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Original Investigation

**Preoperative assessment of inferior vena cava collapsibility index by ultrasound is not a reliable predictor of post-spinal anesthesia hypotension**

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**Abstract**

*Background*: Post-spinal anesthesia hypotension is of common occurrence, and it hampers tissue perfusion. Several preoperative factors determine patient susceptibility to hypotension. This study aimed to assess the effectiveness of the Inferior Vena Cava Collapsibility Index (IVCCI) for predicting intraoperative hypotension.

*Methods*: One hundred twenty-nine adult patients who were scheduled for elective surgical procedures after administration of spinal (intrathecal) anesthesia were included in the study. Ultrasound evaluation of the Inferior Vena Cava (IVC) was done in the preoperative area, and the patients were shifted to the Operating Room (OR) for spinal anesthesia. An independent observer recorded the change in blood pressure after spinal anesthesia inside the OR.

*Results*: Twenty-five patients developed hypotension (19.37%). Baseline systolic blood pressure and mean blood pressures were statistically higher in those patients who developed hypotension ($p$ = 0.001). The logistic regression analysis for IVCCI and the incidence of hypotension showed $r^2$ of 0.025. Receiver Operating Characteristic (ROC) curve analysis demonstrated the Area Under the Curve (AUC) of 0.467 (95% Confidence Interval, 0.338 to 0.597; $p$ = 0.615).

*Conclusions*: Preoperative evaluation of IVCCI is not a good predictor for the occurrence of hypotension after spinal anesthesia.

**KEYWORDS**

Hypotension; IVCCI; Spinal anaesthesia; Ultrasound

## Introduction

Intraoperative hypotension has been the most frequent side effect after spinal anesthesia, with an incidence of 15.3% to 33%.[1] Hypotension can be severe (incidence 5.4%) and may cause systemic hypoperfusion and ischemic events. The magnitude of hypotension is determined by the preoperative volume status, which varies depending on ASA physical status, preoperative comorbidities, preoperative medications, and fasting. To prevent hypotension, neither crystalloid nor colloid (preloading or co-loading) was found to be superior.[1] Studies have shown the use of vasopressors like mephentermine, phenylephrine, or ephedrine to prevent or treat hypotension. Still, there is no accurate predictive tool to correctly evaluate the incidence of hypotension following spinal anesthesia in high-risk patients (old age/cardiac diseases/autonomic neuropathy) to avoid preemptive volume loading.[2] Hypotension occurs because of vasodilation due to preganglionic sympathetic fiber blockade resulting in peripheral vasodilatation. When spinal anesthesia reaches up to T4–T6 level, Systemic Vascular Resistance (SVR) decreases by 23%–26%, Left Ventricular End-Diastolic Volume (LVEDV) by 20%, and Central Venous Pressure (CVP) by 2–3 mm.Hg.[3]

In patients with pre-existing intravascular fluid deficit, the effects of hypotension are more pronounced, leading to many unwanted side effects like nausea, vomiting, aspiration, dizziness, syncope, cardiac arrhythmias. However, we cannot preload every patient prophylactically because there are side effects of volume overload like pulmonary edema, congestive cardiac failure, and renal dysfunction. That’s why many new guidelines and recommendations are coming up which advocate only maintenance fluid administration in fasting patients preoperatively.[4-6] The goal should be to discover a new suitable predictive tool for hypotension to find at-risk patients in an easy, feasible, cost-effective, and non-invasive way.

Recently, ultrasound has come up as a new modality to predict the intravascular volume status of patients undergoing surgery. There are many methods for assessing intravascular volume preoperatively (CVP measurements, esophageal Doppler Ultrasound, pulmonary arterial catheterization, and transesophageal echocardiography). Still, most of them are invasive, time-consuming, or may require complex calculations. The ultrasound-guided measurement of the diameter of the Inferior Vena Cava (IVC) can indirectly assess the intravascular volume.

In this study, we hypothesized that preoperative Inferior Vena Cava Collapsibility Index (IVCCI) assessment is a good predictor of intraoperative hypotension within thirty minutes of giving spinal anesthesia in patients undergoing elective surgery.

