Original Article

Efficacy of inferior vena cava collapsibility index and caval aorta index in predicting the incidence of hypotension after spinal anaesthesia- A prospective, blinded, observational study

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ABSTRACT

Background and Aim: Spinal anaesthesia-induced hypotension (SAIH) is a frequent side effect of spinal anaesthesia. SAIH is usually observed in patients with hypovolemia. Ultrasonography has evolved as a non-invasive tool for volume status assessment. **Methods:** This prospective, blinded, observational study was conducted on 75 adult patients who required spinal anaesthesia after receiving ethical approval and registering the study. Ultrasonographic evaluation of the aorta and the inferior vena cava (IVC) was done preoperatively, and the IVC collapsibility index (IVCCI) and caval aorta index were calculated. The incidence of SAIH was recorded. The strength of the association between different parameters and SAIH was calculated. To find out the value of the optimal cut-off for the prediction of SAIH, receiver operating characteristic (ROC) analysis for various ultrasound parameters was done. The bidirectional stepwise selection was utilised for multivariate analysis to choose the single best predictor. **Results:** SAIH was observed in 36 patients. Among demographic parameters, age, female gender, and height showed a medium correlation. Among ultrasonographic measurements, minimum IVC internal diameter (IVC_{min}) and IVCCI showed a strong association with SAIH. The best parameter regarding area under the ROC curve (AUC) and diagnostic accuracy was IVCCI (0.828 and 85%, respectively). On multivariate analysis, age (95% CI [1.01, 1.12], $P = 0.024$) and IVCCI (95% CI [1.05, 1.18], $P < 0.001$) were significant independent predictors. At a cut-off point of ≥43.5%, IVCCI accurately predicted SAIH (sensitivity 81% and specificity 90%). **Conclusion:** Preoperative ultrasonographic assessment of IVC to evaluate its collapsibility index is a convenient, cost-effective, and reproducible tool for predicting SAIH.

Key words: Aorta, collapsibility index, hypotension, hypovolemia, inferior vena cava, ultrasonography, vena cava, spinal anaesthesia-induced hypotension

INTRODUCTION

Spinal anaesthesia–induced hypotension (SAIH) is a frequent side effect of spinal anaesthesia (SA). It occurs due to the combined effect of the sympathetic block and paradoxical activation of cardioinhibitory receptors.[1] SAIH is more common in patients with hypovolemia. Pre-loading or co-loading with crystalloid or colloid to optimise the intravascular volume has shown variable results.[2] Empirical volume loading to prevent SAIH only temporarily increases the cardiac

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output by increasing the pre-load, which may not always prevent spinal hypotension.[3] Therefore, blind volume loading to prevent SAIH is not routinely done in non-obstetric patients.[4]

Previously, invasive devices such as central venous and pulmonary artery catheters were considered helpful for volume status assessment. Several less-invasive techniques, like arterial waveform analysis, have been recently introduced, but they need more standardisation and reliability.[5] Ultrasonography (USG)-guided measurement of inferior vena cava (IVC) diameters and IVC collapsibility index (IVCCI) are reliable indicators of intravascular volume status and of clinical response to volume resuscitation with a sensitivity and specificity of 0.75 and 0.83, respectively in predicting the fluid responsiveness.[6]

The IVC diameter not only vary with respiration, but the initial reference diameter of the IVC (maximum IVC diameter [IVC_{max}]) also affects it. To overcome it, the IVC_{max}-to-IVCCI ratio that combines static (IVC_{max}) and dynamic components (IVCCI) was studied and was found to be a better predictor of intravascular volume.[7,8] Likewise, the caval aorta index (IVC/Ao) compares the maximum diameter of the IVC with the abdominal aorta (Ao), which is independent of intravascular fluid status. It correlates with body surface area (BSA) and has been studied by a few researchers to predict SAIH.[9] At a cut-off point of less than 1.2, the caval aorta index was found to have a sensitivity and specificity of 96% and 88%, respectively, to predict SAIH.[9] But the literature on these new predictors is limited, and results are conflicting for IVCCI to predict SAIH.

