Inferior Vena Cava Ultrasonography before General Anesthesia Can Predict Hypotension after Induction

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ABSTRACT

Background: Hypotension is a common side effect of general anesthesia induction, and when severe, it is related to adverse outcomes. Ultrasonography of inferior vena cava (IVC) is a reliable indicator of intravascular volume status. This study investigated whether preoperative ultrasound IVC measurements could predict hypotension after induction of anesthesia.

Methods: One hundred four adult patients, conforming to American Society of Anesthesiologists physical status I to III, scheduled for elective surgery after general anesthesia were recruited. Maximum IVC diameter ($dIVC_{max}$) and collapsibility index (CI) were measured preoperatively. Before induction, mean blood pressure (MBP) was recorded. After induction, MBP was recorded for 10 min after intubation. Hypotension was defined as greater than 30% decrease in MBP from baseline or MBP less than 60 mmHg. Receiver operating characteristic curve analysis with gray zone approach and regression analyses were used.

Results: IVC scanning was unsuccessful in 13.5% of patients. Data from 90 patients were analyzed. After induction, 42 patients developed hypotension. Areas (95% confidence interval) under the curves were 0.90 (0.82 to 0.95) for CI and 0.76 (0.66 to 0.84) for $dIVC_{max}$. The optimal cutoff values were 43% for CI and 1.8 cm for $dIVC_{max}$. The gray zone for CI was 38 to 43% and included 12% of patients and that for $dIVC_{max}$ was 1.5 to 2.1 cm and included 59% of patients. After adjusting for other factors, it was found that CI was an independent predictor of hypotension with the odds ratio of 1.17 (1.09 to 1.26). CI was also positively associated with a percentage decrease in MBP (regression coefficient = 0.27).

Conclusions: Preoperative ultrasound IVC CI measurement was a reliable predictor of hypotension after induction of general anesthesia, wherein CI greater than 43% was the threshold. (Anesthesiology 2016; 124:00-00)

HYPOTENSION is common during surgery in patients under anesthesia[1] and may cause organ underperfusion and ischemia.[2] After induction of general anesthesia, patients are at particular risk of developing hypotension because of the cardiovascular depressant and vasodilatory effects of anesthetic agents, as well as lack of surgical stimulation. Furthermore, patients may have preexisting hypovolemia resulting from dehydration and impaired compensatory responses, which increase the risk.[3,4] Severe episodes of intraoperative hypotension have been proposed as an independent risk factor in the development of postoperative adverse outcomes such as myocardial infarction, stroke, heart failure, acute kidney injury, prolonged hospital stay, and even increased 1-yr mortality rates both in patients undergoing cardiac surgery and in those undergoing noncardiac surgery.[5–11] Predictors of hypotension after induction of anesthesia include American Society of Anesthesiologists physical status (ASA) III and IV, baseline mean arterial pressure lower than 70 mmHg, age more than 50 yr, use of propofol, and high fentanyl dose.[8] Heart rate (HR) variability can predict hypotension and bradycardia after induction of anesthesia.[12] However, the role of preoperative volume status in the development of hypotension after induction has not been assessed fully. A surgical patient's preoperative volume status may vary due to physical status, comorbidities, and preoperative treatments such as bowel preparation and fasting, and these contributory factors have been shown to have an influence on the patient's susceptibility to intraoperative hypotension.[13]

What We Already Know about This Topic

- Hypotension is commonly associated with induction of general anesthesia and potential adverse outcomes
- Ultrasonography of the inferior vena cava is being used as a reliable indicator of intravascular volume in many out–of–operation room settings

What This Article Tells Us That Is New

- The authors have shown that preoperative ultrasound of the inferior vena cava can be used to predict significant hypotension after anesthetic induction
- The findings expand the potential clinical utility of ultrasound in the perioperative period

Assessing intravascular volume status is a challenge for clinicians. Traditional static parameters such as central venous pressure have been criticized for invasiveness and lack of accuracy.[14] A number of dynamic parameters that assess

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volume status have been recommended recently.[15,16] Ultrasound measurements of inferior vena cava (IVC) diameter with respiration, which include (1) maximum diameter of the IVC ($dIVC_{max}$) at the end of expiration during spontaneous respiration and (2) collapsibility index (CI), have been recommended as rapid and noninvasive methods for estimating volume status.[17,18] These parameters have been proposed as repeatable and easily obtainable parameters by operators with little experience in echocardiography.[19] Ultrasound measurement of the IVC has been studied extensively as a predictor of fluid responsiveness in different clinical settings,[20,21] and several studies have demonstrated that $dIVC_{max}$ and CI are reliable indicators of intravascular volume status.[19,22–25]

Therefore, we hypothesized that preoperative $dIVC_{max}$ and its respiratory variation, that is, CI, could predict the incidence of hypotension after induction of general anesthesia, with a high degree of sensitivity and specificity. The aim of our prospective study was to evaluate the predictive power of bedside ultrasound IVC measurement to predict episodes of hypotension after induction of general anesthesia. Our statistical methodology included receiver operating characteristic (ROC) curve analysis with gray zone approach.[26,27]

Materials and Methods

Patients

The current study was approved by The Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee and the Institutional Ethics Committee of the First Affiliated Hospital of Zhengzhou University, Zhengzhou, China. A pilot study was performed in the Prince of Wales Hospital, and the main data collection was completed in the First Affiliated Hospital of Zhengzhou University. Adult patients, conforming to ASA I to III, scheduled for elective surgery under general anesthesia at the First Affiliated Hospital of Zhengzhou University were recruited from July to September 2014 and from January to February 2015. Patients with major peripheral vascular disease, severe vascular disease, unstable angina or ejection fraction less than 40%, respiratory distress, increased intra-abdominal pressure, autonomic nervous system disorders, implanted pacemaker/cardioverter, anticipated difficult airway, or mental incompetence were excluded. Patients who have currently taken angiotensin-converting enzyme inhibitor or angiotensin receptor blocker were also excluded. Written informed consent was obtained from all eligible patients.

