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Comparison of ultrasound-based measures of inferior vena cava and internal jugular vein for prediction of hypotension during induction of general anesthesia

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ABSTRACT

Background: Hypotension after GA induction may induce organ injury. Ultrasonographic IVC and IJV studies for intravascular volume assessment and hypotension prediction were established. This study compared between them in prolonged hypotension during induction of GA prediction.

Methods: One-hundred sixty three adult patients, of ASA physical status I & II, for elective surgery under GA were screened. One hundred thirty three patients were included. Preoperative ultrasonographic IVC parameters (dIVC max, dIVC min & CI) and IJV parameters (IJV area in supine and Trendelenberg positions & IJV change rate) measurements were recorded with baseline MBP. After anesthetics administration, MBP was recorded every minute for 15 minutes. Intubation was established after 3 minutes. Study used hypotension definition as over 20% decrease from baseline MBP. Prolonged hypotension definition used was hypotension duration ≥ 2 minutes. Severe hypotension definition used was decreased MBP from baseline value over 40%.

Results: Six patients didn't satisfy inclusion criteria; seventeen patients showed low IVC visualization and 133 patients were involved. The prolonged hypotension after GA induction incidence was 63.2% (84 patients), while severe hypotension incidence was 9% (12 patients). IJV change rate > 0.28 predicted prolonged post-induction hypotension with specificity 76% (95% confidence interval, 61–87%) and sensitivity 55% (95% confidence interval, 44–66%). IJV change rate > 0.35 predicted severe post-induction hypotension with specificity 72% (95% confidence interval, 63–80%) and sensitivity 75% (95% confidence interval, 43–95%). Alternatively, no IVC measure reliably estimated prolonged or severe post-induction hypotension.

Conclusion: IJV surpasses IVC in prolonged post-induction hypotension prediction with moderate predictive value.

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Hypotension; ultrasonography; IVC; IJV

1. Introduction

Hypotension repeatedly follows general anesthesia (GA) induction [1] and no matter how short the period is, it may possibly lead to tissue hypoperfusion and prompt postoperative complications [2]. Intra-operative hypotension may as well be accompanied with renal injury, ischemic stroke, myocardial injury and postoperative mortality in non-cardiac surgeries under GA [3–5]. Therefore, safe intraoperative management compels prevention of such adverse hypotension.

While most of the risk factors for post-induction hypotension can't be improved [6,7], hypovolemia is considered the most common modifiable risk factor for hypotension after anesthetics administration [8]. The majority of perioperative patients present with some degree of hypovolemia before surgery. Although the deficit is usually minor, some patients present with a deficit of clinical significance [9] and this has been shown to be associated with worse clinical consequences [10].

Assessment of volume status can be done with non-invasive, insignificantly invasive and invasive methods [11]. A simple non-invasive method like ultrasonography can precisely identify hypovolemia to help optimization of the volume state before proceeding with GA & subsequently prevent post-induction hypotension.

Ultrasonographic scanning of the inferior vena cava [8,12] and the internal jugular vein [13,14] for assessment of intravascular volume state and hypotension estimation during induction of GA has been separately established in many previous studies, yet no studies had compared IVC & IJV ultrasonographic measurements in prediction of prolonged hypotension after induction of GA (hypotension of duration ≥ 2 minutes) [15].

1.1. *IVC ultrasonography*

Assessment of IVC diameter with respiration in addition to its collapsibility index (CI) using ultrasonography were suggested as noninvasive and rapid methods to

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evaluate the volume state [16,17]. Moreover, these measurements were suggested as easily obtainable and repeatable by personnel with not much experience performing echocardiography [18]. In addition, IVC ultrasonography has been widely considered to predict fluid responsiveness in a diverse of medical situations [19]. Preoperative estimate of IVC collapsibility index provided a dependable prediction of hypotension after GA induction in 75% of patients. The predicting threshold of hypotension was CI more than 43%. CI was also clearly connected to a proportionate reduction in MBP following GA induction [8].