**Methods**

The current prospective observational double-blinded study was conducted between the 8$^{th}$ of March 2018 to the 31$^{st}$ of December, 2019. Ethical approval was obtained from the Institute’s Ethics

Committee (AIIMS/IEC/2018/450) before enrolling the patients. This study adheres to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. Potentially eligible participants aged between 18 and 75 years, with American Society of Anesthesiologists (ASA) physical status I or II were identified conveniently during the study period and scheduled for elective surgery under spinal anesthesia in the supine position. The written informed consent was taken from all the included patients. Exclusion Criteria were contraindications for spinal anesthesia (both absolute and relative), preoperative mean arterial blood pressure < 65 mmHg, preoperative heart rate < 45 beats.min$^{-1}$, preoperative dysrhythmia, psychiatric illness and pre-existing neurological deficits, patient with BMI > 30 kg.m$^{-2}$, and previous diaphragmatic surgery. After confirming fasting status in the preoperative room, the patient was instructed to relax in the supine position and breathe spontaneously for 5-minutes. An 18G peripheral IV line was secured, and maintenance crystalloid infusion (Ringer Lactate) was started at the rate of 2 mL.$^{-1}$.kg$^{-1}$.hr$^{-1}$. Using a portable ultrasound machine (LOGIQ-e by GE health care) and a 3.5–5 MHz curvilinear probe, IVC was scanned in the subxiphoid region (paramedian long-axis view) just proximal to the drainage of the common hepatic vein to the IVC, according to the American Society of Echocardiography, by an independent observer who was trained in ultrasound (basic level I experience in echocardiography) and was supervised by an anesthesia faculty.[7] A 2D image was obtained where the IVC was joining the right atrium. IVC diameter variation was registered using M-mode imaging in both inspiration and expiration. It was done 2 to 3 cm distally from the junction of the IVC and the right atrium. The attending anesthetist registered the time from putting the probe on the patient and localizing the IVC. If the measurement time exceeded ≥ 15 minutes[8] and still the IVC could not be located due to any reason (like excess fat/bowel gas shadows), the case was excluded. Minimum ($IVCD_{Min}$) and Maximum Diameter ($IVCD_{Max}$) of IVC was assessed by the M mode of the ultrasound, and the IVC Collapsibility Index (IVCCI) was measured using the formula: ([Maximum IVCD - Minimum IVCD]/Maximum IVCD) ×100. Three such measurements were taken at one-minute interval, and the average was taken as IVCCI (Fig. 1). Each measurement was saved to be reviewed later by an expert radiologist.[8]

After arrival to the operation theatre, patients did not receive any fluid preloading. Standard noninvasive monitoring, including Noninvasive Blood Pressure (NIBP), Electrocardiography (ECG), and Pulse Oximetry (SpO2), was attached to the patients, and baseline parameters were recorded. All the patients received spinal anesthesia using a 25/27G Quincke needle (B. Braun Medical SA, Melsungen, Germany) with the needle orifice oriented cranially and the patient in the sitting position by the median approach at the level of the L3–L4 and L4–L5 intervertebral space with 25 mcg of fentanyl and 2.5 to 3 mL of 0.5% bupivacaine (hyperbaric) (considering the type of surgery and patient's constitution) to achieve spinal block height to the level of T9 to T10. The patient was made supine immediately after spinal drug administration and remained supine till the end of the study period (30 min). The pinprick test was used to determine the sensory level by an anesthetist who was not further involved in the study.[9] Then, serial heart rate and NIBP were recorded at 0, 5, 10, 15, 20, 25, and 30 minutes after spinal anesthesia by an independent observer who was not present at the time of IVCCI assessment. Clinically significant hypotension was defined as more than or an equal to 30% reduction in pre-induction baseline values. If the procedure was converted to GA or abandoned due to any reason before 30 minutes after giving spinal anesthesia, the case was excluded from the study.

Significant hypotension was managed with intravenous fluid administration and boluses of phenylephrine (100 µg) every 2 min to increase mean blood pressure > 70 mmHg or systolic blood pressure to 80% of the baseline.[10,11] Atropine 0.5 mg was used intravenously, when the heart rate was < 50 bpm. Nausea, vomiting, shivering, discomfort, allergic reaction, or any other complications were managed as per standard protocol. The patients were monitored after surgery in the recovery area in the immediate postoperative period, followed by observation in the ward. Data were collected on separate proforma sheets by the USG operator and the intraoperative attending anesthetist who performed the spinal anesthesia (unaware of the IVCCI of that patient) to overcome bias. The primary outcome was to assess whether IVCCI can predict hypotension and the secondary outcomes were to detect if there are other clinical predictors of hypotension.