IVC Ultrasonography

All patients were conscious, lying supine, and spontaneously breathing for at least 5 min before IVC examination. Ultrasound measurements were performed using a Sonosite Edge (Sonosite Inc., USA) machine and a C60X curved linear phased array transducer (Sonosite Inc.) set to abdominal mode. All IVC measurements were performed by one operator (J.Z.) who was a fully trained anesthesiologist and had basic level 1 experience in echocardiography.[28]

The IVC was visualized using a paramedian long-axis view *via* a subcostal approach according to the methodology described by the American Society of Echocardiography.[29] A two-dimensional image of the IVC as it entered the right atrium was first obtained. Pulse wave Doppler was used to differentiate the IVC from the aorta. Variations in IVC diameter with respiration were assessed using M-mode imaging performed 2 to 3 cm distal to the right atrium.[30] The M-mode image was generated at a medium sweep speed. To ensure consistent IVC measurements, three scans were performed in each patient. If there was a difference of more than 0.2 cm in $dIVC_{max}$ measurements between any two of the images, then that patient's data were excluded from the study. The whole IVC scan procedure took less than 10 min. For each patient, the best quality scan image was chosen. Maximum and minimum IVC diameters over a single respiratory cycle were measured using a built-in software. The CI was calculated as $CI = (dIVC_{max} - dIVC_{min})/dIVC_{max}$ and was expressed as percentage[31] (fig. 1).

Anesthesia Management

All patients' electrocardiogram, blood pressure (BP), peripheral oximeter readings, end-tidal carbon dioxide, and airway pressures were monitored. BP was measured by either noninvasive oscillometric cuff or invasive arterial pressure. The method of measuring BP was decided by the attending anesthesiologists. If BP was measured invasively, the arterial line was set up before induction. Premedication with 0.01 mg/kg intravenous midazolam was given 10 min before induction. Induction was performed using a regimen of 2 to 3 μg/kg fentanyl followed by 0.3 mg/kg etomidate. Tracheal intubation was facilitated using a nondepolarizing muscle relaxant, cisatracurium or rocuronium. Anesthesia was

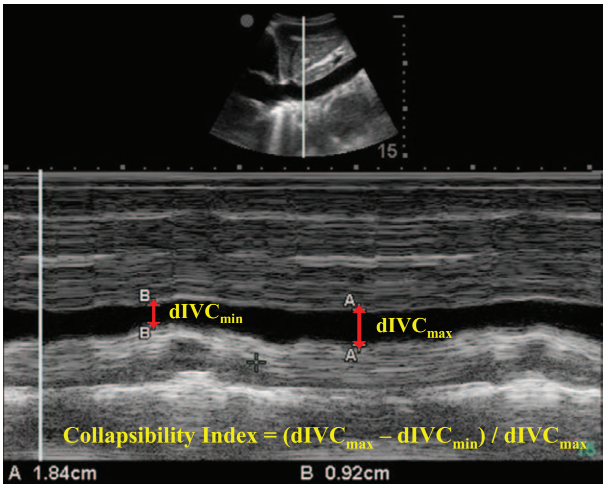

Fig. 1. Ultrasound measurements of inferior vena cava (IVC) and calculation of collapsibility index. Panel *above* shows two-dimensional scan of the IVC with right atrium to the left and panel *below* shows M-mode scan with respiratory variations in diameter. $dIVC_{max}$ = maximum diameter of IVC; $dIVC_{min}$ = minimum diameter of IVC.

maintained with inhaled sevoflurane (1 to 2 vol%) in oxygen-enriched air. Normal saline was initially infused at a rate of 10 ml · kg^{-1} · h^{-} . Patients who experienced prolonged airway instrumentation due to a difficult intubation were excluded from further data analysis because of excessive stimulation. Once surgery started, no further hemodynamic data were collected, and anesthetic management was at the discretion of the attending anesthesiologists.

Data Collection

Demographic data including age, sex, height, and weight were recorded. Patients diagnosed with preexisting cardiovascular disease (CVD) (*i.e.*, ischemic heart disease, heart failure, mild to moderate valve disease, stroke, and/or hypertension) were identified. Current medications for treating hypertension were also recorded. BP and HR were collected just before induction (*i.e.*, baseline) and then after induction for 10 min after tracheal intubation. The mean blood pressure (MBP) reading immediately before induction was defined as baseline. Patients with a baseline MBP lower than 70 mmHg were excluded. BP and HR were recorded during the postinduction study period; noninvasive BP was recorded at least every 2 min, while invasive BP was recorded every 1 min. Patients remained supine throughout the study, and only mild-level stimulation, such as urinary catheterization and surgical area prepping, was allowed. Severe (*i.e.*, MBP less than 55 mmHg) or prolonged (*i.e.*, duration greater than or equal to 2 min) episodes of hypotension were treated using intravenous boluses of ephedrine (3 mg) or phenylephrine (100 µg). Atropine (0.3 mg) was used for significant bradycardia (HR less than 40 beats/min).

