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VALUE OF CORRECTED FLOW TIME IN COMMON CAROTID ARTERY IN PREDICTING VOLUME RESPONSIVENESS UNDER MECHANICAL VENTILATION

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ABSTRACT—Objective: The present study aimed to investigate whether corrected flow time (FTc) in common carotid artery could predict volume responsiveness under mechanical ventilation and to further explore whether the sensitivity and specificity would be influenced by positive end-expiratory pressure (PEEP). **Methods:** The first stage of this study included 80 patients from the general surgery department undergoing laparotomy. After induction of general anesthesia, FTc in the common carotid artery was measured when hemodynamic indicators, such as blood pressure, heart rate, and cardiac output (CO), were stabilized. Then, 7 mg/kg (ideal body weight) of hydroxyethyl starch 130/0.4 sodium chloride was rapidly infused from the peripheral venous system. The infusion was completed within 15 minutes, and hemodynamic indicators were measured again immediately to evaluate volume responsiveness. The patients with change rate of CO (ΔCO ≥15%) were categorized into the responsive (R) group, whereas those with ΔCO <15% were categorized into the nonresponsive group (NR) group. In the second stage, 29 patients undergoing laparotomy were included. After induction of general anesthesia, PEEP of 0, 5, and 10 cmH_2O was applied sequentially. Corrected flow time and hemodynamic indicators were recorded. Then, 7 mg/g of hydroxyethyl starch 130/0.4 sodium chloride was rapidly infused for 15 minutes, after which PEEP of 0, 5, and 10 cmH_2O was applied sequentially, and the indicators were measured again. The patients with FTc equal to or less than the threshold in the first stage were categorized into the R group, otherwise into the NR group. **Results:** In the first stage of the study, CO and FTc differed significantly between the 2 groups, before and after volume load ($P < 0.05$). Mean arterial pressure in the R group was significantly different, whereas heart rate did not differ before and after fluid infusion. Also, heart rate and mean arterial pressure were not significantly different before and after fluid infusion in the NR group. The area under the receiver operating characteristic curve was 0.786 ± 0.056 (95% confidence interval, 0.676–0.896; $P = 0.00$) for FTc before infusing volume load for predicting volume responsiveness. In the second stage of the study, PEEP did not have significant effects on FTc ($F_{2, 56} = 1.930$, $P = 0.155$), whereas volume load had statistically significant effects on FTc ($F_{1, 28}$) = 9.381, $P < 0.05$). Moreover, FTc differed significantly different before and after fluid infusion ($P < 0.05$). The area under the receiver operating characteristic curve for FTc in predicting volume responsiveness was 0.921, 0.805, and 0.719 when PEEP was 0, 5, and 10 cmH_2O ($P < 0.05$), respectively, and the cutoff value of FTc for diagnosing volume responsiveness was 323.42 milliseconds, 326.69 milliseconds, and 312.03 milliseconds, respectively. **Conclusion:** Corrected flow time in the common carotid artery can predict volume responsiveness under mechanical ventilation, and the predictive performance is not influenced by PEEP. Clinical Trial Registration Clinical register number: ChicTR2000029519

KEYWORDS—Volume responsiveness, corrected flow time, positive end-expiratory pressure, laparotomy

INTRODUCTION

Appropriate fluid therapy reduces the incidence of perioperative complications, such as pulmonary edema and delayed incision healing, and also decreases the mortality rate (1). The common clinical method to evaluate volume responsiveness is to monitor whether the cardiac output (CO) is increased with the volume load (2). The most widely accepted standard for monitoring CO is the Swan-Ganz catheter. However, the operation is not only complicated but can also induce severe complications (3). Because of advanced perioperative bedside ultrasound techniques, screening an indicator with good predictive performance, robust results, and easy operation procedure to predict the volume responsiveness and guide fluid therapy has become an urgent requirement for clinicians.