Following the approach defined by the American Society of Echocardiography, IVC visualization can be done with a long-axis para-median view using a subcostal approach [20]. Using Pulse wave Doppler, the IVC can be differentiated from the aorta. After obtaining a two-dimensional image of the IVC entering the right atrium, variants in diameter of IVC with respiration were calculated by M-mode imaging 2–3 cm distal to the right atrium [21]. The maximum diameter (dIVC max) and minimum diameter (dIVC min) of IVC along a single cycle of respiration are obtained via built-in software. Then CI was calculated as follows: CI = (dIVC max − dIVC min)/dIVC max [8].

1.2. IJV ultrasonography

Non-invasive estimation of CVP using IJV ultrasonography has been previously reported [22]. Furthermore, intravascular volume and fluid responsiveness estimation using ultrasound IJV has been demonstrated in previous studies [14,23]. In shock patients, assessment of intravascular volume deficit and fluid responsiveness using passive leg raising test showed some value. Similar to passive leg raising, change in the IJV size variation with posture alteration from supine to Trendelenburg position was shown to be a predictor of post-induction hypotension [13].

To obtain a clear transverse view of the IJV, the ultrasound probe is positioned horizontally to one side of the central level of thyroid cartilage accompanied with the slightest pressure using enough gel not to push the IJV during the procedure [13].

To our knowledge, we didn't find any studies comparing IVC & IJV ultrasonographic measurements in prediction of prolonged hypotension after GA induction (hypotension of duration ≥ 2 minutes) [15].

2. Methodology

This was an Observational study performed at Kasr Al-Ainy hospital, Cairo University. The study population was chosen to be patients undergoing elective non-cardiac surgery under GA. Inclusion criteria were patients ages between 18 and 50 years old, belonging to ASA I, II and listed for non-cardiac surgical procedure under GA. Exclusion criteria included patients presenting with major vascular disease, ejection fraction < 40%, unstable angina, respiratory distress, elevated intra-abdominal pressure, diabetes mellitus, implanted pacemaker and patients on ACEI or ARB or with anticipated difficult intubation.

On arrival to the operating theatre, routine monitors in the form of pulse oximetry, electrocardiogram and non-invasive blood pressure monitors were applied. An intravenous line was inserted and routine premedications (ondansetron 4 mg and ranitidine 50 mg) were administered.

2.1. IVC Ultrasonography

IVC evaluation was done with patients in supine position. The examination was performed after 5 minutes rest. Using the curved ultrasound transducer adjusted to abdominal mode (1–5 MHz; Acuson x300; Siemens Healthcare, Seoul, Korea) was placed in the subcostal area to visualize the IVC in the paramedian long-axis view [20]. The IVC was visualized using two-dimensional mode at the site where it enters the right atrium; then, pulse wave Doppler was used to distinguish if the viewed structure is the IVC or the aorta. Respiratory variants of the diameter of IVC were evaluated using M-mode imaging at medium sweep speed 2–3 cm distal to the right atrium site [21]. The measures were obtained 3 times and their average was calculated. Maximum IVC diameter and minimum IVC diameter were used along a single respiratory cycle to calculate the collapsibility index as follows:

$$\frac{dIVCmax - dIVCmin}{dIVCmax}$$

Collapsibility index was expressed as a percentage [24].

2.2. IJV Ultrasonography

IJV measurements were obtained in the supine position using a linear ultrasound transducer (5–13 MHz; Acuson x300; Siemens Healthcare, Seoul, Korea). We positioned the probe horizontally at the middle level of the thyroid cartilage. After obtaining a transverse clear view of the right IJV, the IJV area was measured. The measures were repeated after shifting the position of the patient to 10° Trendelenburg position [13]. The maximum IJV area in supine and Trendelenburg positions was recorded and the rate of change in IJV area was calculated as follows: [13].

$$\text{IJV change rate with posture} = \frac{\text{IJV area in Trendelenburg position} - \text{IJV area in supine position}}{\text{IJV area in Trendelenburg position}}$$

All ultrasonographic measurements were accomplished by a solitary trained anesthesiologist.