Episodes of hypotension in the period after induction of anesthesia were defined by a more than 30% decrease in MBP from the baseline level or any recorded period of MBP lower than 60 mmHg.

Statistical Analysis

Sample Size. A pilot study of 26 patients detected an area under the ROC curve (AUC) of 0.7 for CI, which predicted a more than 30% decrease in MBP. Based on this result, a sample of 89 patients achieved 90% power to detect a difference of 0.2 between the AUC of 0.5 computed using the null hypothesis and the AUC of 0.7 computed using an alternative hypothesis using a two-tailed *z*-test at a significance level of 0.05.[32]

Data Analysis. Data collected during the study were compiled using Excel spreadsheets (Microsoft, USA). The lowest MBP recorded after induction was used to calculate the percentage decrease in MBP from baseline in each patient. The percentage changes in HR from baseline level, either increase or decrease, were also calculated, and the largest change was used for analysis. Normality of data was tested with Kolmogorov–Smirnov one-sample test. Data were presented as mean ± standard deviation (SD) for continuous variables and as absolute numbers or percentages for categorical variables. The development of clinically significant hypotension after induction was analyzed with respect to patient characteristics, hemodynamic data, and IVC measurements using Student's *t* test or χ^2 test where appropriate. The Pearson correlation coefficient (*r*) was used to test the relationship between IVC measurements and percentage decrease in MBP from baseline level after induction of general anesthesia.

The ROC curve analysis was performed to determine the ability of the two ultrasound-derived parameters, $dIVC_{max}$ and CI, to predict clinically significant hypotension after induction of general anesthesia for all patients. The AUCs with 95% confidence intervals were calculated. Comparison of the two ROC curves was performed using the nonparametric technique described by DeLong *et al.*[33] The optimal cutoff values were identified as the values that maximize the Youden index (sensitivity + specificity − 1).[34] Sensitivity and specificity with 95% confidence intervals for the optimal cutoff values were calculated. The gray zone approach described by Coste and Pouchot[26] was used to determine an inconclusive range of IVC measurement values. The cutoff values delimiting the gray zone were defined by the values associated with a sensitivity of 90% and a specificity of 90%. One of the IVC measurements (CI or $dIVC_{max}$) with greater predictive ability based on ROC curve analysis was chosen for subgroup analyses of patients with and without CVD.

To test the association between IVC measurements and hypotension after induction, a multivariate logistic regression was performed. According to clinical practice and review of literature, the following confounders were included: age, ASA physical status, preexisting CVD, and the baseline MBP. Multivariate linear regression was also conducted to predict the percentage decrease in MBP after induction from IVC measurements and other parameters. Independent predictors included in the analysis were age, ASA physical status, preexisting CVD, baseline MBP, IVC-CI, and $dIVC_{max}$. A series of models with different predictors were tested, and the model with the maximum adjusted R^2 was chosen.

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp, USA) and MedCalc for Windows, version 13.0 (MedCalc Software, Belgium). A *P* value of less than 0.05 (two-tailed) was considered statistically significant.

Results

Patient Data

One hundred four patients were recruited. Fourteen (13.5%) were excluded because of poor IVC visualization. Data from the remaining 90 patients were analyzed. Fifty-four patients had preexisting CVD. Among these, 34 patients had a history of hypertension, 17 were taking β-blockers, 18 were on calcium channel blockers, 4 were on thiazide diuretics, and 5 were not on medications. Patients taking angiotensin-converting enzyme inhibitor and angiotensin receptor blocker were excluded. No patient had a difficult and prolonged intubation. The following surgical operations were included: cardiac (n = 33), orthopedic (n = 30), general (n = 12), urology (n = 6), thoracic (n = 5), neurosurgical (n = 2), and gynecology (n = 2). Of the 90 patients, 49 had invasive BP monitoring. No patient had a baseline MBP of less than 70 mmHg. Demographic characteristics are summarized in table 1.

Hemodynamic Data

After induction of general anesthesia, 42 (46.7%) patients developed hypotension according to the study criteria. Among these, 11 had an MBP less than 60 mmHg and 3 did not have more than 30% decrease in MBP. Three patients received phenylephrine and three received ephedrine for severe hypotension lasting more than 2 min. Another patient received atropine for bradycardia. There were 23 of 49 patients having BP measured invasively, and 19 of 41 patients having BP measured noninvasively developed hypotension. No statistical differences were detected between them ($P = 0.96$). Patients who developed hypotension were older ($P = 0.03$). There were no significant differences in baseline MBP, HR, and percentage changes in HR after induction between patients who developed hypotension and those with more stable blood pressures. Patients who developed hypotension had a smaller $dIVC_{max}$ ($P < 0.0001$) and a larger CI ($P < 0.0001$; table 2). There was a weak association between the decreases in MBP after induction and the IVC measurements. The percentage decrease was negatively correlated with $dIVC_{max}$ ($r = -0.27$; $P = 0.01$) and positively correlated with CI ($r = 0.46$; $P < 0.0001$; fig. 2).

