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ORIGINAL RESEARCH PERIOPERATIVE MEDICINE

Accuracy of preoperative evaluation of inferior vena cava collapsibility index and caval aorta index for prediction of hypotension after induction of general anesthesia: a prospective observational study

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ABSTRACT

Background & Objective: Post general anesthesia induction hypotension (PGAH) is not a rare event. Almost every induction agent has been incriminated to a variable extent. Preoperative ultrasound assessment of Inferior Vena Cava Collapsibility Index (IVCCI) has been investigated for predicting hypotension with mixed results. Inferior vena cava to aorta diameter index (IVC/Ao) hasn't been studied before as a predictor for PGAH. We studied the comparative accuracy of preoperative IVCC and IVC/Ao index for PGAH prediction.

Methodology: This observational prospective blinded study involved 102 participants undergoing different surgeries under general anesthesia. Preoperative ultrasound assessment of IVCCI and IVC/Ao index was done. Mean arterial pressure (MAP) was assessed 6 times; before induction, 1 min and 3 min after induction and 1, 5 and 10 min after endotracheal intubation. The area under the receiver operating characteristic curve (AUROC) was calculated for the ability of IVCC and IVC/Ao index to predict PGAH. Stepwise, backward logistic regression model was constructed to detect and quantify the predictive factors of PGAH.

Results: A total of 80 (78.43%) patients developed PGAH. ROC curve analysis for PGAH prediction demonstrated better diagnostic accuracy for IVC/Ao index than IVCCI, as the AUC of both were 0.666 ($P < 0.017$) and 0.487 ($P = 0.852$) respectively. IVC/Ao index cutoff value was 0.852

Conclusions: Inferior vena cava collapsibility index and inferior vena cava to aorta diameter ratio (IVC/Ao) index are both reliable indicators of post general anesthesia induction hypotension. IVC/Ao index is a more accurate and reliable indicator than inferior vena cava collapsibility index.

Abbreviations: CVP: Central Venous Pressure; IVCCI: Inferior Vena Cava Collapsibility Index; IVC/Ao: Inferior Vena Cava to Aorta Diameter Index; IVCD: Inferior Vena Cava Diameter; PAOP: Pulmonary Artery Occlusion Pressure; PGAH: Post General Anesthesia Induction Hypotension

Key words: Hypotension; General Anesthesia; Ultrasound; IVCCI; Aorta

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1. INTRODUCTION

General Anesthesia (GA) is a frequent hospital practice for different types of surgeries and procedures. Post GA induction hypotension (PGAH) is a not a rare phenomenon which may be a serious risk and may cause organ hypoperfusion which may not be tolerated by every patient.[1] Intraoperative hypotension may solely be responsible for unfavorable consequences during or after surgery, including myocardial infarction, stroke, acute kidney injury, extended hospital stay, and higher death rates after one year in both cardiac and non-cardiac operations.[2-4]

GA causes significant alterations in hemodynamics, as both inhalational and intravenous anesthetics cause bradycardia, decrease in systemic vascular resistance and vasodilatation, and decrease in myocardial contractility, cardiac output and stroke volume, with the absence of surgical stimulus, making induction of anesthesia is the most crucial period at which hypotension occurs. There are non-modifiable factors for PGAH as ASA III & IV, old age, and the inevitable use of propofol and fentanyl, however there are modifiable factors and preoperative intravascular volume is one of the most important of them.[5]

For anesthetists and intensivists, determining the status of intravascular volume remains difficult. Conventional static variables like central venous pressure (CVP), pulmonary artery occlusion pressure (PAOP) and the pulse index continuous cardiac output (PiCCO) system have been accused for being invasive, costly and with limited sensitivity and relatively high incidence of complications.[6,7] Some dynamic parameters such as heart rate variability, perfusion index and the passive leg lifting test were used to assess volume status with conflicting results.[8,9]

inferior vena cava diameter (IVCD) ultrasonography measures during respiration are suggested as quick and non-invasive dynamic parameters for assessment of status of intravascular volume, and they include maximum diameter of the IVC (IVCDmax) when the expiration end, minimum diameter (IVCDmin) when the inspiration end when there is spontaneous respiration as well as the collapsibility index (IVCCI).[10,11] These parameters in addition to aortic diameter (Ao) in systole were recommended as readily accessible variables by anesthetists with less echocardiography knowledge.[12, 13] However, only one study assessed the ratio between IVCDmax and Ao in systole (IVCDmax/Ao index) and compared it with IVCCI for predicting hypotension after spinal anesthesia (SA) induction.[14] While no previous studies have assessed IVCDmax/Ao index versus IVCCI for the prediction of PGAH.

We hypothesize that IVCDmax/Ao index will be more accurate predictor of PGAH than IVCCI, so assessed and compared the sensitivity, the specificity and the accuracy between IVCCI and IVCDmax/Ao index for predicting hypotension after GA induction.