2.3. Induction of anesthesia

After finishing the ultrasonographic inspections, GA was induced injecting 2 mg/kg of propofol and 2 mcg/kg of fentanyl, then by injecting atracurium (0.5 mg/kg) to aid endotracheal tube insertion. Mask ventilation was commenced with the cessation of spontaneous breathing caused by propofol administration and inhalational isoflurane targeting a MAC of 0.7–0.8 was started. The rate of crystalloid fluid infusion was fixed at 4 mL/kg/hr during the study period. After 3 minutes of mask ventilation, endotracheal intubation was performed. Patients who for any reason experienced prolonged instrumentation of their airway accompanied by difficult endotracheal intubation were omitted from further data analysis due to extreme stimulation.

Any hypotension episode, defined as MBP <80% of the baseline reading [25], was managed by intravenous bolus of norepinephrine (5 μg). If the hypotension continued for 2 minutes, another bolus of norepinephrine was injected. Any bradycardia episode (defined as heart rate less than 55 bpm) was managed by atropine (0.01 mg/kg).

2.4. Measurement tools

Mean blood pressure was measured with the patient lying in supine position in either upper limb beginning from the baseline preoperative reading till skin incision at 1-minute intervals, taking in consideration that the maximum duration for recording the readings of the blood pressure is 15 minutes because if hypotension occurred after this duration it is unlikely to be due to the effect of induction of anesthesia. **Heart rate** recorded beginning from the baseline pre-operative reading at 1-minute intervals until 15 minutes after anesthetics administration or until skin incision whichever is earlier. **Norepinephrine consumption** was calculated for each patient. **Demographic data**: (age – gender – comorbidities – current medications) were routinely collected. Also **incidence of prolonged post-induction hypotension, incidence of severe post-induction hypotension** and **incidence of bradycardia** were determined.

3. Study outcomes

The primary outcome was comparing the accurateness (area under receiver operating characteristic curves) of IVC and IJV variations in prediction of prolonged post-induction hypotension (defined as MBP < 80% of the baseline reading for 2 minutes or more), while **secondary outcomes** included incidence of prolonged post-induction hypotension, accuracy of maximum diameter of IVC in predicting prolonged post-induction hypotension, accuracy of minimum diameter of IVC in predicting prolonged post-induction hypotension, accuracy of IVC collapsibility index in predicting prolonged post-induction hypotension, accuracy of IJV area in supine position in predicting prolonged post-induction hypotension, accuracy of IJV area in Trendelenburg position in predicting prolonged post-induction hypotension, accuracy of IJV change rate in predicting prolonged post-induction hypotension, incidence of severe post-induction hypotension (defined as MBP < 60% of the baseline preoperative reading) until 15 minutes after anesthetics administration or until skin incision whichever is earlier, mean blood pressure measured beginning from the baseline preoperative reading at 1-minute intervals until 15 minutes after anesthetics administration or until skin incision whichever is earlier, heart rate recorded beginning from the baseline pre-operative reading at 1-minute intervals until 15 minutes after anesthetics administration or until skin incision whichever is earlier and norepinephrine consumption.

3.1. Statistical analysis

3.1.1. Sample size

In a previous study, the AUROC of IVC-CI in predicting hypotension was 0.9 (8). We designed our sample size using MedCalc software to detect a difference of 0.1 between the AUROC of both desired outcomes. The minimum number that was needed to have a study power of 80% and alpha error of 0.05 was 93 patients with at least 31 positive cases (prolonged hypotension).

3.1.2. Statistical analysis

Data was computer entered using "Microsoft Office Excel Software" program (2010) for windows, then transported to the Statistical Package of Social Science Software program, version 23 (IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.) for statistical analysis. Categorical data was presented as frequencies (%) and analyzed using chi-square test. Continuous data was presented as means (standard deviations) or medians (quartiles) and was analyzed using unpaired t-test or Mann Whitney test as suitable. Repeated measures were analyzed using two-way analysis of variance (ANOVA) test. AUROC was calculated for the accuracy of the two measures in predicting post-induction hypotension. Sensitivity, specificity, positive predictive values, negative predictive values, and cutoff values for both measures were calculated. The AUROC was compared using Henley McNeil test. Correlation was tested using either Pearson's or Spearman's tests according to data normality. A P value less than 0.05 was considered statistically significant.