Prediction of Hypotension

ROC Curve Analysis for All Patients. The ROC curve analysis for predicting hypotension after induction of general anesthesia demonstrated good diagnostic accuracy when using the CI as the AUC was 0.90 (95% confidence interval, 0.82 to 0.95; $P < 0.0001$). The optimal cutoff value of CI was 43%, with a sensitivity of 78.6% (63.2 to 89.7%) and a specificity of 91.7% (80.0 to 97.7%). The diagnostic accuracy was less good when using $dIVC_{max}$ compared with the accuracy when using the IVC-CI ($P = 0.002$) as the AUC was 0.76 (0.66 to 0.84; $P < 0.0001$). The optimal cutoff value of $dIVC_{max}$ was 1.8 cm, with a sensitivity of 73.8% (58.0 to 86.1%) and a specificity of 70.8% (55.9 to 83.0%; fig. 3).

Gray zone plots were drawn (fig. 4) using the sensitivity and specificity for hypotension after induction (as y-axis) against the two IVC measurements, CI and $dIVC_{max}$ (as x-axis). The gray zone was created between the 90% sensitivity and the 90% specificity points on the two sigma curves. For CI, the gray zone lay between 38.2 and 42.7%. For convenience, the zone was extended to integers (*i.e.*, 38 to 43%) and contained 11 (12%) patients. Three patients who had a CI less than the lower limit of the gray zone developed hypotension. Two of them had coronary artery disease and the third had hypertension. The gray zone for $dIVC_{max}$ lay between 1.5 and 2.1 cm and contained 53 (59%) patients.

Subgroup Analysis. In patients with preexisting CVD (n = 54), the AUC was 0.86 (0.73 to 0.93) for CI ($P < 0.0001$) and the optimal cutoff value was 38%, with a sensitivity of 85.2% (66.3 to 95.8%) and a specificity of 81.5% (61.9 to 93.7%). The gray zone lay between 29 and 43%.

In patients without preexisting CVD (n = 36), the AUC was 0.89 (0.62 to 0.95) for CI ($P < 0.0001$) and the optimal cutoff value was 43%, with a sensitivity of 93.3% (68.1 to 99.8%) and a specificity of 81.5% (76.2 to 99.9%). The gray zone lay between 42 and 44% (fig. 5).

Regression Analysis. After adjusting for age, ASA physical status, preexisting CVD, and baseline MBP, it was found that CI was a significant independent predictor of hypotension after induction ($P < 0.0001$), whereas the $dIVC_{max}$ was not ($P = 0.62$). Patients with larger CI were more likely to

Table 1. Patients Characteristics (n = 90)

Variable	
Age, yr	52 ± 17
Sex (male/female)	43/47
Height, cm	165 ± 8
Weight, kg	66 ± 12
BMI, kg/m^2	24.2 ± 4.1
History of hypertension	34 (38%)
Preexisting CVD	54 (60%)
ASA (I/II/III)	27/36/27

Data are expressed as mean ± SD or absolute number (percentage).
ASA = American Society of Anesthesiologists physical status; BMI = body mass index; CVD = cardiovascular disease.

Table 2. Comparison of Patient Characteristics, Hemodynamic Data, and Preoperative Inferior Vena Cava (IVC) Ultrasound Measurements between Patients Who Did and Did Not Develop Hypotension after Induction of General Anesthesia

	Developed Hypotension		
Variable	Yes (n = 42)	No (n = 48)	*P* Value
Age, yr	56 ± 18	48 ± 15	0.03
Sex (male/female)	17/25	26/22	0.20
BMI, kg/m^2	23.5 ± 4.0	24.8 ± 4.2	0.16
ASA (I/II/III)	11/18/13	16/18/14	0.75
History of hypertension (yes/no)	19/23	15/33	0.17
Preexisting CVD (yes/no)	27/15	27/21	0.44
Baseline MBP, mmHg	104 ± 17	98 ± 12	0.06
Baseline HR, beats/min	79 ± 14	74 ± 13	0.10
Percentage change in HR (%)	23.6 ± 0.1	23.2 ± 0.1	0.82
IVC-CI (%)	50 ± 11	31 ± 12	<0.0001
$dIVC_{max}$, cm	1.6 ± 0.4	2.0 ± 0.3	<0.0001

ASA = American Society of Anesthesiologists physical status; BMI = body mass index; CI = collapsibility index; CVD = cardiovascular disease; $dIVC_{max}$ = maximum diameter of IVC; HR = heart rate; MBP = mean blood pressure.