2. METHODOLOGY

This observational, prospective study was carried out at Kasr El-Aini Hospital between May 2022 and July 2022 on 102 patients scheduled for various elective surgical operations under GA. Written permission was obtained from every patient or his/her guardian. The ages ranged 18−60 y, ASA physical status I or II, and BMI 20−35 kg/m^2. Patients with high intra-abdominal pressure (e.g., intra-abdominal mass pressing IVC), uncontrolled hypertension, uncompensated respiratory diseases (deficient functional capacity, generalized wheezing, peripheral saturation of O2 < 90% on room air), uncompensated cardiac morbidities (tight valvular lesion, unstable coronary artery disease and diminished contractility with ejection fraction < 40%), and individuals with a mean arterial pressure (MAP) < 70 mmHg or baseline arterial SBP < 90 mmHg, suspected difficult airway patients, pregnant patients, and for emergency surgeries, were excluded.

All patients underwent preoperative evaluation including full history, clinical examination, and standard investigations. Patients were fasted for 6-8 h preoperatively. In the operating room, ECG, noninvasive blood pressure (NIBP) and pulse oximetry were applied and baseline readings recorded. An infusion of ringer lactate solution was started at 2 ml/kg/h. Premedication, e.g., ondansetron 4 mg, famotidine 40 mg and midazolam 0.01 mg/kg were given slow IV.

The inferior vena cava (IVC) may be seen utilizing a paramedian long-axis view with a subcostal technique in a supine posture, based on the American Society of Echocardiography's defined technique, and during spontaneous breathing.[15] We used a curvilinear transducer (1−5 MHz, Acuson x300, Siemens Healthcare, Seoul, Korea) in abdominal mode with a B-

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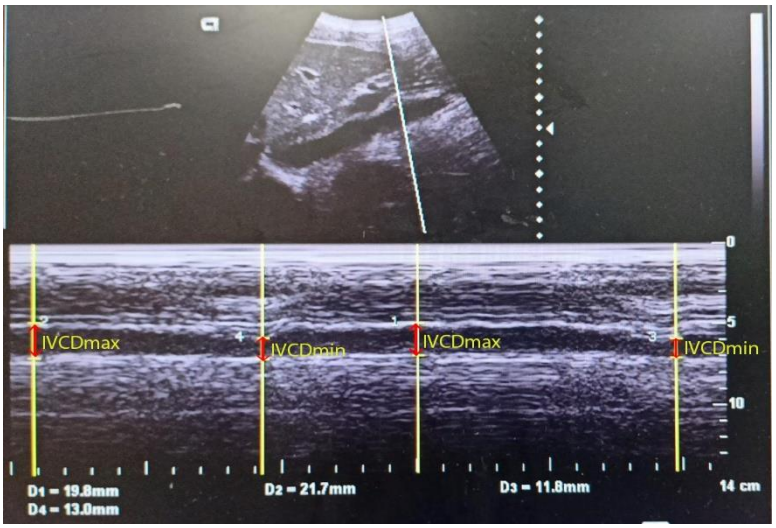

Figure 1: IVC ultrasonography & calculation of collapsibility index. Panel above shows two-dimensional view of the IVC with right atrium to the left and panel below shows M-mode image with respiratory variations in diameter.

mode scan. All measurements were taken 3 times and the mean value was recorded. IVC can be differentiated from the aorta utilizing pulse wave Doppler. M-mode imaging, done 2 to 3 cm distant to the right atrium, is used to measure changes in IVC diameter with respiration after acquiring a two-dimensional picture of the IVC where it meets the right atrium.[16] Utilizing built-in software, the maximal (IVCDmax) and minimal (IVCDmin) IVC diameters during only one respiratory cycle are calculated. Then the calculation of IVCCI can be done as follows: IVCCI = (IVCDmax–IVCDmin)/IVCDmax) x 100 (Figure 1).

The abdominal aorta could be visualized 10 mm over the celiac trunk, just lateral to IVC. During systole, the abdominal aorta's maximal internal AP diameter was determined. The ratio of the IVCDmax during expiration to the maximum abdominal aortic diameter during systole produces the IVCDmax/Ao index.[17] Short video recordings of both measures were recorded for subsequent review by an expert cardiologist (Figure 2).

After that, GA was induced with fentanyl 1 µg/kg, propofol 2 mg/kg, and 0.5 mg/kg atracurium and intubation done. Anesthesia was maintained with isoflurane 1–1.5% in air: O_2 mixture, atracurium 0.1 mg/kg every 20 min. MAP was recorded 6 times as follows: at baseline, at 1 and 3 min after induction, then at 1, 5 and 10 min after intubation. PGAH was defined as MAP < 60 mmHg or ≥ 20% decrease in MAP anytime from the baseline measurement.