3.2. Results

One-hundred and sixty three patients were examined for eligibility, 6 patients were excluded for not fulfilling the inclusion criteria, 14 patients were excluded due to poor visualization of IVC, 10 patients were excluded for prolonged airway instrumentation during intubation and 133 patients were included and were presented for the final analysis (Figure 1 and 2).

The included patients had median (quartiles) age of 32 (23, 43) years and 72 (44%) of them were males (Table 1).

The incidence of severe post-induction hypotension was 12 (9%), and the incidence of prolonged post-induction hypotension was 84 (63%) (Table 1).

The IJV change rate, baseline systolic blood pressure and baseline mean blood pressure were greater in the hypotensive patients than non-hypotensive patients. The IVC derived parameters showed no statistically significant difference between hypotensive and non-hypotensive patients (Table 2).

The AUC for the ability to predict either severe or prolonged post-induction hypotension was only significant for the IJV change rate (AUC [95% confidence interval]: 0.74 [0.66–0.81] and 0.61 (0.52–0.69), respectively. (Tables 3 and 4)

4. Discussion

In the current study, the ultrasound guided measurements of IJV change rate demonstrated moderate ability to predict prolonged and severe post-induction hypotension. Otherwise; other IJV parameters (IJV

Table 1. Demographic data and hemodynamic characteristics. Presenting data as median (quartiles) and frequency (percentage).

Age (years)	32 [23, 43]
Male sex	72 (44%)
ASA physical status	
I	117 (72%)
II	16 (10%)
Weight (kg)	74 (63, 83)
Height (cm)	166 (157, 175)
Inferior vena cava	
• Maximum diameter (mm)	15.6 (13.2, 18.2)
• Minimum diameter (mm)	10.2 (8.1, 12.2
• Collapsibility index	0.36 (0.25, 0.45)
Internal jugular vein	
• Supine area (mm^2)	9.7 (6.8, 14.5)
• Trendelenburg area (mm^2)	14.7 (9.8, 19.3)
• Change rate	0.24 (0.13, 0.39)
Baseline systolic blood pressure (mmHg)	123 (111, 135)
Baseline mean blood pressure (mmHg)	89 (81, 98)
Baseline heart rate (bpm)	83 (75, 90)
Total norepinephrine dose (mcg)	10 [5,20]
Incidence of severe post-induction hypotension	12 (9%)
Incidence of prolonged post-induction hypotension	84 (63%)
Incidence of bradycardia	16 (12%)
Time to hypotensive episode (minutes)	2 [1,5]
Time to skin incision (minutes)	15 [12,15]

Table 2. Demographic data and hemodynamic characteristics in hypotensive and non-hypotensive patients. Presenting data as median (quartiles) and frequency (percentage).

	Non-hypotension (n = 49)	Hypotension (n = 84)	P-value
Age (years)	31 [24, 39]	33 [22, 45]	0.422
Male sex	28 (57%)	44 (52%)	0.595
ASA physical status			
I	46 (94%)	71 (85%)	0.110
II	3 (6%)	13 (15%)	
Weight (kg)	73 (62, 82)	75 (64, 85)	0.422
Height (cm)	171 (158, 176)	165 (156, 175)	0.249
Inferior vena cava			
• Maximum diameter (mm)	15.9 (13.2, 18.9)	15.4 (13.2, 18.0)	0.437
• Minimum diameter (mm)	11.0 (8.9, 12.5)	9.8 (7.8, 12.0)	0.115
• Collapsibility index	0.3 (0.2, 0.4)	0.4 (0.3, 0.5)	0.070
Internal jugular vein			
• Supine area (mm^2)	10.0 (7.2, 16.6)	9.5 (6.5, 12.9)	0.184
• Trendelenburg area (mm^2)	14.8 (9.4, 19.9)	14.6 (10.1, 19.0)	0.792
• Change rate	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.033*
Baseline Systolic blood pressure (mmHg)	119 (111, 131)	127 (113, 140)	0.025*
Baseline mean blood pressure (mmHg)	85 (77, 93)	91 (83, 103)	0.004*
Baseline heart rate (bpm)	82 (75, 90)	83 (74, 90)	0.663