The total number of patients who came to our institution during the study period were assessed as per our inclusion and exclusion criteria. Software SPSS version 21 (SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis. A *p*-value of < 0.05 (two-tailed) was regarded as statistically significant. Excel spreadsheets (Microsoft, USA) were used to collect the data. The lowest Mean Blood Pressure (MBP) was documented after induction, and the percentage decrease in MBP was calculated as a fall from baseline in each patient. Kolmogorov-Smirnov one-sample test was used for checking normality. Data were expressed as mean ± Standard Deviation (SD) for continuous variables, and for categorical variables, percentages or absolute numbers were used.

Student's *t*-test or the $\chi 2$ test was applied to analyze patient characteristics, hemodynamic data, and IVC measurements, and the Pearson correlation coefficient (*r*) to examine the relationship between IVCCI and % fall of MBP. The Receiver Operator Characteristics (ROC) curve analysis was performed between IVCCI and % MBP reduction. Multivariate logistic regression was applied for the following confounders: age, ASA physical status, baseline Heart Rate (HR), and baseline Mean Blood Pressure (MBP).

**Results**

One hundred sixty-five patients were included in our study; in 18 patients, the vena cava was not seen on ultrasound, and we were unable to follow 18 patients. For the purpose of the study, 129 patients underwent statistical analysis. The flow diagram of the STROBE statement is shown in Figure 2. Among the 129 patients, 105 were male (81.4%), and 24 were female (18.6%). Ninety-eight patients were ASA I (76%), and 31 were ASA II (24%). The mean age was 43.15 years, with a standard deviation of 17.8. Thirty-seven patients (28.68%) had a history of hypertension, but it was controlled in every patient. The following surgical procedures were included: Orthopedic Surgery 38% (n = 49), General Surgery 26.4% (n = 34), Urology 19.4% (n = 25), Gynecology Surgery 8.5% (n = 11), and Plastic Surgery 7.8% (n = 10). Of the 129 patients studied, we observed significant hypotension in 25 (19.37%). Eleven patients received phenylephrine for severe hypotension, which lasted more than 2 min and/or severe hypotension persisting even after 500 mL of the fluid bolus. Three patients received atropine for bradycardia. After comparing the two groups (patients who developed hypotension vs. patients with no hypotension) (Table 1), no major differences were found in age, sex, IVCCI, and baseline HR after spinal anesthesia. However, patients with higher baseline SBP ($p = 0.012$), baseline DBP ($p = 0.006$), baseline MBP ($p = 0.001$) developed hypotension more often. ASA II patients developed hypotension more often than ASA I patients ($p = 0.009$). The scatter plot (Fig. 3) suggests a linear relationship between the % decrease in MBP and IVCCI ($r^2 = 0.025$), which is not significant. That denotes that a progressive increase in IVCCI does not necessarily cause a more progressive fall in BP. The ROC curve analysis (Fig. 4) for predicting post-spinal hypotension did not demonstrate good diagnostic accuracy as the area under the curve was 0.467 (95% Confidence Interval, 0.338 to 0.597; $p = 0.615$). Multivariate logistic regression analysis demonstrated that neither IVCCI nor baseline MBP has good hypotension predicting capabilities (Table 2).