Hence, we planned the present study primarily to assess the correlation of the IVCCI and the caval aorta index with SAIH. Additionally, the correlations of SAIH with other demographic factors and ultrasonographic indices were also studied. Finally, multiple regression analysis was done to find the most helpful variable associated with SAIH.

METHODS

This prospective, blinded, observational study was conducted in a tertiary care hospital after obtaining approval from the institutional ethics committee (PGIMS/UHS biomedical research ethics committee vide approval number IEC/Th/19/Anst01 dated 30.12.2019) and after registering the trial with the Clinical Trials Registry-India (http://www.ctri.nic.in vide registration number CTRI/2021/08/036004). The 2013 Helsinki Declaration was followed in the study's execution. Written and informed consent was obtained from all the patients for their participation in the study after explaining the study protocol and for the use of patient data for research and educational purposes. This study included patients of either sex, age 18–65 years, with American Society of Anesthesiologists (ASA) physical status I or II and who were scheduled for elective surgery under SA in a supine position. Restriction in inclusion criteria was used to avoid factors associated with SAIH, like ASA III/IV, elderly and pregnant patients. The study did not include patients with hypertension, increased intraabdominal pressure, body mass index (BMI) greater than 30 kg/m^2, undergoing unilateral SA, and pregnant women. If, after recruiting, the level of anaesthesia achieved was above T5, then that patient was excluded from the analysis. All patients were fasting as per standard protocol (6 h for solids and 2 h for clear liquids).

An anaesthesiologist with more than 5 years of experience in perioperative USG performed the assessments in the preoperative room and was not involved in further patient management. All observations were made in the supine position using Sonosite M-Turbo (Sonosite Corp. Bothell, WA, USA) ultrasound machine with a curvilinear (3.5–5 MHz) transducer in a B-mode scan. For scanning, the transducer was kept longitudinally in the subxiphoid region. Measurements were taken by applying M-mode on IVC lateral to the IVC hepatic vein junction. In M-mode, measurements of IVC internal anteroposterior diameter, which is maximum during expiration (IVC_{max}) and minimum during inspiration (IVC_{min}), were taken in one respiratory cycle [Figure 1]. The Ao was identified on the left side of the IVC, approximately 1cm above the celiac trunk, and its maximum internal diameter at systole was recorded. The IVCCI was calculated using the formula: IVCCI = $[(IVC_{max} - IVC_{min})/IVC\ max] \times 100$. The caval aorta index was derived using the IVC_{max} and Ao diameter ratio.

Standard monitoring was applied in the operating theatre, and an 18-gauge cannula was secured in a peripheral vein. Baseline heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP) and mean arterial pressure (MAP), were recorded before administering SA. No fluid pre-loading was done, and

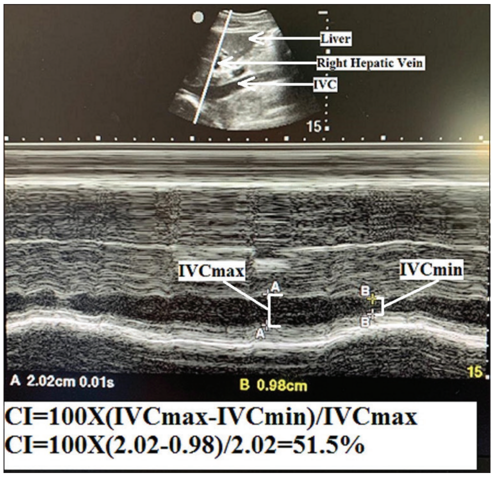

Figure 1: M-mode measurement of the inferior vena cava (IVC = inferior vena cava, IVC_{max} = maximum IVC diameter at expiration, IVC_{min} = minimum diameter at inspiration over the same respiratory cycle, CI = collapsibility index)

the infusion of Ringer's lactate solution at a rate of 10ml/kg/h was started only after the administration of SA. SA was administered in a sitting position at L3–L4 or L4–L5 intervertebral space. A dose of 2.8 ml (14 mg) of 0.5% hyperbaric bupivacaine was injected through a 25-gauge needle (Quincke) to achieve spinal blockade below T5. Patients were kept supine after SA and remained supine throughout the study period (1h). The pinprick test was used to evaluate the level of sensory blockade. The non-invasive blood pressure NIBP, HR, and oxygen saturation were recorded every minute for 5 min and then every 5 min until 60 min since the administration subarachnoid block had passed. SAIH was defined as a decrease in SBP by more than 20% of the baseline value or an absolute value of SBP less than 90 mmHg or MAP less than 60 mmHg. Any episode of hypotension was noted and managed with a bolus of 3mg intravenous mephentermine to keep BP within 20% of baseline. Any complications, like bradycardia and nausea or vomiting, were noted and managed accordingly.