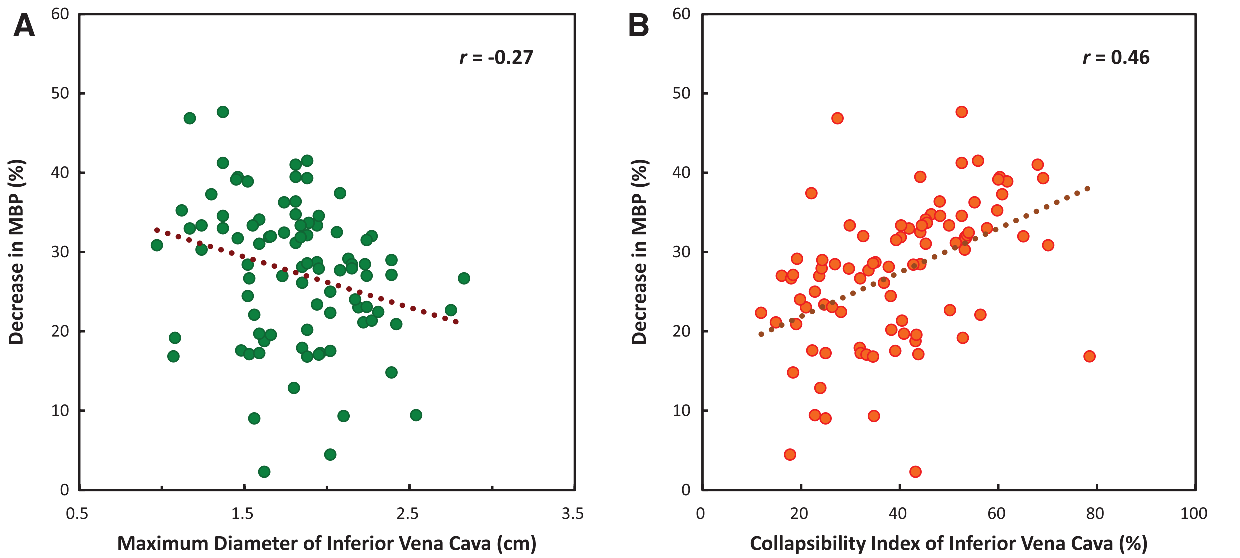

Fig. 2. Scatter plots showing the relationships of preoperative maximum diameter (*A*) and collapsibility index (*B*) of inferior vena cava with percentage decrease in mean blood pressure from baseline after induction of general anesthesia. Trend lines are presented as *dotted line*. MBP = mean blood pressure.

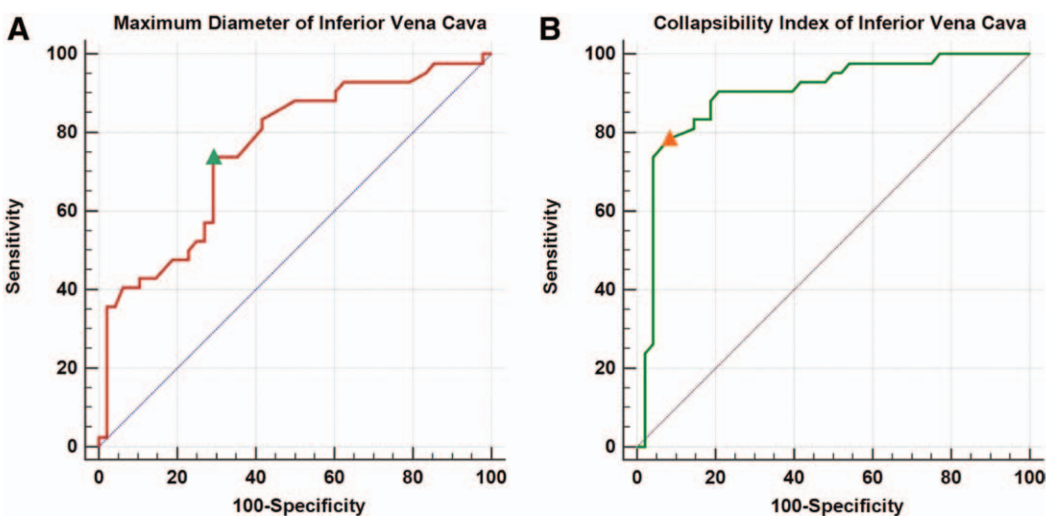

Fig. 3. Receiver operating characteristic curves showing the ability of preoperative maximum diameter (*A*) and collapsibility index (*B*) of inferior vena cava to predict hypotension after induction of general anesthesia. The *triangles* on the curves indicate the optimal cutoff values determined by maximizing the Youden index.

develop hypotension after induction, with the odds ratio of 1.17 (1.09 to 1.26). There was also an association between baseline MBP and hypotension, with the odds ratio of 1.05 (1.01 to 1.11; $P = 0.03$). The results are presented in table 3.

The multivariate linear regression model that included age, preexisting CVD, baseline MBP, and CI as predictors produced adjusted $R^2 = 0.33$, $R^2 = 0.36$, and $F(4,85) = 11.83$ ($P < 0.0001$). As can be seen in table 4, CI and baseline MBP had a significant positive association with the percentage decrease in MBP after induction ($P < 0.0001$ and $P = 0.001$, respectively).

Discussion

We found that ultrasound IVC measurements before induction of general anesthesia were predictive of subsequent hypotension, and the CI was more predictive than $dIVC_{max}$ ($P = 0.002$). Cutoff values for predicting hypotension after induction from IVC scanning were 43% for CI and 1.8 cm for $dIVC_{max}$. Gray zones were 38 to 43% and 1.5 to 2.1 cm, respectively.