Table 3. Accuracy of IVC and IJV parameters in predicting severe post-induction hypotension.

	AUC (95%CI)	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	Cut-off value
Maximum diameter	0.56 (0.47–0.64)	75 (43–95)	46 (37–56)	12 [6–22]	95 (86–99)	≤16.3 mm
Minimum diameter	0.58 (0.49–0.66)	67 (35–90)	50 (41–60)	12 [5–22]	94 (85–98)	≤10.3 mm
Collapsibility index	0.56 (0.47–0.64)	50 (21–79)	70 (61–78)	14 (5–29)	93 (86–98)	>0.42
Supine area	0.56 (0.47–0.65)	83 (52–98)	37 (29–46)	12 [6–20]	96 (86–100)	≤11.9 mm2
Trendelenburg area	0.56 (0.47–0.64)	75 (43–95)	64 (44–63)	14 [7–25]	96 (88–99)	>14.8 mm2
Change rate	0.74 (0.66–0.81)	75 (43–95)	72 (63–80)	21 (10–36)	97 (91–99)	>0.35

AUC: area under receiver operating characteristic curve, CI: confidence interval, PPV: positive predictive value, NPV: negative predictive value.

Table 4. Accuracy of IVC and IJV parameters in predicting prolonged post-induction hypotension.

	AUC (95%CI)	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	Cut-off value
Inferior Vena Cava						
Maximum diameter	0.54 (0.45–0.63)	70 (59–80)	43 (29–58)	68 (57–77)	46 (31–61)	≤17.3 mm
Minimum diameter	0.58 (0.49–0.67)	36 (26–47)	84 (70–93)	79 (63–90)	43 (33–54)	≤8.4 mm
Collapsibility index	0.59 (0.51–0.68)	57 (46–68)	67 (53–80)	75 (63–85)	48 (36–60)	>0.363
Internal Jugular Vein						
Supine area	0.60 (0.48–0.66)	82 (72–90)	41 (27–56)	70 (60–79)	57 (39–74)	≤14.4 mm2
Trendelenburg area	0.51 (0.43–0.60)	70 (59–80)	39 (25–54)	66 (56–76)	43 (28–59)	≤17.4 mm2
Change rate	0.61 (0.52–0.69)	55 (44–66)	76 (61–87)	79 (67–89)	49 (38–61)	>0.28

AUC: area under receiver operating characteristic curve, CI: confidence interval, PPV: positive predictive value, NPV: negative predictive value.

areas in supine & Trendelenberg positions) & all IVC parameters (dIVC max, dIVC min & CI) verified poor diagnostic accurateness for prediction of prolonged and severe post-induction hypotension.

Regarding the IJV, we found that IJV change rate > 0.28 could predict prolonged post-induction hypotension with a specificity of 76% (95% confidence interval, 61–87%) and a sensitivity of 55% (95% confidence interval, 44–66%). Moreover, IJV change rate > 0.35 could predict severe post-induction hypotension with a specificity of 72% (95% confidence interval, 63–80%) and a sensitivity of 75% (95% confidence interval, 43–95%).

Few data are available about the use of ultrasound-derived IJV parameters in prediction of post-induction hypotension. Okamura et al. showed that big IJV area in Trendelenburg position increased the risk of hypotension during GA induction. However, no cut-off value could be determined due to low diagnostic accuracy [13].

As regards the IVC, none of its parameters (CI, dIVC max & dIVC min) showed a reliable accuracy in prediction of prolonged or severe post-induction hypotension.