The sample size was calculated based on a study that recorded 84%–96% sensitivity of IVCCI and caval aorta index in predicting SAIH in patients undergoing elective surgery.[9] Therefore, assuming a sensitivity of 90% and a margin of error of 7%, the minimum required sample size at a significance level of 5% was 71 patients. Our study included 75 patients in total.

Continuous variables are presented as mean ± SD or median and interquartile range (IQR) and were compared using a *t*-test or the Wilcoxon–Mann–Whitney test. Categorical variables are expressed as frequencies and percentages and were compared using Pearson's Chi-squared test. The strength of association between different parameters (demographic and ultrasonographic indices) and SAIH was calculated using the point-biserial correlation coefficient or bias correction for Cramér's V test. Receiver operating characteristic (ROC) analysis was done to find the optimal cut-off value and predictive accuracy of various ultrasound parameters. The area under the ROC curve (AUC), 95% confidence interval (95% CI), and the diagnostic accuracy in assessing SAIH were recorded for all predictors. All the factors known to affect SAIH, like age, gender, BMI, baseline MAP, IVCCI, and caval aorta index, were included in the final multivariable predictive model for finding the most useful dependent variable. A P value less than 0.05 was considered a significant difference for all statistical tests.

RESULTS

Patient flow for the study as per Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement has been incorporated in Figure 2. The baseline demographic and ultrasonographic parameters of the study population ($n = 75$) and patients with SAIH ($n = 36$) and without SAIH ($n = 39$) are depicted in Tables 1 and 2.

There was a significant difference in IVCCI (mean ± SD) between the groups ($P = 0.001$), with IVCCI being higher (50.22 ± 15.51%) in the SAIH group compared to the normotensive group (35.23 ± 9.00%). The overall caval aorta index (mean ± SD) was 0.97 ± 0.18, and the difference between the groups was insignificant [Table 2]. We found that more patients belonged to ASA physical status II (16 vs 8 patients) in the SAIH group. Patients with SAIH were older (44.19 ± 14.80 vs 35.15 ± 12.27 years; $P = 0.006$). SAIH was more commonly seen in women (13/17women vs 23/58 men; $P = 0.008$). Patients with SAIH were slightly shorter in height than patients without SAIH (163.82 ± 8.31 vs 167.66 ± 7.30 cm; $P = 0.038$) [Table 1].

ROC curves were constructed for IVC_{max}, IVC_{min}, IVCCI (%), aorta diameter, and caval aorta index to predict SAIH [Figure 3]. The area AUC 95% CI, best cut-off, sensitivity, and specificity for different parameters to predict SAIH are depicted in Table 3. The best parameter regarding AUC and diagnostic accuracy was IVCCI (%). Multivariate logistic regression

Table 1: Demographic variables of the study population

Variables	Study population (*n*=75)	With SAIH (*n*=36)	Without SAIH (*n*=39)	*P*
Age (years)	39.49±14.20	44.19±14.80	35.15±12.27	0.006
Sex (M:F, *n*)	58:17	23:13	35:4	0.008
Weight (kg)	64.41±8.83	62.78±7.90	65.92±9.47	0.122
Height (cm)	165.81±7.99	163.82±8.31	167.66±7.30	0.038
BMI (kg/m^2)	23.29±2.96	23.10±2.92	23.46±3.03	0.598
ASA I:II (*n*)	51:24	20:16	31:8	0.026
Ortho: GS: Uro (*n*)	45:26:4	19:14:3	26:12:1	0.334
L3–4:L4–5 IVS (*n*)	50:25	28:8	22:17	0.050