Guidelines from the American Society of Echocardiography support the use of IVC size and collapsibility in the assessment of volume status.[29] Evidence suggests that IVC diameter is a reliable indicator of volume status,[25] and respiratory variation is of value when predicting fluid responsiveness.[21] A greater CI suggested a low volume status, especially with a small IVC diameter.[17] The IVC measurements we investigated were based on the above and had moderate to good reliability.[35] Wallace *et al.*[36] found that CI was affected by sampling location. We limited sampling to 2 to 3 cm

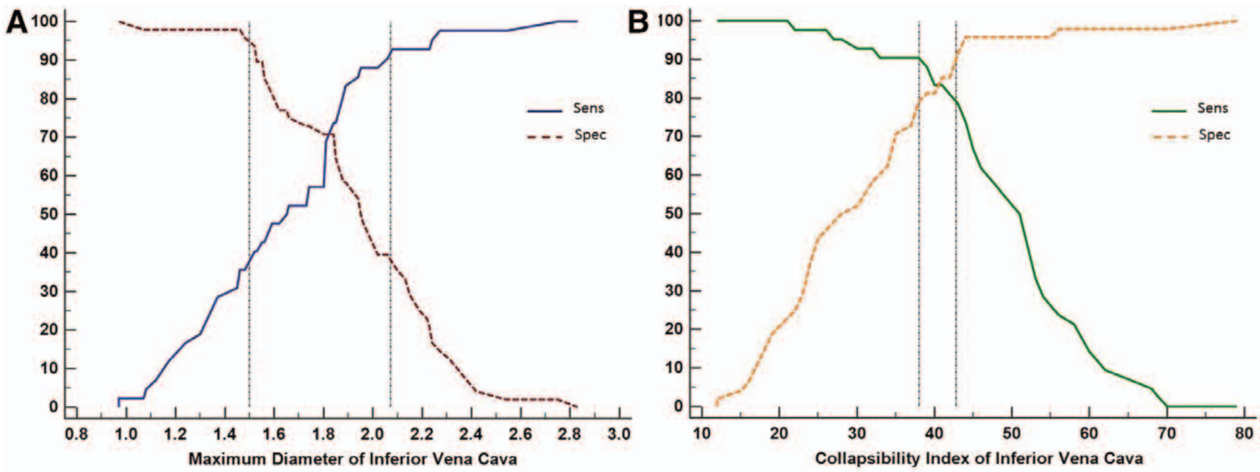

Fig. 4. Sensitivity and specificity plots predicting hypotension after induction according to values of preoperative maximum diameter (*A*) and collapsibility index (*B*) of inferior vena cava to determine their gray zones. The two *dotted lines* indicate the gray zone. Sens = sensitivity; Spec = specificity.