**Discussion**

Intraoperative hypotension is a frequent complication after intrathecal local anesthetic administration. In this study, a fall in mean BP ≥ 30% from the baseline was taken as the cut-off for significant hypotension because this definition is included in most of these studies[3,11,12] and because mean BP is a better indicator for tissue perfusion than SBP or DBP. As only one cut-off of hypotension was taken, the incidence of clinically significant hypotension found in our study (19.37%) was much lower than what was found in other studies.[3,11] The study period was from intrathecal drug administration to 30-min after spinal anaesthesia,[11] during which no significant hemodynamic changes were expected due to the external factors. Female patients developed hypotension more often (33.3%) than males (16.19%) (*p*-value = 0.05). Many studies have tried to demonstrate the IVCCI as a fluid-responsiveness-predicting tool for guiding fluid therapy in resuscitation and intensive care settings.[13-17] In anesthesia, volume status optimization is the primary concern. Fluid responsiveness is a 10% to 15% increment in the cardiac output after a fluid bolus.[10] But very few anesthesiologists use cardiac output monitoring regularly.[18,19] So, most anesthesiologists use basic monitoring like blood pressure and HR as their main hemodynamic monitoring tool, and that's why we can include bedside IVC ultrasound to identify volume-depleted patients who need fluid optimization.

As a part of POCUS (point of care ultrasound), IVC ultrasound examination before spinal anesthesia to screen high-risk patients, the elderly, and suspected hypovolemic patients, is desirable. A significantly large IVCCI denotes truncated volume status, increasing the predicting value when the IVC diameter is smaller.[20] IVCCI was influenced by the sampling location[21] and that's why the measurement point was limited to 3 cm inferior to the right atrium.

The IVC scan failure rate was 10.9%, which was better than the study done by Dust et al.[22] The time taken to locate IVC was very variable from 5 up to 660 seconds, but was within the normal limits of 10 minutes as described by another study.[9]

In this study, we have failed to demonstrate the usefulness of IVC ultrasonography to anticipate blood pressure fluctuations after spinal anesthesia in spontaneously breathing patients like the study conducted by Ceruti et al.[3] and Ayyanagouda et al.[23] The ROC curve analysis showed an area under the curve of 0.467 (95% CI 0.338 to 0.597; $p = 0.615$). When the scatter plot was drawn between the percentage decrease in MBP and the IVVCI, it failed to demonstrate any correlation ($R^2 = 0.025$). But baseline SBP, DBP, and MBP were found to be higher in those patients who developed hypotension ($p < 0.05$). Logistic regression found that IVCCI was not a good predictor of post-induction hypotension (Odds Ratio = 0.988 with 95% CI 0.967 to 1.010; $p = 0.302$). There was no association between post-spinal hypotension and baseline MBP (OR = 1.041 with 95% CI 0.948 to 1.143; *p*-value = 0.402). In this study, 2.5 to 3 mL of local anesthetic was used for spinal block, depending on the type of surgery and patient constitution, to achieve spinal block height to the level of T9 to T10. There was no correlation between the amount of drug used and post-spinal hypotension though there was a 20% difference in local anesthetic mass.

Our findings can be explained by the fact that IVC is a high-capacity vessel and its diameter vary significantly from person to person. It also depends on age, body surface area, and BMI.[24,25] Intrathoracic and intra-abdominal pressures alter its diameter, and it is modified by various diseases like pneumonia or chronic obstructive diseases. The Inferior Vena Cava (IVC) diameter changes during the respiratory cycles because of the intrathoracic pressure changes.

Most of the previous data were from ICU settings, where IVC diameter changes were used to find out volume-responsive patients in circulatory shock. Our approach has this new aspect of finding its utility in the spinal anesthesiology setting. Some studies claim that it is controversial to use IVCCI after spinal anesthesia because it causes sympathetic denervation and reveals insufficient fluid reserve. One study could not detect the predictive role of the IVCCI in patients undergoing knee surgery,[26] while another found it as a useful tool to decrease the magnitude of hypotension by giving ultrasound-guided fluid therapy.[3] In a more recent study,[11] e caval-aorta index was found to be a stronger predictor than IVCCI. So, further investigations should focus on this aspect.

There were many limitations in the present study. USG observer experience was variable in some measurements. We included ASA I and II patients, because ASA III and IV patients might have more chances of hemodynamic instability in the post-spinal period. It could be either due to the depleted intravascular status or due to the poor optimization of the actual disease process. It was a single-center study. Furthermore, a multicenter study is recommended to assess the ideal prognostic value of IVCCI. Respiration caused diaphragmatic movement, which resulted in two distinct sites of measurement of the IVC in the respiratory cycle. This might have led to an underestimation of IVCCI (because IVC is less collapsible when the measurement is taken near the diaphragm during inspiration).