In recent years, using echocardiography to predict volume responsiveness has become a research hotspot. The body surface echocardiography mainly measures the size of cardiac chambers, ventricular wall thickness, ventricular wall motion, variation of the left ventricular short-axis area, variation of the left ventricular outflow tract velocity time integral, and cardiac systolic and diastolic functions. However, such measurements are highly dependent on the skill and experience of the operators (4). Other indicators that have been widely investigated include an internal diameter of inferior vena cava and the variation rate (4). However, the cover of the sterilized dressing during operation restricted the application of these indicators in most surgeries. Continuous Doppler also can be used to measure the flow time, which is also known as the left ventricular contraction time (FT). The length of FT can reflect the stroke volume. For all the comparisons, the flow time is corrected to the heart rate of 60 beats/min to acquire the corrected flow time (FTc) (5). Previous studies have demonstrated that measuring FTc in descending aorta through transesophageal echocardiography could be used to guide fluid therapy, reduce complications, improve outcomes, and, consequently, shorten the hospital stay. However, transesophageal echocardiography has

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high requirements; also, the test results rely on the operators, which limits the clinical application of this technique (6,7). Second, the common carotid artery can be clearly displayed by ultrasound examination, providing reliable measurements. Third, the common carotid artery can be easily exposed during surgery without influencing the surgical procedure. Several recent studies have also demonstrated that FTc in the common carotid artery can be used to predict volume responsiveness with high sensitivity and specificity. However, whether FTc in the common carotid artery can be applied under mechanical ventilation is yet to be clarified. Therefore, the present study aimed to investigate whether FTc in the common carotid artery can be applied for patients under mechanical ventilation.

Positive end-expiratory pressure (PEEP) is widely used as a pulmonary protecting ventilation strategy in anesthesia. Some studies have demonstrated that the commonly used indicators, such as stroke volume variation to reflect volume responsiveness, could be influenced under PEEP. When high-level PEEP is applied, these indicators lose sensitivity and specificity (8). Herein, we speculated that the common carotid artery is outside of the thoracic cavity and might not be influenced by intrathoracic pressure. Therefore, FTc in the common carotid artery also may not be influenced by PEEP. This study aimed to investigate whether FTc in the common carotid artery can be used to effectively predict the volume responsiveness of patients under mechanical ventilation and further explore whether the accuracy and threshold of the prediction are influenced by PEEP.

PATIENTS AND METHODS

Patients

This prospective, noninterventional, single-center clinical trial had two study stages. The study was approved by the Ethics Committee of the First Affiliated Hospital of Wannan Medical College (Wuhu, China; ethics approval number: ChiECRCT20200027) and registered in the Chinese Clinical Trial Registry (register number: ChicTR2000029519). In the study of Maitra et al. (9), in the prediction of common carotid artery FTc on predicting induced hypotension, they assumed that the minimum area under the receiver operating characteristic (AUROC) curve was 0.7. Therefore, the present study assumed that the AUROC was 0.70 for FTc in the common carotid artery in the first stage of the study. The α was set at 0.05 and β was 0.10; therefore, the sample size should be 52 in this study. After considering a rate of 20% loss to follow-up, at least 62 patients should be included in the first stage of the study; finally, 80 patients were included in the first stage of the study. For the second stage of the study, the statistical power was set at 0.80, α was 0.05, β was 0.20, and the autocorrelation coefficient of the sequential measurements was 0.7; therefore, the sample size should be 24. After considering a rate of 10% loss to follow-up, at least 26 patients should be included. Finally, 29 patients were included in the second stage of the study.

All the included patients signed informed consent. The inclusion criteria were as follows: (1) underwent laparotomy in the general surgery department between January 2020 and October 2020; (2) American Society of Anesthesiology (ASA) stages I and II; and (3) no vital organ damages, acid-base disturbance, or electrolyte imbalance. No restrictions were implied on the sex of patients, and the patients were not required to receive drug therapy before the surgery. The exclusion criteria were as follows: (1) the preoperative hemoglobin level of <100 g/L; (2) accompanied by arrhythmia, hypertension, heart failure, coronary heart disease, diabetes, congenital heart diseases, or peripheral vascular diseases; (3) treated with long-term oral vasoactive drugs; (4) chronic obstructive pulmonary disease, bronchiectasis, pulmonary heart disease, or spinal deformity; (5) pregnant or breast-feeding women; (6) peak airway pressure (P_{peak}) was >35 cmH_2O after ventilation (volume control mode; tidal volume, 8 mL/kg); and (7) requiring vasoactive drugs or blood transfusion to support circulation during surgery.