SAIH=spinal anaesthesia–induced hypotension; *n*=number of patients; M=male; F=female; BMI=body mass index; ASA=American Society of Anesthesiologists; Ortho=orthopaedics; GS=general surgery; Uro=urosurgery; L3–4;IVS=lumber intervertebral space, Standard Deviation. Data presented as Mean±SD or Number

Table 2: Ultrasonographic parameters of the study population

Variable	Total (*n*=75)	With SAIH (*n*=36)	Without SAIH (*n*=39)	Test	*P*	95% CI of difference of mean	Strength of association	
							Test	Effect size
IVC_{max} (cm)	1.45±0.25	1.45±0.25	1.44±0.25	*t*-test	0.811	−0.13, 0.11	Point BC	0.03
IVC_{min} (cm)	0.84±0.26	0.73±0.25	0.93±0.23	W	<0.001	0.09, 0.31	Point BC	0.39
IVCCI (%)	42.42±14.57	50.22±15.51	35.23±9.00	W	<0.001	−20.89, −9.09	Point BC	0.52
Aorta diameter (cm)	1.49±0.25	1.53±0.25	1.45±0.25	*t*-test	0.182	−0.2,0.04	Point BC	0.16
Caval aorta index	0.97±0.18	0.94±0.17	1.00±0.19	*t*-test	0.131	−0.02, 0.14	Point BC	0.18

SAIH=spinal anaesthesia–induced hypotension; *n*=number of patients; IVC_{max}=maximum inferior vena cava diameter on expiration, IVC_{min}=minimum inferior vena cava diameter on inspiration, IVCCI=inferior vena cava collapsibility index; W=Wilcoxon–Mann–Whitney test; Point BC=point-biserial correlation coefficient; CI=confidence interval, Standard Deviation. Data presented as Mean±SD or Number

Table 3: Comparison of the diagnostic performance of various predictors

Predictor	Cut-off	AUC	95% CI	*P*	Sn	Sp	PPV	NPV	DA
IVC_{max}	1.27 cm	0.527	0.394,0.66	0.695	86%	28%	52%	69%	56%
IVC_{min}	0.73 cm	0.752	0.64, 0.865	<0.001	67%	82%	77%	73%	75%
IVCCI	43.5%	0.828	0.72,0.936	<0.001	81%	90%	88%	83%	85%
Aorta diameter	1.48cm	0.571	0.439,0.703	0.293	56%	64%	59%	61%	60%
Caval aorta index	0.98	0.635	0.506,0.764	0.045	75%	62%	64%	73%	68%

AUC=area under the receiver operating characteristic curve; CI=confidence interval; *P*=*P* value; Sn=sensitivity; Sp=specificity; PPV=positive predictive value; NPV=negative predictive value; DA=diagnostic accuracy, IVC_{max}=maximum inferior vena cava diameter on expiration, IVC_{min}=minimum inferior vena cava diameter on inspiration, IVCCI=inferior vena cava collapsibility index

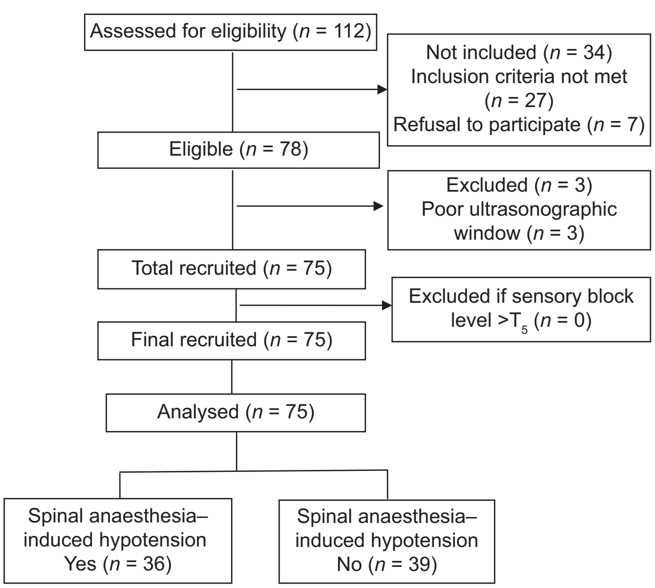

Figure 2: Patient flow for the study as per Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement

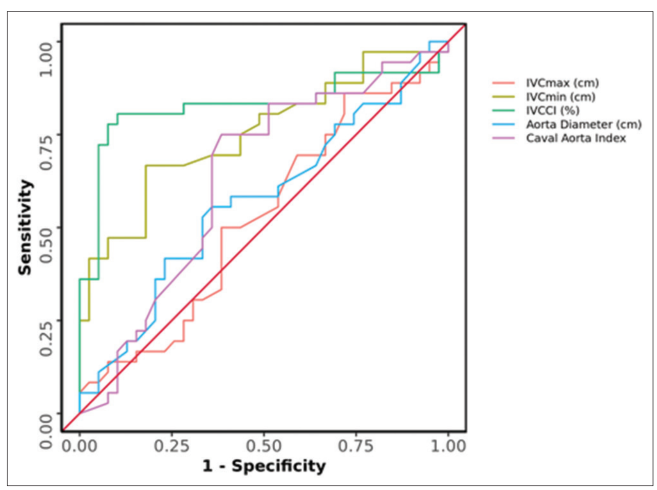

Figure 3: ROC curves of USG parameters to predict post-spinal hypotension (ROC = receiver operating characteristic, USG = ultrasonography, IVCmax = maximum inferior vena cava diameter on expiration, IVCmin = minimum inferior vena cava diameter on inspiration, IVCCI = inferior vena cava collapsibility index)

analysis was done to find the most significant predictors of SAIH [Table 4]. We observed that IVCCI was the most significant predictor of SAIH (95% CI [1.05, 1.18], $P < 0.001$), whereas age and BMI were

Table 4: Multivariable regression analysis for a most helpful predictor of post-spinal anaesthesia hypotension

Variable	Univariate			Multivariate		
	Odd ratio	95% Confidence interval	*P*	Odd ratio	95% Confidence interval	*P*
Age (years)	1.05	1.01, 1.09	0.007	1.06	1.01, 1.12	0.024
Gender (female)	4.95	1.54, 19.30	0.011	3.08	0.56, 19.24	0.203
BMI (kg/m²)	0.96	0.82, 1.12	0.593	0.78	0.60, 0.97	0.038
IVCCI (%)	1.10	1.05, 1.16	<0.001	1.10	1.05,1.18	0.001
Caval aorta index	0.13	0.01, 1.74	0.136	0.08	0.00,2.24	0.151
MAP (mmHg; baseline)	1.05	0.99, 1.10	0.092	1.06	0.99,1.17	0.136

MAP=mean arterial pressure, IVCCI=inferior vena cava collapsibility index, BMI=body mass index

the least significant predictors (*P* = 0.024 and 0.038, respectively). Gender, baseline MAP, and caval aorta index were not good predictors. None of the patients experienced complications like nausea, vomiting, and any episode of bradycardia or desaturation.

DISCUSSION

In the present study, we observed that IVCCI had a good diagnostic performance in predicting hypotension with an AUC of 0.828 at a cut-off of ≥43.5%, a sensitivity of 81%, and a specificity of 90% in spontaneously breathing patients. We found a lower mean caval aorta index in the SAIH group compared to the normotensive group (0.94 ± 0.17 vs 1.00 ± 0.19), but the difference was statistically insignificant (*P* = 0.131). Even though we found a medium degree of association of SAIH with age, female gender, and shorter height, on multiple regression, age, BMI, and IVCCI were the predictors of SAIH, with IVCCI being the strongest.

Hypotension is a common side effect of SA, often necessitating early and prompt treatment.[2] The incidence of SAIH was 48.0% in our study. However, the incidence has varied in different studies.[7–11] This variation may be due to the difference in the definition of hypotension and the variable amount of intravenous fluid administered during SA.