Intraoperative severe hypotension (MAP < 55 mmHg) was treated with ephedrine 5 mg incremental boluses. In the event of bradycardia (HR < 50 beats/min), atropine 0.01 mg/kg was used. Patients were extubated after surgery, and shifted to the post-anesthesia care unit (PACU).

2.1. Outcomes of the current study

The primary outcome was preoperative IVCCI's area under receiver operating characteristic curves (AUROC) and IVC/Ao ratio index in prediction of postinduction hypotension. The secondary outcomes were correlation between maximal diameter of aorta and the proportion of the maximum MAP fall after induction of GA; relationship between the IVCCI and the maximum MAP reduction percentage after induction of anesthesia; correlation between IVCDmax/Ao and the percentage of the maximum reduction in MAP following induction of GA and the incidence of post-induction hypotension.

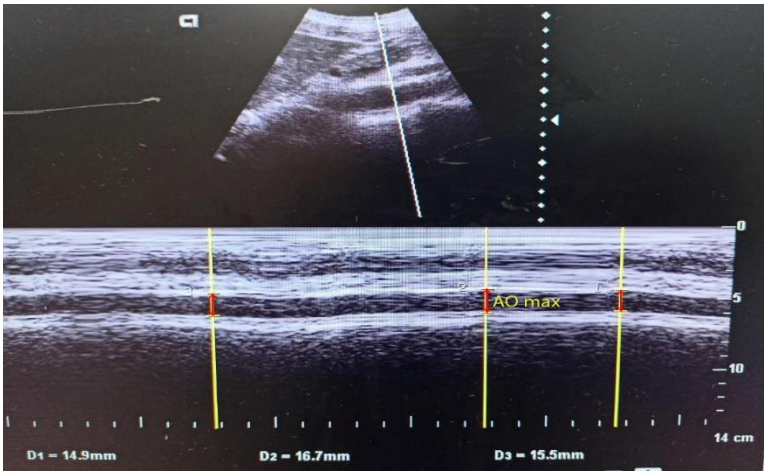

Figure 2: Descending abdominal aorta ultrasonography. Ao max: maximum aortic diameter in systole

2.2. Sample size

According to the study of Salama et al.[14], and the assumption that a substantial difference was exist in the mean value of IVC collapsibility index between patients who developed hypotension (49.9 ± 6.1) and those who didn't (40.6 ± 5.8), with α = 0.05, type l error, two-tailed, power of 80%, and an effect size of 0.5. So, a sample size of 102 participants were needed (GPower 301 http: www.psycho.uniduesseldorf.de).

2.3. Statistical analysis

SPSS software program (SPSS for Windows®, Version 16.0, Chicago, SPSS Inc.) was used to process, categorize, and then analyze the data. While categorical

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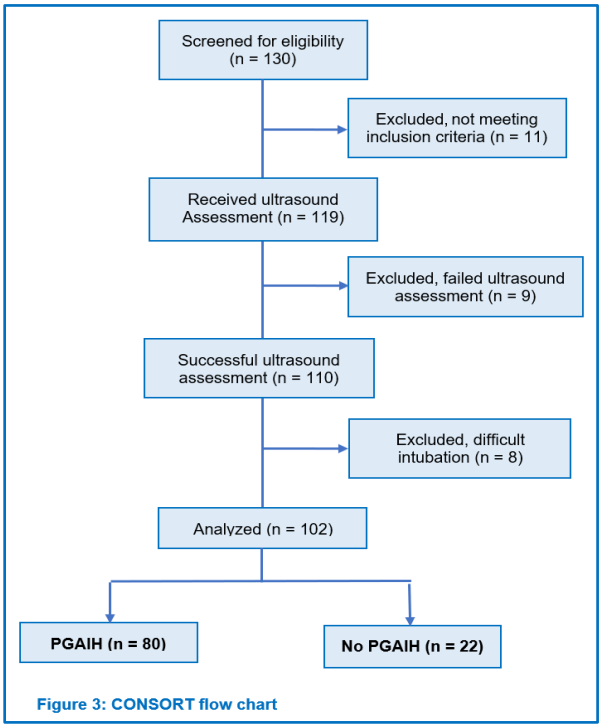

Figure 3: CONSORT flow chart

data were shown as frequency (%), numerical data were shown as mean ± standard deviation. Comparisons among patients, who developed hypotension and those who didn't, were performed by chi-square test or Student's t-test as suitable. The diagnostic efficacy of

IVCCI and IVC/Ao, as well as their ideal cutoff values, were estimated using a receiver operating characteristic (ROC) curve. With a 95% confidence interval, the optimum cutoff values' specificity, sensitivity, negative predictive value, positive predictive value, and total accuracy were calculated. To identify and measure the PGAH prognostic parameters, a stepwise, backward logistical regression model was created. Statistical significance was defined as $P < 0.05$.