Study procedures

In the first stage, we hypothesized that the absolute value of FTc in the common carotid artery before fluid infusion could be used to predict volume responsiveness. The Pulse Indicator Continuous Cardiac Output (PICCO) hemodynamic monitor was used to evaluate CO, and FTc in the common carotid artery was measured by ultrasound examination. The second stage of this study focused on the effects of different levels of PEEP on the predictive power of FTc in the common carotid artery for volume responsiveness. The PEEP level was changed sequentially, and the FTc value and other hemodynamic indicators were measured sequentially to explore whether the accuracy of FTc can be influenced under PEEP.

The patients were transferred to the operating room, and electrocardiogram, noninvasive blood pressure, and pulse oxygen saturation were monitored. Subsequently, radial artery catheterization was performed under local anesthesia, and the PICCO hemodynamic monitor was connected. After 5 minutes of rest, general anesthesia was induced (midazolam, 0.05 mg/kg; propofol, 2 mg/kg; rocuronium bromide, 0.6 mg/kg; and sufentanil 0.5 μg/kg). Then, intubation mechanical ventilation was performed (ventilation parameters were set as follows: tidal volume, 8 mL/kg; respiration rate, 10–14 times/min; oxygen flow, 2 L/min). When hemodynamics were stabilized, baseline FTc in the common carotid artery, CO, and hemodynamic indicators were measured. Then, the patients underwent the volume load test by infusing 7 mg/kg (ideal body weight) of hydroxyethyl starch 130/0.4 sodium chloride. After the volume load test was completed and hemodynamics stabilized, the indicators were measured again. During the trial, no vasoactive drug was used. Volume responsiveness was defined as the CO after liquid infusion increased by 15% or more than the CO before the infusion. In the second stage of the study, the baseline FTc in the common carotid artery, CO, and hemodynamic indicators were measured. Positive end-expiratory pressure of 0, 5, and 10 cmH_2O was applied sequentially, with each level maintained for 5 minutes, and the indicators were measured again; 7 mL/kg of hydroxyethyl starch 130/0.4 sodium chloride was infused within 15 minutes. When hemodynamics was stabilized, PEEP value was adjusted back to 0, 5, and 10 cmH_2O sequentially again, and the indicators were measured again. The patients with FTc equal to or less than the threshold in the first stage were categorized into the responsive (R) group, otherwise into the nonresponsive (NR) group.

Ultrasound examination of carotid artery

Ultrasound examination was performed by two independent investigators with Mindray ultrasound apparatus (M9). First, the linear array probe was placed vertically at the neck, with the gauge point toward the head of the patient. The long axis image of the right common carotid artery was acquired at the level of thyroid cartilage margin, after which the sample volume was placed at the center of the lumen, 2 cm to the carotid artery bifurcation. Then, the angle was adjusted to acquire the pulse-Doppler image of the common carotid artery (10). The caliper function of the apparatus was used to measure the duration of blood flow from the start of the ascending systolic phase to double incisures. The FTc was measured twice by each of the two investigators, and the average of the four measurements was calculated for subsequent statistical analysis. The FTc in the common carotid artery was calculated according to Wodey equation (5): $FTc = FT + 1.29(\text{heart rate} - 60)$. The spectrum images were reviewed and measured before processing to avoid selection and investigator biases (Fig. 1).

Statistical analysis

A normality test was performed for all the quantitative data. The normal distribution quantitative data were described as mean ± SD and otherwise described as median (interquartile range). Qualitative data were described by frequencies and percentages (%).

An independent t test was used to compare the CO and FTc in common carotid artery between patients with different volume responsiveness, and paired t test was performed to compare before and after the volume load within the same group. The receiver operating characteristic (ROC) curve was used to evaluate the predictive value of FTc in the common carotid artery before fluid infusion for volume responsiveness of patients. The Youden index was calculated to deduce the best cutoff value of FTc in the common carotid artery before the fluid infusion to assess volume responsiveness. Two-way analysis of variance (ANOVA) for repeated measurements was used for the comparison of indicators among the sequential adjustment of PEEP (11). The accuracy of different levels of PEEP in predicting the volume responsiveness was evaluated by the ROC curve.

PASS 14 software (version 14.0.5; NCSS; Kaysville, UT) was used for estimating the sample size. SPSS 23.0 software was used for independent t test, paired t test, and ANOVA of repeated measurements. MedCalc software was used for plotting and analyses of ROC curves. $P < 0.05$ indicated statistical significance.