SAIH occurs due to a relative decrease in arterial resistance and intravascular volume. To prevent SAIH, co-loading or pre-loading with crystalloid or colloid are equally effective, but none of the methods can stop SAIH solely; a vasopressor is usually required to maintain arterial resistance.[2] Various authors have used IVCCI—a dynamic measure of intravascular fluid assessment—and guided fluid administration to prevent SAIH, eliciting a favourable response.[12–14] But results are conflicting regarding the predictive ability of IVCCI to predict fluid responsiveness in spontaneously breathing or mechanically ventilated patients.[7,8,15,16] Similar to our results, Salama *et al*.[9] and Ni *et al*.[11] found IVCCI to be a significant predictor of SAIH. Contrarily, Mačiulienė *et al*.[17] found that IVCCI did not predict SAIH in spontaneously breathing patients. A decrease in arterial resistance—not a fall in intravascular volume—was the primary mechanism for SAIH in their study. They allowed patients to drink until 2h before surgery, the patient's one leg was kept bent after SA, which increased the venous return, and intravenous fluid was started before SA. Similarly, in a study by Jaremko *et al*.,[10] IVCCI was ineffective in predicting SAIH as measurements were performed with the patient's one leg bent, and IVCCI before SA was not high (33% and 35% in both groups). In another observational study, IVCCI was found to have poor diagnostic accuracy in predicting SAIH in adult patients undergoing elective infra-umbilical surgery.[7] The differing results could be due to the use of co-loading that might have prevented hypovolemic patients from developing SAIH and included about 30% of patients aged 60 years and older in that study.[7]

IVCCI is a valuable and early detector of increased intravascular volume; age, BMI, and baseline CI influence its values.[18] To minimise the effect of these variables and change in the IVC relative position with respiration on IVC diameter and IVCCI, some researchers studied the ratio of IVC_{max} to IVCCI or the caval aorta index to improve predictive accuracy for SAIH. In the present study, we also measured the caval aorta index. The caval aorta index was found to have poor diagnostic performance (68%) in predicting hypotension [Figure 3, Table 3]. Contrary to our results, Salama *et al*.[9] A significantly lower caval aorta index (<1.2) was observed in patients who developed SAIH, and the caval aorta index had higher sensitivity and specificity than IVCCI for predicting SAIH.

Preoperative fluid status, comorbidities, preoperative medication, fasting group, and the patient's physical status—all contribute to the development of SAIH.[19] In our study, patients in SAIH group were older [Table 1]. We also found on multiple regression analysis that age is significant predictor of SAIH [Table 4]. Similarly, Salama *et al*.[9] found a statistically significant difference in age between patients who developed SAIH and those who did not. In contrast to our study, Jaremko *et al*.[10] and Ni *et al*.[11] there was no significant difference in age between groups with or without SAIH. This difference could be because the mean age (years) of all patients in their study was higher than the mean age in our study (69.35 ± 9.14 and 52 ± 1 years in the study by Jaremeko *et al*. and Ni *et al*., respectively, vs 39.49 ± 14.20 years in our research). In our study, the incidence of hypotension was higher in women (13/17, 76%) compared to men (23/58, 39%) [Table 1]. No other authors assessed the correlation of gender with SAIH. We could not find a probable cause for this association and assumed that this association occurred by chance since, on multivariate regression analysis, gender was not found to be a good predictor.

Our study showed no significant difference between the groups regarding weight. Still, the difference in height between the two groups was significant, with patients in the SAIH group being shorter [Table 1]. On multivariate regression analysis, BMI was found to be associated with SAIH [Table 4]. A relatively higher block level has been observed in obese patients with a similar amount of drug used due to increased abdominal pressure. No other study found a significant difference in BMI among the two groups, whereas other authors did not assess height and weight as predictors of SAIH.[7–11]

Our study had some limitations. First, we did not include pregnant females, obese patients, and patients with cardiac diseases because SAIH is commonly observed in these populations. Repeat assessment of volume status after co-loading, and SA administration was not done. Finally, the recording of IVC collapsibility may have been affected by the movement of the diaphragm during the respiratory cycle, which may have resulted in an underestimation of IVCCI.

CONCLUSION

Our study demonstrated that preoperative ultrasonographic assessment of IVC to evaluate its collapsibility index is a convenient, and reproducible tool for predicting SAIH. On the other hand, the preoperative caval aorta index was found to have poor diagnostic performance in predicting SAIH. Thus, we recommend calculating the IVC collapsibility index before administering SA to the patient to predict the risk of subsequent hypotension, especially when hypovolemia is suspected.

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Conflicts of interest

There are no conflicts of interest.

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