To overcome limitations caused by the varying respiratory parameters in spontaneously breathing patients, we can simultaneously take IVC and Aorta measurements to get the Caval-Aorta index. Further research should be directed on this index to assess intravascular volume status to predict intraoperative hypotension.

**Conclusion**

This study found that IVCCI does not have the same hypotension predicting capability in spontaneously breathing patients undergoing spinal anesthesia that it has in mechanically ventilated patients.

**Authors' contributions**

Shayak Roy: Acquisition of data, analysis, and interpretation of data, revising it critically for important intellectual content. Nikhil Kothari: Substantial contribution to conception and design, analysis and interpretation of data, final approval of the version to be published. Shilpa Goyal: Acquisition of data and drafting the article. Ankur Sharma: Acquisition of data and drafting the article. Rakesh Kumar: Acquisition of data; manuscript review. Narender Kaloria: Acquisition of data; manuscript review. Pradeep Bhatia: Substantial contribution to conception and design, drafting the article and revising it critically for important intellectual content.

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**Conflicts of interest**

The authors declare no conflicts of interest.

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**Table 1** Patient characteristics, hemodynamic data, and preoperative Inferior Vena Cava (IVC) ultrasound measurements of the study participants.

| **Variable** | **Developed Hypotension (n = 25)** | **No Hypotension (n = 104)** | ***t*-value** | ***p*-value** |
|---|---|---|---|---|
| Age (years) | 48.0 ± 18.2 | 41.4 ± 18.0 | -1.636 | 0.104 |
| Sex (male/female) | 17/08 | 88/16 | NA | 0.055[b] |
| ASA (I/II) | 14/11 | 84/20 | NA | 0.009[a,b] |
| IVCCI (%) | 37.6 ± 23.9 | 39.7 ± 22.9 | 0.427 | 0.670 |
| Baseline HR (beats.min$^{-1}$) | 79.2 ± 17.2 | 83.2 ± 16.3 | 1.087 | 0.279 |
| Baseline SBP (mmHg) | 142.3 ± 15.1 | 133.2 ± 16.2 | -2.542 | 0.012[a] |
| Baseline DBP (mmHg) | 86.9 ± 11.2 | 80.5 ± 10.2 | -2.777 | 0.006[a] |
| Baseline MBP (mmHg) | 111.1 ± 11.8 | 101.6 ± 13.2 | -3.257 | 0.001[a] |

Data are presented as absolute (n) and mean ± SD. SD, standard deviation; ASA, American Society of Anesthesiologists physical status; IVCCI, Inferior Vena Cava Collapsibility Index; HR, Heart Rate; SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure; MBP, Mean Blood Pressure.

[a] Significant difference between groups ($p < 0.05$).

[b] Chi-Square test.

**Table 2** Multivariate Logistic Regression of patients for hypotension after Induction (n = 129).

| **Predictors** | **Regression Coefficient** | **Odds Ratio** | **95% Confidence Interval of Odds Ratio** | ***p*-value** |
|---|---|---|---|---|
| Constant | -4.468 | 0.011 | NA | NA |
| Age | 0.002 | 1.002 | 0.969 to 1.035 | 1.035 |
| IVCCI | -0.012 | 0.988 | 0.967 to 1.010 | 0.302 |
| Baseline HR | -0.026 | 0.975 | 0.943 to 1.008 | 0.131 |
| Baseline MBP | 0.040 | 1.041 | 0.948 to 1.143 | 0.402 |

IVCCI, Inferior Vena Cava Collapsibility Index; HR, Heart Rate; SBP, MBP, Mean Blood Pressure.

**Figure 1** The Motion (M) mode of ultrasound scanning of the Inferior Vena Cava (IVC) showing minimum diameter 0.64 cm, maximum diameter of 1.09 cm, and thus Inferior Vena Cava Collapsibility Index (IVCCI) 41.3%.