3. RESULTS

A total of 119 participants were enrolled in this study. IVC ultrasonographic scanning was unsuccessful in 9 patients and 8 patients were excluded due to difficult and prolonged airway intubation (Figure 3).

Medical history and type of surgeries shown in Table 1.

Out of 102 patients, 80 (78.43%) patients developed PGAH. Hence, we got two groups of patients: Hypotensive Group (n = 80) and Normotensive Group (n = 22).

All patients were comparable regarding age, BMI, and ASA classification (Table 1). But, for sex differences, 49 out of 57 (61.2%) female patients developed hypotension with (P = 0.037) when compared to male patients. (Table 1)

Baseline MAP, and IVCCI demonstrated no substantial statistical variation in between two groups (P = 0.077, 0.786 respectively). However, A substantial variation existed among both groups concerning IVCDmax/Ao index (P = 0.039**)** (Table 2).

Analysis using several logistic variables detected that female sex was one of the PGAH predictors (95% CI 0.123 to 0.957, P = 0.037). IVCDmax/Ao-index was a substantial indicator of PGAH (95% CI 1.187 to 57.690). MBP at baseline was not a reliable indicator of PGAH (95 % CI 0.999 to 1.118) (Table 3).

The ROC curve study for PGAH prediction showed acceptable accuracy in diagnosis when utilizing the IVCDmax/Ao index as the AUC was 0.666 (95% CI: 0.519−0.813, P = 0.017). The optimum cutoff level of IVCDmax/Ao index was 0.852, with a sensitivity of 77.5% (71.9−82.1%) and a specificity of 63.6% (43.4−80.5%) and accuracy of 74.5% (65.8−81.8%) with positive predictive value of 88.6% (82.2−93.9%) and

Table 1: Demographic data and type of surgeries in the study groups.

Parameters	Hypotensive Group (n = 80)	Normotensive Group (n = 22)	P value
Age (years)	34.38 ± 10.9	35.09 ± 12.2	0.792
Sex (male: female)	31: 49	14: 8	**0.037***
BMI (kg/m^2)	29.4 ± 6.26	29 ± 5.38	0.784
ASA physical status I: II	70: 10	20: 2	0.660
Comorbids:			
• Diabetes mellitus	9	4	
• Asthma	5	1	
• Hypothyroidism	1	2	
Type pf surgeries:			
• Plastic / reconstructive surgeries	30	9	
• General surgery	45	11	
• Urology	5	2	

*Data presented as mean ± standard deviation or number. * P < 0.05 statistically significant, BMI: Body Mass Index.*

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Table 2: Hemodynamic and ultrasonographic parameters

Parameter	Hypotensive Group n=80	Normotensive Group n=22	P value
Baseline MAP (mmHg)	89.5 ± 8.57	85.7 ± 9.8	0.077
IVCCI	44.5 ± 9.8	43.8 ± 11.9	0.786
IVCDmax : Ao index	1.03 ± 0.28	0.88 ± 0.3	0.039*

*Data presented as mean ± standard deviation or numbers. * P < 0.05 statistically significant, IVCDmax : Ao index: inferior vena cava to aortic diameter index; IVCCI: inferior vena cava collapsibility index; MAP: baseline mean arterial pressure.*

Table 3: Multivariable logistic regression analysis.

	B	Sig.	Odds ratio	95.0% C.I.
Female Sex	-1.071	0.041	0.343	0.123-0.957
IVCDmax : Ao	2.113	0.033	8.276	1.187-57.690
MBP	0.055	0.056	1.057	0.999-1.118
Constant	-5.011	0.073	0.007	

IVCDmax : Ao index - inferior vena cava to aortic diameter index; IVCCI - inferior vena cava collapsibility index; MAP - baseline mean arterial pressure.

negative predictive value of 43.8% (29.9−55.3%) (Table 4, Figure 4).

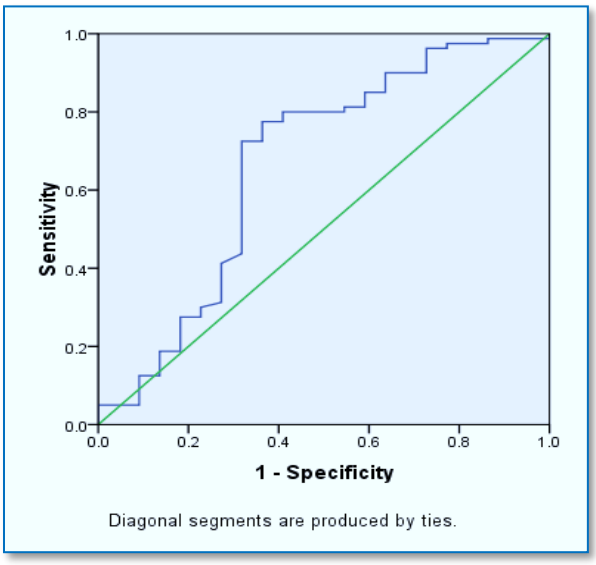

Figure 4: ROC curve showing the ability of preoperative IVC/Ao index to predict hypotension after induction of GA. Area under the curve is 0.666