Ultrasonographic studies of the IVC for prediction of hypotension during induction of GA have been established with variable results. In the study by Zhang et al. [8], CI was found to predict of hypotension after induction of GA with etomidate. The cut-off value for hypotension was CI more than 43% with sensitivity of 78.6% & a specificity of 91.7%.

Similarly, Au et al. [12]conducted their study to evaluate IVC parameters in predicting hypotension after induction of GA with propofol in 40 patients. They found that CI more than 50% could predict hypotension with high specificity (77.3% & 90.0% respectively) and moderate-to-low sensitivity (66.7% & 45.5%, respectively).

Salama et al. studied IVC collapsibility index in prediction of post-spinal anesthesia hypotension. They found that it had a sensitivity of 84%, a specificity of 77%, and an accuracy of 84% to predict hypotension after spinal anesthesia at a cut-off point more than 44.7% [26].

In contrast to the above mentioned studies, our study shows different results. However, this difference may be attributed to different type of anesthesia, different drug used for induction of anesthesia and different number of patients included in the study which was markedly greater in our study (133 patients). Moreover, many previous studies demonstrated that ultrasound-derived IVC parameters are poorly diagnostic in prediction of hypotension with anesthesia.

Mohammed et al. [15], found that all IVC parameters (CI, dIVC max & dIVC min) had low diagnostic accuracy for prediction of post-induction hypotension and severe hypotension after induction of GA with propofol in young adults.

Moreover, Louro et al. [27], found that CI did not correlate with intra-operative hypotension and fluid responsiveness in patients underwent elective surgeries under GA.

Similarly, Mačiulienė et al, found that decrease in IVC diameters and rise in CI of IVC did not predict hypotension during spinal anesthesia in patients performing elective replacement of knee joint surgery [28].

4.1. Study limitations

Our study had few limitations. First, the blood pressure was measured using non-invasive method at 1 minute intervals. Invasive blood pressure assessment might be better to provide immediate information about the

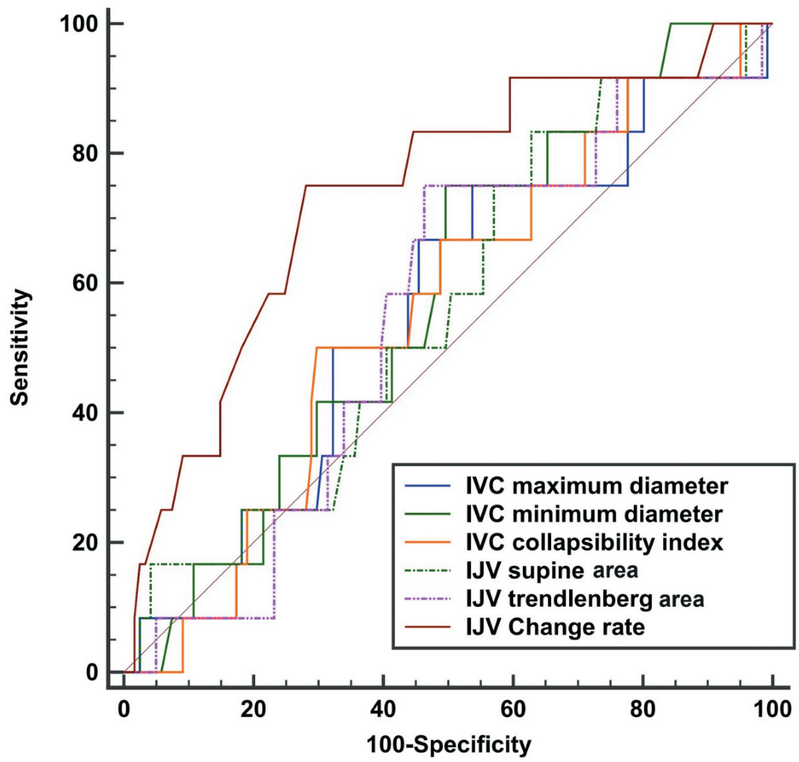

Figure 1. The AUC analysis for the ability to predict severe post-induction hypotension. AUC: area under receiver operating characteristic curve, IJV: internal jugular vein, IVC: inferior vena cava.