RESULTS

In the first stage of the study, 39 males and 41 females were included. One patient was excluded from the study because vasoactive drugs were used to maintain blood pressure after anesthesia induction. Therefore, 79 patients completed the study, and the

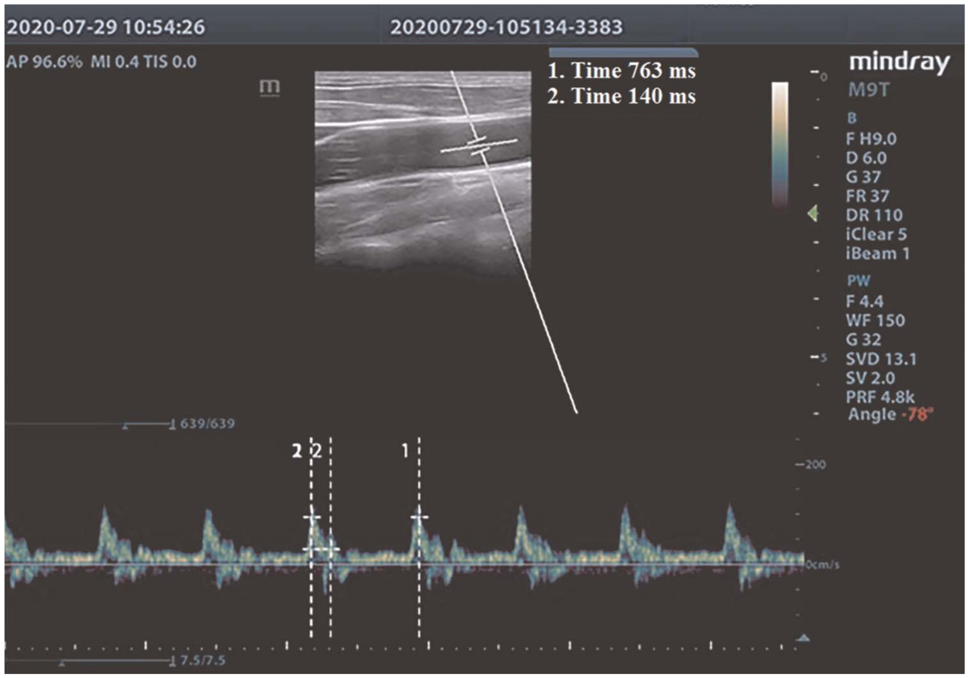

Fig. 1. **Image for the measurement of FTc in the common carotid artery: time 1 was the time of the cardiac cycle (CT), and time 2 was the time of the systolic phase (FT).**

baseline characteristics are shown in Table 1. According to the measured CO, these patients were categorized into two groups: patients with the CO increased by 15% or more than the CO before liquid infusion were categorized into the R group, whereas the ones with CO increased by <15% were categorized into the NR group. The CO of the patients in the R group was 4.26 ± 0.84 and 5.32 ± 0.9, and the FTc was 297.64 ± 59.34 and 331.57 ± 58.14 before and after the liquid infusion, respectively; the differences were statistically significant. As for patients in the NR group, the CO was 4.76 ± 1.06 and 5.01 ± 1.008, and FTc was 364.85 ± 80.33 and 322.60 ± 62.57 before and after the liquid infusion, respectively; the differences were statistically significant (Table 2). The AUROC of FTc before volume load for predicting volume responsiveness was 0.786 ± 0.056 (95% confidence interval, 0.676–0.896; $P = 0.00$). When the FTc before volume load was <331.93 milliseconds, the sensitivity and specificity were 0.816 and 0.767, respectively (Fig. 2).

The second stage of the study included 29 patients. The two-way ANOVA of repeated measurements was used to explore the different levels of PEEPs on FTc before and after fluid infusion. The analysis of the studentized residuals by Shapiro-Wilk test showed that the data were in normal distribution ($P > 0.05$). Furthermore, the studentized residuals were evaluated based on ±3-folds of SD, and the results showed no abnormal data. Mauchly test of sphericity analyzed the interaction between PEEP and volume load, and the results showed equal variance-covariance matrix of the dependent factor ($P > 0.05$). The findings indicated that the interaction between PEEP and time did not have statistically