The ROC curve analysis of IVCCI as PGAH predictor demonstrated AUC was 0.487 (95% CI: 0.344−0.630, P = 0.852). The optimum cutoff level of IVCCI was 28.3, with a sensitivity of 92.5% (89.3−96.4%) and a specificity of 18.2% (6.4−32.3%) and accuracy of 76.5% (71.4−82.6%) with a positive predictive value 80.4% (77.6−83.8%) and a negative predictive value 40.0% (14.2−71.0%) (Table 3 & 4, Figure 5).

4. DISCUSSION

The current study is the first study to investigate IVCDmax/Ao as an indicator for post-induction hypotension following GA and to compare it with IVCCI.

It was found that according to ROC curve analysis for PGAH prediction, IVCDmax/Ao index was more predictive than IVCCI (p = 0.017, 0.852 respectively), with higher specificity with IVCDmax/Ao than IVCCI (63.6%, 18.2% respectively). However, IVCDmax/Ao showed less sensitivity than IVCCI (77.5%, 92.5% respectively) with nearly equal accuracy of both (74.5%, 76.5% respectively)

The current study showed no statistically significant differences concerning age, ASA status, BMI, baseline MBP, medical history, between individuals who had hypotension and those who didn't. Yet, female hypotension than males (P = 0.037). This was found by

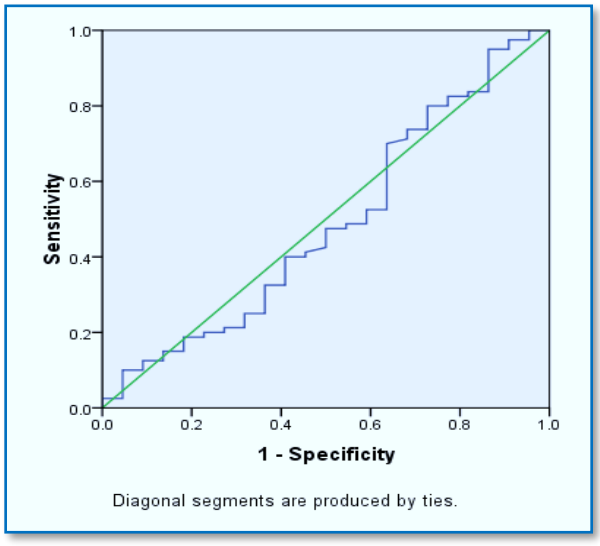

Figure 4: ROC curve showing the ability of preoperative IVC/Ao index to predict hypotension after induction of GA. Area under the curve is 0.666

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Table 1: Diagnostic accuracy of various variables for prediction of PGAH

Variable	Cut-off value	Sensitivity	Specificity	PPV	NPV	Youden index accuracy	AUC	95% CI	P value
IVCDmax : Ao	0.852	77.5%	63.6%	88.6%	43.8%	74.5%	0.666	0.519−0.813	**0.017***
IVCCI	28.3	92.5%	18.2%	80.4%	40.0%	76.5%	0.487	0.344−0.630	0.852

**P < 0.05 Statistically significant, IVCDmax : Ao index - inferior vena cava to aortic diameter index; IVCCI - inferior vena cava collapsibility index.*

participants were more prone to post-induction Roy et al., as female patients who developed PGAIH were (33.3%) compared to males (16.19%) (P = 0.05).[18] Mechanisms are not fully understood, but the theories state that woman's autonomic system displays more parasympathetic activity. Also, sex hormones have an important role in blood pressure regulation, as estrogen can inversely affect the release of epinephrine, norepinephrine, decreasing the sympathetic tone.[19] Perioperative hemodynamic stability is the corner stone for the favorable outcomes regarding the perfusion of the vital organs like the brain, myocardium, liver and kidney. Hypovolemia is considered the most common factor leading to post-induction hypotension.[20] Luckily enough it is a modifiable factor in most cases; however, poor response to optimizing intravascular volume is still present in spite of the improvement in preoperative practices abandoning the unnecessary prolonged fasting hours and vigorous mechanical bowel preparation. It may be due to the still existing reliance, by a considerable number of anesthesiologists, on the basic monitoring of hemodynamics, such as blood pressure, HR and CVP,[21] which makes intravascular volume optimization swinging between hypovolemia and volume overload with the serious consequences of each of them.