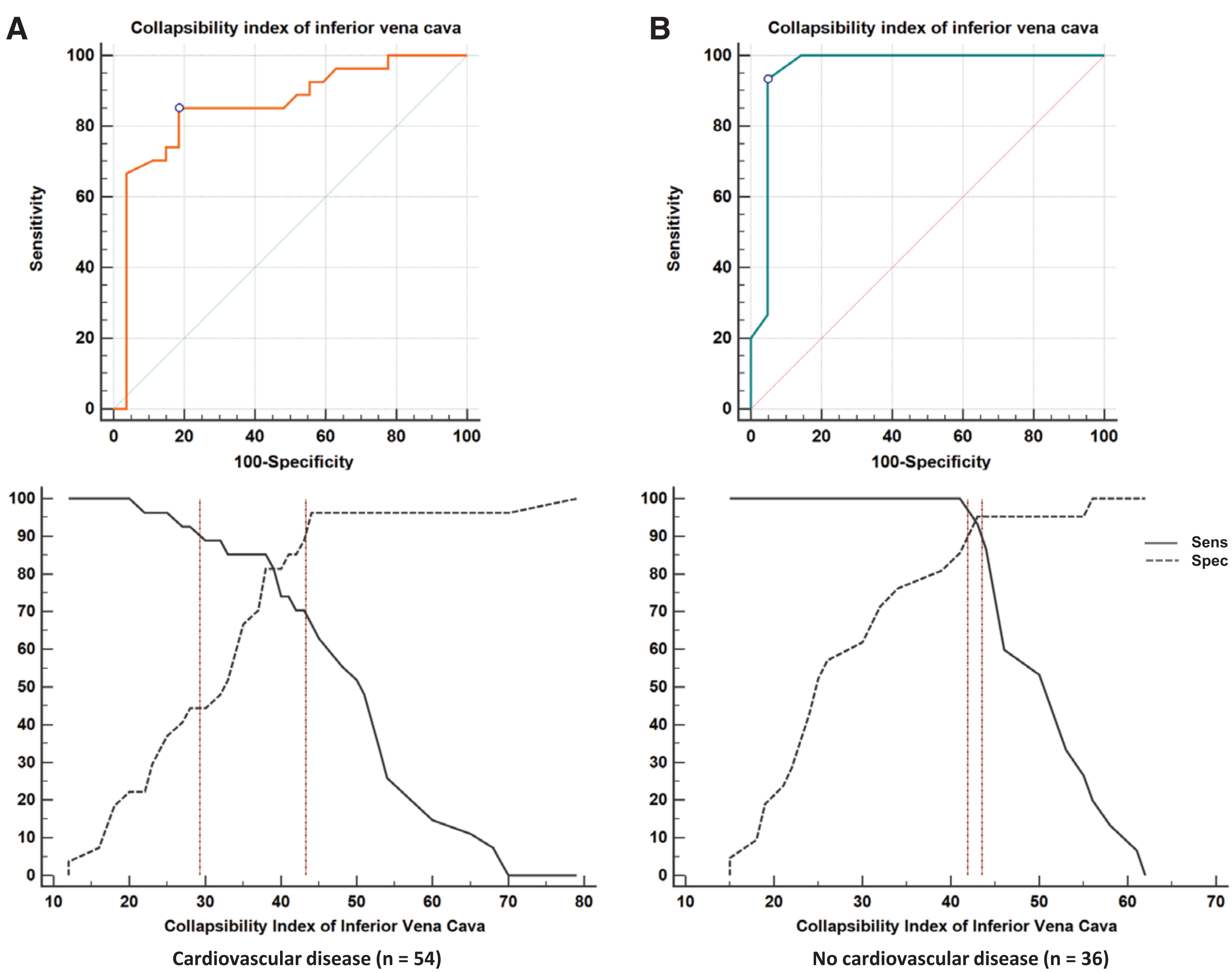

Fig. 5. Receiver operating characteristic curves and plots of sensitivity and specificity showing the predictive ability and gray zones of collapsibility index of inferior vena cava for hypotension after induction in patients with (*A*) (n = 54) and without (*B*) (n = 36) preexisting cardiovascular disease. The *open circles* on the curves indicate the optimal cutoff value. Sens = sensitivity; Spec = specificity.

Table 3. Multivariate Logistic Regression of 90 Patients for Hypotension after Induction

Predictors	Regression Coefficient	Odds Ratio	95% Confidence Interval of Odds Ratio	*P* Value
Constant	−11.37	NA	NA	0.003
Age	0.02	1.03	0.97–1.08	0.42
ASA overall				0.71
ASA II	−0.09	0.92	0.12–6.85	0.93
ASA III	0.62	1.85	0.16–22.15	0.63
Preexisting CVD	−1.14	0.32	0.04–2.36	0.27
Baseline MBP	0.05	1.05	1.01–1.11	0.03
IVC-CI	0.16	1.17	1.09–1.26	<0.0001
$dIVC_{max}$	−0.50	0.61	0.08–4.37	0.62

ASA = American Society of Anesthesiologists physical status; CI = collapsibility index; CVD = cardiovascular disease; $dIVC_{max}$ = maximum diameter of IVC; IVC = inferior vena cava; MBP = mean blood pressure; NA = not applicable.

Table 4. Multivariate Linear Regression Model for Predicting Percentage Decrease in MBP (%) after Induction of General Anesthesia (n = 90)

Predictors	Regression Coefficient (β)	95% Confidence Interval	*P* Value
Constant	−7.55	−19.66 to 4.57	0.22
Age	0.08	−0.03 to 0.18	0.15
Preexisting CVD	−2.14	−5.88 to 1.60	0.26
Baseline MBP	0.21	0.09 to 0.33	0.001
IVC-CI	0.27	0.17 to 0.38	<0.0001

Preexisting CVD was coded as 0 = no, 1 = yes.

CI = collapsibility index; CVD = cardiovascular disease; IVC = inferior vena cava; MBP = mean blood pressure.

distal to the entry of IVC into the right atrium. Our patients were Chinese who are slimmer than Europeans or Africans and potentially easier to scan. Thus, our scan failure rate of IVC of 13.5% was better than that in other studies.[37] Muller *et al.*[38] found that a CI of more than 40% was predictive of fluid responsiveness. Our study found a similar optimal cutoff value of 43% for predicting hypotension after induction. The predictive ability of $dIVC_{max}$ for hypotension was less reliable as the size of IVC varies widely among healthy individuals.[20]

We used etomidate for anesthesia induction because propofol causes hypotension after induction[8] due to vasodilation and myocardial inhibition.[39,40] The adrenal suppression of etomidate is primarily a concern in septic and trauma patients, and its hemodynamic stability was a desirable property.[41] Furthermore, etomidate is being used for the induction of cardiac surgery cases, which represented 36.7% of studied patients.

Although intraoperative hypotension is a frequent side effect of anesthesia, its definition varies among clinical studies. Bijker *et al.*[1] found 140 definitions in the literature, which results in different reported incidences of hypotension. We chose an MBP decrease greater than 30% from baseline or MBP less than 60 mmHg as our definitions of hypotension.[1] Our study period was from induction to 10 min after tracheal intubation during which no dramatic hemodynamic changes from major external interference were expected. The incidence of hypotension was 47%. The inclusion of older patients (mean 52 ± 17 yr) and patients with CVD (60% cases) might have contributed to this high incidence.

Most IVC ultrasonography studies have investigated the ability to predict fluid responsiveness for guiding fluid therapy in resuscitation and intensive care settings. In anesthesia, optimizing volume status is the focus, with fluid responsiveness being defined as a 10 to 15% increase in cardiac output.[42] However, a recent survey found that only 34% of anesthesiologists in America and Europe used cardiac output monitoring in high-risk surgery.[43] Therefore, most anesthesiologists use a very basic level of hemodynamic monitoring, with blood pressure and HR being their main measurements, and hence, inclusion of bedside IVC ultrasound would help identify those patients who need fluid optimization.