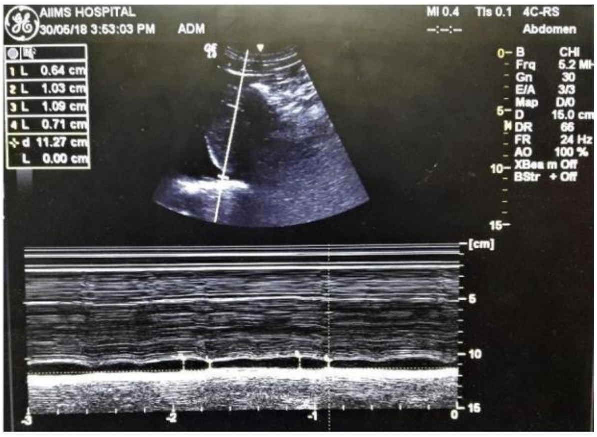


**Figure 2** The flow diagram of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement

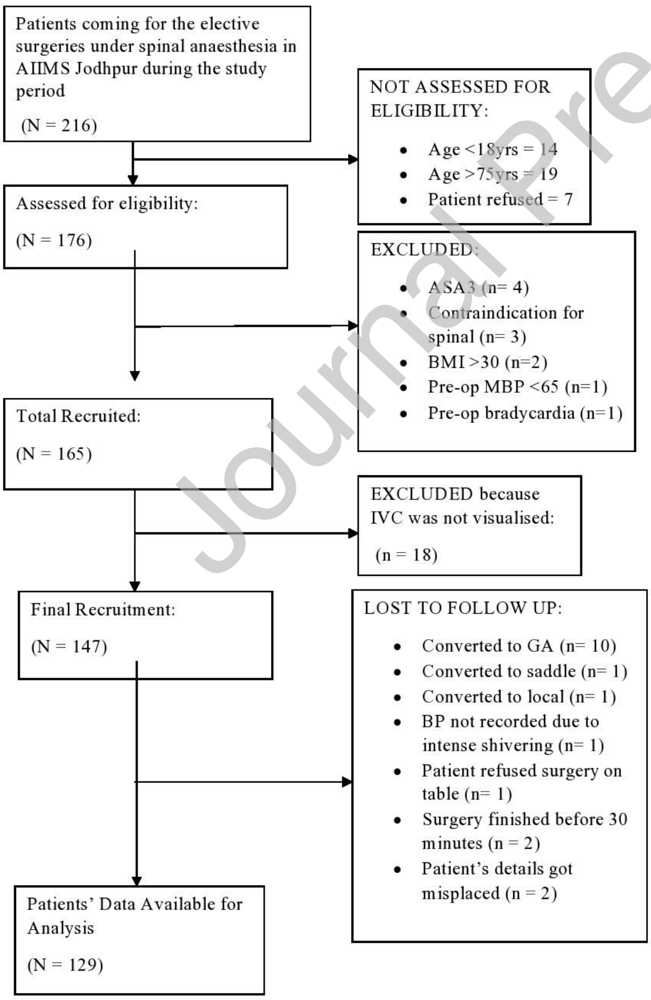

**Figure 3** Scatter plot showing relationships of preoperative Inferior Vena Cava Collapsibility Index (IVCCI) with percentage decrease in Mean Blood Pressure (MBP) from baseline after induction of spinal anesthesia. The trend line is presented as the percent line.

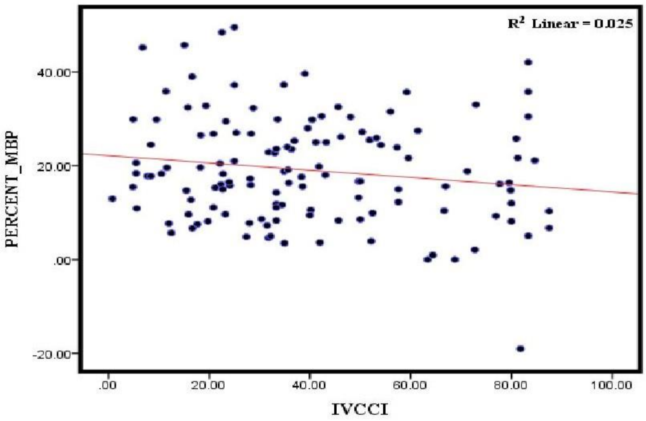


**Figure 4** Receiver Operator Characteristic (ROC) curve for predicting post-spinal hypotension showing area under the curve of 0.467 (95% CI 0.338–0.597; $p = 0.615$).