Recently ultrasound examination gained wide popularity among anesthesiologists for transthoracic echocardiography, peripheral nerve blocks, and central venous catheterization, and has been found that there is about 31% improvement when ultrasound is utilized in anesthetic management.[15]

Ultrasound assessment of IVCCI and IVC/Ao index was introduced into clinical practice as a reliable, easy, rapid and noninvasive technique for determining the state of the intravascular volume.[12]

Studied have shown mixed results regarding the reliability and accuracy of IVCCI to predict anesthesia related hypotension. After comparing many previous studies, our analysis about these mixed results is that it may be due to many factors, the most important of which is the lack of agreement to a standard definition of intraoperative hypotension.[22] Second, most of the studies depend on the noninvasive dynamometer for BP assessment, which is affected by many factors in measurement.[23] Third, there is great variation between the studies for the frequency and duration of BP measurement to detect hypotension. There may be other causative factors of hypotension as well, including the variability of the studied population comprising of adults, young adults, geriatrics, pregnant, traumatic and septic patients.[24-28]

In concordance with our results, some other researchers found that preoperative evaluation of IVC parameters including IVCCI are not good predictors. Considering the possibility of hypotension following SA neither dIVCmax nor IVCCI values obtained prior to SA serve as reliable predictors of post-spinal hypotension, there was no statistical variation among the cases considering hypotension following SA correlated with dIVCmax and IVCCI.[18,29,30] Another researcher found poor diagnostic accuracy of different sonographic IVC parameters to predict hypotension following induction of GA in appropriate adult individuals, with comparable dIVCmax, dIVCmin and IVCCI among individuals with hypotension and those without hypotension.[25] IVCCI is not an indicator of post-spinal hypotension in parturient having an elective cesarean section.[26]

Szabó M et al.[31] verified that a high IVCCI value (≥ 50%) before GA induction, was linked to an additional substantial alteration in systolic and mean blood pressure having a high level of specificity but low level of sensitivity. This extraordinary occurrence in line with our findings that the IVCCI can be used as a screening tool not a reliable parameter for volume changes.

Two researchers assessed IVCCI before GA and SA respectively and found it an accurate indicator of hypotension at a cut-off value of > 43% and 42% respectively. [12,32]

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Doucet et al.[27] examined the ability of US IVCDmin and IVCCI to identify occult hypovolemia in trauma patients, and found that these parameters offer a quick and noninvasive method of determining the 24-h fluid resuscitation of severe trauma patients within a single hour of admission.

The only study that investigated IVCDmax/Ao for hypotension prediction was done by Salama ER et al.[14] but it was in SA. Similar to our findings, they discovered that the IVC/Ao index is a more reliable indicator of PSAH than IVCCI, with a specificity of 88%, a sensitivity of 96%, and an accuracy of 95% to expect PSAH at a cut-off point < 1.2. IVCCI had a specificity of 77%, a sensitivity of 84%, and an accuracy of 84% to expect hypotension after SA, at a cut-off point > 44.7%.

5. LIMITATIONS

Limitations of the present study and the recommendations include:

- The relatively small calculated sample size. Nevertheless, the estimated power of the analysis was adequate to detect substantial and accurate results. However, further studies are recommended in different age groups, different types of patients, and in critically ill patients.
- As it was a single-center study, a multicenter study is required to evaluate the optimal cut-off point of such predictors.
- Blood pressure measurement was done non-invasively at different intervals. Invasive BP monitoring might be better for providing more accurate continuous readings.

6. CONCLUSION

We conclude that the inferior vena cava to aorta diameter (IVC/Ao) index is a more reliable, rapid, and accessible method for predicting post general anesthesia induction hypotension than IVC collapsibility changes during the respiratory cycle. Adding an automated programmed software to the ultrasound device to automatically calculate the IVCCI and IVCDmax/Ao index, would be of great value of saving time and avoiding human errors in calculation.

7. Data availability

The numerical data pertaining to this study is available with authors.

8. Conflict of interest

The authors declare no conflict of interest. The study was entirely sponsored by Faculty of Medicine, Cairo University, Kasr Alainy Street, Cairo, Egypt.

9. Ethical issues

Approval of the Cairo University Study Ethics Committee (No. MD-266-2020) was secured, and the study was registered with clinicaltrial.gov (Registration ID: NCT05368363),

10. Authors' contributions

All authors contributed to the study concept and design, material preparation, data collection and statistical analysis. All authors read and approved the final draft.