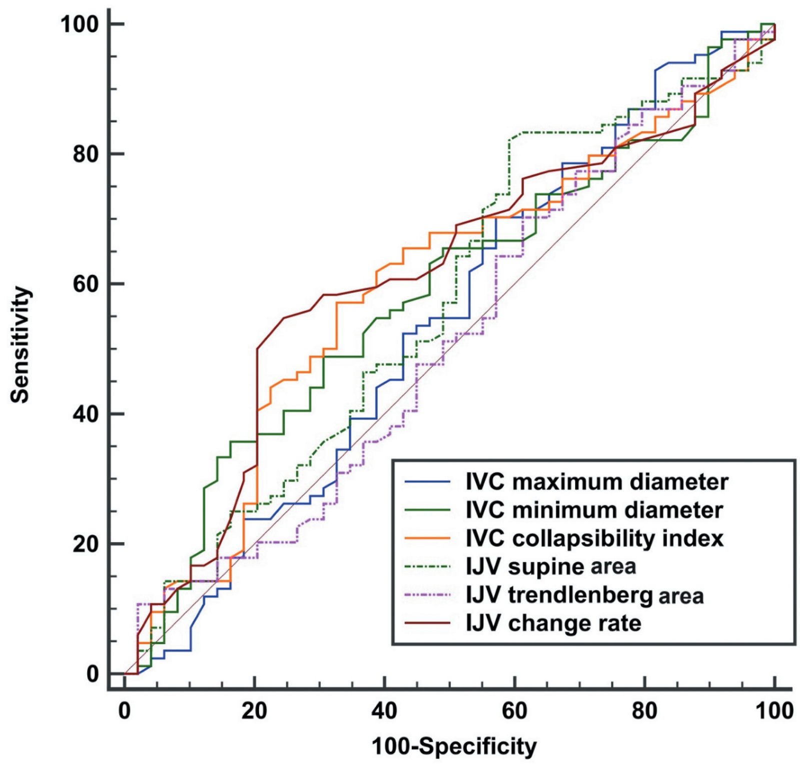

Figure 2. The AUC analysis for the ability to predict prolonged post-induction hypotension. AUC: area under receiver operating characteristic curve, IJV: internal jugular vein, IVC: inferior vena cava.

blood pressure and the duration of hypotensive episodes. Second, it is difficult to standardize spontaneous breathing while scanning the IVC which may affect measurements of IVC. Third, ultrasonographic visualization of a clear view of IVC is sometimes difficult to obtain and occasionally fails.

5. Conclusion

Our study demonstrated that ultrasound scanning of the IJV change rate preoperatively could predict prolonged post-induction hypotension. The threshold for predicting prolonged hypotension was IJV change rate > 0.28 with a specificity of 76% and a sensitivity of 55%. Furthermore, IJV change rate > 0.35 could predict severe post-induction hypotension with a specificity of 72% and a sensitivity of 75%.

On the other hand, none of IVC parameters (CI, dIVC max & dIVC min) showed a reliable accuracy in prediction of prolonged or severe post-induction hypotension.

Abbreviations

GA	General Anesthesia
ACEI	Angiotensin converting enzyme inhibitor
ANOVA	Analysis of variance
ARB	Angiotensin receptor blocker
ASA	American Society of Anesthesiologists
AUR	
AUROC	Area under receiver operating characteristic curve
CI	Collapsibility index
CVP	Central venous pressure
dIVCmax	Maximum diameter of inferior vena cava
dIVCmin	Minimum diameter of inferior vena cava
IJV	Internal jugular vein
IVC	Inferior vena cava
MAC	Minimum alveolar concentration
MBP	Mean blood pressure

Disclosure statement

No potential conflict of interest was reported by the author(s).

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