We determined the utility of IVC ultrasonography to predict blood pressure changes after induction. A CI of more than 43% was highly predictive, with high specificity (91.7%) and moderate sensitivity (78.6%). In comparison, a $dIVC_{max}$ of less than 1.8 cm was less predictive (P = 0.002), with moderate sensitivity (73.8%) and specificity (70.8%). To avoid dichotomizing the results, a gray zone approach based on 90% sensitivity and specificity has been developed.[27,44] The proportion of results in the gray zone is critical to test utility.[26] For $dIVC_{max}$, 59% of patients were in the gray zone (1.5–2.1 cm) compared with only 12% of patients in the gray zone for CI (38 to 43%), suggesting that only CI is clinically useful. IVC visualization failed in another 13.5% of patients, suggesting a 75% success rate for IVC assessment.

Because many of the patients had CVD, we analyzed this subgroup. Results showed that patients with CVD had a lower cutoff value of 38% for CI, with a wider gray zone (29 to 43%). For patients without CVD, results were 43% with a narrower gray zone (41 to 44%), suggesting that CI was less reliable in patients with CVD. In patients with CVD, compromise of the cardiovascular system may play a role in hemodynamic changes associated with induction. Furthermore, all the three false-negative patients who developed hypotension and yet had CIs below the lower gray zone limit of 38% had CVD. Furthermore, larger sample size studies on different subgroups of patients are merited.

CI was an independent predictor of hypotension after induction after adjusting for age, ASA physical status, CVD, and baseline MBP (table 3). Adjusted odds ratio was 1.17. CI was also positively correlated with the percentage decrease in MBP (r = 0.46). This association persisted after adjustment for age, preexisting CVD, and baseline MBP. According to the multivariate linear regression, an increase of 10% in CI resulted in a 3% larger decrease in MBP (table 4). Baseline MBP was also a predictor of hypotension with adjusted odds ratio of 1.05, possibly because we defined hypotension based on MBP. The decrease in MBP was 2% larger for each 10 mmHg increase in baseline MBP (table 4). However, only one reading of MBP was taken before induction to define its baseline; thus, some effects can be attributed to the statistical phenomenon of "regression to the mean."[45] Reich *et al.*[8] found old age to be a significant predictor of hypotension after induction, but it was not a significant predictor in the current study. This may have been due to the small sample size and inclusion of older patients. Moreover, comparison analysis showed that patients who developed hypotension tended to be older.

Ultrasound techniques are increasingly in use throughout clinical anesthesia practice, such as in peripheral nerve blocks, central venous catheterization, and transthoracic echocardiography. With greater availability of high-definition point-of-care ultrasound technology in the operating room, incorporating scanning into daily anesthesia practice becomes easier. Therefore, ultrasound examination of the IVC before general anesthesia to screen those patients at risk of developing hypotension, especially the elderly and those suspected of hypovolemia, is desirable. Future clinical research should focus on the effectiveness of preinduction intravenous fluids when CI readings predict postinduction hypotension.

Limitations

The current study had several limitations. First, an operator with basic level experience in echocardiography performed the ultrasound IVC measurements. However, reliability of ultrasound IVC evaluation does not depend on the operator's level of echocardiography experience.[37] A short period of training with 20 clinical cases significantly improved the diagnosis of vascular overload by internal medicine residents.[46] Second, we did not evaluate the precision of IVC measurements. A previous study had demonstrated moderate inter-rater reliability for IVC measurement. Furthermore, we repeated the IVC scan three times in each patient, and differences between $dIVC_{max}$ readings were always less than 0.2 cm. Third, we were unable to measure IVC collapsibility reliably after induction because the patient's ventilation changed from spontaneous to positive pressure. Thus, changes in CI after induction were lacking from the study. Fourth, blood pressure was measured by two different methods (*i.e.*, oscillometric and invasive). However, these measurements are interchangeable when routinely used during surgery and correlate well with each other in adults.[47] The numbers of hypotensive patients measured by the invasive or noninvasive blood pressure groups were similar in this study. After induction, the lowest reading of MBP was used to calculate the percentage decrease in MBP, which introduced random errors. Given that blood pressure data were collected at 1- to 2-min intervals and restricted to a short duration of 10 min, the data points were limited and the lowest value was used and alternatives such as the mean of the lowest three values would not be practical. Finally, heterogeneity of the types of surgery studied may have influenced the power of the study. However, the inclusion of different types of surgery does reflect clinical practice and provides a more general result.

Conclusions

Ultrasound scanning of the IVC and measurement of the CI preoperatively provides a reliable predictor of hypotension after induction of general anesthesia in 75% of patients, wherein clinically relevant hypotension is defined as a decrease in MBP from baseline more than 30% or MBP lower than 60 mmHg. The threshold for predicting hypotension was a CI greater than 43%. CI was also positively associated with a percentage decrease in MBP after induction. However, 12% of patients' CI values fell into the inconclusive gray range of 38 to 43%, and in 13.5% of patients, the IVC could not be scanned successfully. The gray zone for CI was wider in patients with preexisting CVD. Clinically, preoperative CI measurements were easy and rapid (*i.e.*, scan time less than 10 min) to obtain, and point-of-care ultrasound is becoming more-and-more readily available in anesthesia areas. Thus, in patients at high risk of complications resulting from intraoperative hypovolemia and hypotension, measurement of IVC-CI may provide clinically useful information. Future research based on CI measurements is needed to determine the best intravenous fluid strategies to reduce postinduction hypotension.

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Competing Interests

The authors declare no competing interests.

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