11. REFERENCES

1. Südfeld S, Brechnitz S, Wagner JY, Reese PC, Pinnschmidt HO, Reuter DA, et al. Post-induction hypotension and early intraoperative hypotension associated with general anaesthesia. Br J Anaesth. 2017 Jul 1;119(1):57-64. [PubMed] DOI: 10.1093/bja/aex127
2. Reich DL, Bodian CA, Krol M, Kuroda M, Osinski T, Thys DM. Intraoperative hemodynamic predictors of mortality, stroke, and myocardial infarction after coronary artery bypass surgery. Anesth Analg. 1999; 89:814–22. [PubMed] DOI: 10.1097/00000539-199910000-00002
3. Walsh M, Devereaux PJ, Garg AX, Kurz A, Turan A, Rodseth RN, et al. Relationship between intraoperative mean arterial pressure and clinical outcomes after noncardiac surgery: Toward an empirical definition of hypotension. Anesthesiology 2013;119:507–15. [PubMed] DOI: 10.1097/ALN.0b013e3182a10e26
4. Monk TG, Saini V, Weldon BC, Sigl JC. Anesthetic management and one-year mortality after noncardiac surgery. Anesth Analg. 2005;100:4–10. [PubMed] DOI: 10.1213/01.ANE.0000147519.82841.5E
5. Kouz K, Hoppe P, Briesenick L, Saugel B. Intraoperative hypotension. Pathophysiology, clinical relevance, and therapeutic approaches. Indian J Anaesth. 2020 Feb;64(2):90. [PubMed] DOI: 10.4103/ija.IJA_939_19
6. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness?*: A systematic review of the literature and the tale of seven mares. Chest. 2008 Jul 1;134(1):172-8. [PubMed] DOI: 10.1378/chest.07-2331
7. Vincent JL, Pelosi P, Pearse R, Payen D, Perel A, Hoeft A, et al. Perioperative cardiovascular monitoring of high-risk patients: a consensus of 12. Crit Care. 2015 May 8;19(1):224. [PubMed] DOI: 10.1186/s13054-015-0932-7
8. Kalantari K, Chang JN, Ronco C, Rosner MH. Assessment of intravascular volume status and volume responsiveness in critically ill patients. Kidney Int. 2013 Jun 1;83(6):1017-28. [PubMed] DOI: 10.1038/ki.2012.424
9. Peacock WF, Soto KM. Current techniques of fluid status assessment. Contrib Nephrol. 2010;164:128-42. [PubMed] DOI: 10.1159/000313726
10. Seif D, Mailhot T, Perera P, Mandavia D. Caval sonography in shock: a noninvasive method for evaluating intravascular volume in critically ill patients. J Ultrasound Med. 2012 Dec;31(12):1885-90. [PubMed] DOI: 10.7863/jum.2012.31.12.1885
11. Nakamura K, Tomida M, Ando T, Sen K, Inokuchi R, Kobayashi E, et al. Cardiac variation of inferior vena cava: new concept in the evaluation of intravascular blood volume. J Med Ultrason

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(2001). 2013 Jul;40(3):205-9. [PubMed] DOI: 10.1007/s10396-013-0435-6

