI ($r = 0.080$, $p = 0.543$). This pattern suggests that IVC CI maintains consistent relationships with both peripheral venous indices, whereas the lack of association between IJV CI and SV CI reflects variability in peripheral venous collapsibility. Furthermore, despite similar correlation coefficients, SV CI demonstrated superior diagnostic performance compared to IJV CI, indicating that correlation alone does not determine clinical reliability. Overall, these findings reinforce the role of IVC CI as the most physiologically representative and clinically reliable parameter for assessing intravascular volume status.

Discussion:

The present study demonstrates that the inferior vena cava collapsibility index (IVC CI) is the most reliable predictor of post-spinal hypotension, exhibiting excellent diagnostic performance with an area under the curve (AUC) of 0.91, sensitivity of 76.47%, specificity of 92.31%, and overall accuracy of 83.33%. In comparison, the subclavian vein collapsibility index (SV CI) showed moderate predictive ability (AUC 0.74, sensitivity 76.47%, specificity 69.23%, accuracy 73.33%), whereas the internal jugular vein collapsibility index (IJV CI) demonstrated poor diagnostic performance (AUC 0.40, sensitivity 55.88%, specificity 26.92%, accuracy 43.33%). These findings establish a clear and clinically meaningful hierarchy, with IVC CI outperforming SV CI, and SV CI outperforming IJV CI, indicating that central venous assessment is superior to peripheral venous indices in predicting hemodynamic instability.

This hierarchy is consistently supported by existing literature. Elbadry and Sabaa [6] reported that IVC CI predicted post-spinal hypotension with sensitivity of 84.6% and specificity of 93.1%, compared to IJV CI which showed lower sensitivity (76.9%) and specificity (81.8%). When compared to our findings, the specificity of IVC CI (92.31%) is nearly identical, while the sensitivity (76.47%) is slightly lower but within a comparable range. Importantly, our study demonstrates markedly reduced specificity for IJV CI (26.92%), highlighting greater variability and reduced reliability of jugular measurements outside obstetric populations.

The moderate predictive role of SV CI observed in our study is also supported by Kumar et al. [7], who reported sensitivity of approximately 72% and specificity of 78% for subclavian vein collapsibility. In our study, SV CI demonstrated comparable sensitivity (76.47%) but slightly lower specificity (69.23%), indicating that while SV CI retains acceptable predictive capability, it is less specific than IVC CI. This reinforces its role as a secondary or alternative parameter rather than a primary predictor.

Further evidence supporting the robustness of IVC CI is provided by Ni et al. [8], who reported significantly higher IVC collapsibility values in hypotensive patients (46% ± 10%) compared to normotensive individuals (28% ± 9%), with an AUC of 0.88. This closely parallels our findings (AUC 0.91), confirming the strong discriminatory ability of IVC CI across different patient populations. The consistency of high AUC values across studies highlights the stability and reproducibility of IVC-based measurements.

The clinical applicability of subclavian vein assessment is further supported by Lu et al. [9], who demonstrated that ultrasound-guided fluid management using subclavian vein parameters reduced the incidence of hypotension from approximately 50% to 25%. This aligns with our findings of moderate predictive performance (AUC 0.74), suggesting that SV CI can be effectively used when IVC visualization is limited, although it does not match the accuracy of IVC CI.

Choi et al. [10] reported AUC values of approximately 0.82 for subclavian venous indices, which is higher than the AUC observed in our study (0.74), but still falls within the range of moderate diagnostic performance. Similarly, Mahendran et al. [11] reported sensitivity of approximately 75% and specificity of 80%, closely matching the sensitivity observed in our study (76.47%), although our specificity was slightly lower. These findings collectively suggest that SV CI demonstrates consistent moderate performance across studies, though variability in specificity may be influenced by patient factors and measurement techniques.

The superiority of IVC CI over IJV CI is further reinforced by Khaled et al. [12], who reported AUC values of 0.87 for IVC CI and 0.69 for IJV CI. In our study, this difference was even more pronounced (AUC 0.91 vs 0.40), indicating a substantial reduction in the predictive reliability of IJV CI. This discrepancy highlights the limitations of jugular vein assessment, particularly in non-obstetric populations, where external compression, anatomical variability, and respiratory influences may affect measurement accuracy.

Strong collective evidence further supports the diagnostic value of IVC CI. Chang et al. [13], in a systematic review and meta-analysis, reported pooled sensitivity of 77% and specificity of 82%, which closely align with our findings (76.47% and 92.31%). Similarly, Chowdhury et al. [14] reported sensitivity of 74% and specificity of 83%, while Liu et al. [15] demonstrated AUC values around 0.86. The close agreement between these studies and our results confirms that IVC CI consistently demonstrates high diagnostic accuracy across different clinical settings and patient populations.

Conclusion:

Overall, the present study findings are strongly supported by existing evidence, demonstrating that IVC CI provides the highest and most consistent diagnostic accuracy for predicting post-spinal hypotension. SV CI shows moderate but clinically useful predictive value and may serve as a practical alternative when IVC imaging is not feasible. In contrast, IJV CI demonstrates limited and inconsistent performance, making it less reliable for routine clinical use. These findings reinforce the importance of prioritizing central venous assessment, particularly IVC CI, for accurate evaluation of intravascular volume status and early identification of patients at risk of hypotension following spinal anesthesia.

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