12. Zhang J, Critchley LA. Inferior vena cava ultrasonography before general anesthesia can predict hypotension after Induction. Anesthesiology. 2016;124:580-9. [PubMed] DOI: 10.1097/ALN.0000000000001002
13. Dipti A, Soucy Z, Surana A, Chandra S. Role of inferior vena cava diameter in assessment of volume status: a meta-analysis. Am J Emerg Med. 2012 Oct;30(8):1414-1419.e1. [PubMed] DOI: 10.1016/j.ajem.2011.10.017
14. Salama ER, Elkashlan M. Pre-operative ultrasonographic evaluation of inferior vena cava collapsibility index and caval aorta index as new predictors for hypotension after induction of spinal anaesthesia: A prospective observational study. Eur J Anaesthesiol. 2019 Apr;36(4):297-302. [PubMed] DOI: 10.1097/EJA.0000000000000956
15. Ferreira Albuquerque Costa NT, Gomar Sancho C. Perioperative ultrasound applied to diagnosis and decision making in anesthesia. Minerva Anestesiol. 2018;84:94–107. [PubMed] DOI: 10.23736/S0375-9393.17.12178-4
16. Nakamura K, Tomida M, Ando T, Sen K, Inokuchi R, Kobayashi E, et al. Cardiac variation of inferior vena cava: new concept in the evaluation of intravascular blood volume. J Med Ultrason. 2013;40:205–9. [PubMed] DOI: 10.1007/s10396-013-0435-6
17. Finnerty NM, Panchal AR, Boulger C, Vira A, Bischof JJ, Amick C, et al. Inferior Vena Cava Measurement with Ultrasound: What Is the Best View and Best Mode? West J Emerg Med. 2017 Apr;18(3):496-501. [PubMed] DOI: 10.5811/westjem.2016.12.32489
18. Roy S, Kothari N, Goyal S, Sharma A, Kumar R, Kaloria N, et al. Preoperative assessment of inferior vena cava collapsibility index by ultrasound is not a reliable predictor of post-spinal anesthesia hypotension. Braz J Anesthesiol. 2022 Apr 14:S0104-0014(22)00051-3. [PubMed] DOI: 10.1016/j.bjane.2022.04.001
19. Cheng YC, Vyas A, Hymen E, Perlmuter LC. Gender differences in orthostatic hypotension. Am J Med Sci. 2011 Sep;342(3):221-5. [PubMed] DOI: 10.1097/MAJ.0b013e318208752b
20. Jor O, Maca J, Koutna J, Gemrotova M, Vymazal T, Litschmannova M, et al. Hypotension after induction of general anesthesia: occurrence, risk factors, and therapy. A prospective multicentre observational study. J Anesth. 2018;32:673–80. [PubMed] DOI: 10.1007/s00540-018-2532-6
21. Ceruti S, Anselmi L, Minotti B, Franceschini D, Aguirre JA, Borgeat A, Saporito A. Prevention of arterial hypotension after spinal anaesthesia using vena cava ultrasound to guide fluid management. Br J Anaesth. 2018 Jan;120(1):101-108. [PubMed] DOI: 10.1016/j.bja.2017.08.001
22. Futier E, Lefrant JY, Guinot PG, Godet T, Lorne E, Cuvillon P et al. Effect of individualized vs standard blood pressure management strategies on postoperative organ dysfunction among high-risk patients undergoing major surgery: a randomized clinical trial. JAMA 2017;318:1346-57. [PubMed] DOI: 10.1001/jama.2017.14172
23. Kallioinen N, Hill A, Horswill MS, Ward HE, Watson MO. Sources of inaccuracy in the measurement of adult patients' resting blood pressure in clinical settings: a systematic review. J Hypertens. 2017;35:421-41. [PubMed] DOI: 10.1097/HJH.0000000000001197
24. Ackland GL, Brudney CS, Cecconi M, Ince C, Irwin MG, Lacey J, et al. Perioperative Quality Initiative consensus statement on the physiology of arterial blood pressure control in perioperative medicine. Br J Anaesth. 2019;122:542-51. [PubMed] DOI: 10.1016/j.bja.2019.01.011
25. Mohammed S, Syal R, Bhatia P, Chhabra S, Chouhan RS, Kamal M. Prediction of post-induction hypotension in young adults using ultrasound-derived inferior vena cava parameters: An observational study. Indian J Anaesth. 2021 Oct;65(10):731-737. [PubMed] DOI: 10.4103/ija.IJA_1514_20
26. Singh Y, Anand RK, Gupta S, Chowdhury SR, Maitra S, Baidya DK, et al. Role of IVC collapsibility index to predict post spinal hypotension in pregnant women undergoing caesarean section. An observational trial. Saudi J Anaesth. 2019;13:312-7. [PubMed] DOI: 10.4103/sja.SJA_27_19
27. Doucet JJ, Ferrada P, Murthi S, Nirula R, Edwards S, Cantrell E, et al. Ultrasonographic inferior vena cava diameter response to trauma resuscitation after 1 hour predicts 24-hour fluid requirement. J Trauma Acute Care Surg. 2020 Jan;88(1):70-79. [PubMed] DOI: 10.1097/TA.0000000000002525
28. Zhao J, Wang G. Inferior Vena Cava Collapsibility Index is a Valuable and Non-Invasive Index for Elevated General Heart End-Diastolic Volume Index Estimation in Septic Shock Patients. Med Sci Monit. 2016 Oct 20;22:3843-3848. [PubMed] DOI: 10.12659/msm.897406
29. Topal S, Karasu D, Yilmaz C, Baytar Ç, Tenekecioğlu E, Topal D. The relationship between collapsibility index of inferior vena cava and hypotension after spinal anesthesia. Eur Res J. 2021;7(3):319-325. DOI: 10.18621/eurj.739559
30. Chowdhury SR, Baidya DK, Maitra S, Singh AK, Rewari V, Anand RK. Assessment of role of inferior vena cava collapsibility index and variations in carotid artery peak systolic velocity in prediction of post-spinal anaesthesia hypotension in spontaneously breathing patients: An observational study. Indian J Anaesth. 2022;66:100-6. [PubMed] DOI: 10.4103/ija.ija_828_21
31. Szabó M, Bozó A, Darvas K, Horváth A, Iványi ZD. Role of inferior vena cava collapsibility index in the prediction of hypotension associated with general anesthesia: an observational study. BMC Anesthesiol. 2019 Aug 7;19(1):139. [PubMed] DOI: 10.1186/s12871-019-0809-4
32. Ni TT, Zhou ZF, He B, Zhou QH. Inferior Vena Cava Collapsibility Index Can Predict Hypotension and Guide Fluid Management After Spinal Anesthesia. Front Surg. 2022 Feb 17;9:831539. [PubMed] DOI: 10.3389/fsurg.2022.831539

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