Table 1. **Baseline characteristics of the included patients**

The first stage				
Group	R group (n = 49)	NR group (n = 30)	χ^2/t	*P*
Sex (n, M/F)	25/24	14/16	0.141	0.707
Age (y, $\bar{x}$ ± SD)	29.33 ± 6.07	28.23 ± 5.82	–0.788	0.433
BMI (kg/m^2, $\bar{x}$ ± SD)	22.64 ± 1.43	22.76 ± 1.54	0.352	0.726
ASA (n, II/III)	24/25	16/14	0.141	0.707
Tidal volume	428.98 ± 37.41	444.03 ± 38.03	1.725	0.0.089
Frequency	14.94 ± 2.26	14.53 ± 1.85	–0.827	0.411
Airway pressure	17.18 ± 1.67	17.50 ± 1.83	0.797	0.428
The second stage				
Group	R group (n = 19)	NR group (n = 10)	χ^2/t	*P*
Sex (n, M/F)	12/7	3/7	0.028	0.128*
Age (y, $\bar{x}$ ± SD)	27.10 ± 5.47	29.90 ± 7.33	–1.16	0.255
BMI (kg/m^2, $\bar{x}$ ± SD)	22.87 ± 1.50	23.18 ± 2.02	0.469	0.643
ASA stage (n, II/III)	11/8	3/7	2.042	0.245*
Tidal volume	440.53 ± 34.36	423.00 ± 37.18	1.270	0.215
Frequency	13.84 ± 1.21	13.80 ± 1.55	0.081	0.936

*Fisher exact test.
BMI, body mass index; ASA, American society of Aneshesiologists.

Table 2. **Changes of hemodynamics of the patients in the 2 groups before and after the volume load test ($\bar{x}$ ± SD)**

Indicator	Group	Before fluid infusion	After fluid infusion	T_{pair}	P_{pair}	$\bar{d} \pm s_d$
HR (beats/min)	R group (n = 49)	69.47 ± 11.86	67.51 ± 9.17	1.247	0.219	1.96 ± 11.00
	NR group (n = 30)	67 ± 12	68 ± 13	−0.780	0.442	−1.06 ± 7.49
	t	−0.819	0.278			
	P	0.415	0.782			
MAP (mm Hg)	R group (n = 49)	79.29 ± 10.53	84.35 ± 9.5	−2.485	0.016	−5.06 ± 14.26
	NR group (n = 30)	83.73 ± 14.46	80.03 ± 14.71	1.454	0.157	3.70 ± 13.94
	t	1.464	−1.433			
	P	0.150	0.159			
CO (L/min)	R group (n = 49)	4.26 ± 0.84	5.32 ± 0.97	−16.172	0.000	−1.06 ± 0.46
	NR group (n = 30)	4.76 ± 1.06	5.01 ± 1.008	−6.836	0.000	−0.25 ± 0.20
	t	2.362	−1.346			
	P	0.021	0.182			
FTc (ms)	R group (n = 49)	297.64 ± 59.34	331.57 ± 58.14	−2.05	0.046	−28.10 ± 95.97
	NR group (n = 30)	364.85 ± 80.33	322.60 ± 62.57	2.478	0.019	42.26 ± 93.40
	t	4.263	−0.194			
	P	0.000	0.847			

HR, heart rate; MAP, mean arterial pressure.

significant effects on FTc ($F_{2, 56} = 1.465$, $P = 0.240$). Therefore, the leading effects of the intrinsic factors, PEEP and volume load, were investigated. The results showed that the effect of PEEP on FTc was not statistically significant ($F_{2, 56} = 1.930$, $P = 0.155$). The FTc was 320.79 ± 67.06, 314.02 ± 54.61, and 315.29 ± 66.96 before the fluid infusion when the PEEP was 0, 5, and 10 cmH_2O, respectively, albeit the difference was not statistically significant. The FTc was 329.14 ± 70.16, 357.40 ± 53.93, and 364.28 ± 80.77 before the fluid infusion when the PEEP was 0, 5, and 10 cmH_2O, respectively, and the difference was not statistically significant (Table 3). On the other hand, the effect of volume load on FTc was statistically significant ($F_{1, 28} = 9.381$, $P < 0.05$). The FTc was significantly different before and after the fluid infusion test ($P < 0.05$); the difference was 35.04 milliseconds (95% confidence interval, 11.607–58.480) (Table 3). When the PEEP was 0, 5, and 10 cmH_2O, the AUROC of FTc for predicting the volume responsiveness was 0.921, 0.805, and 0.719 ($P < 0.05$), and the diagnostic cutoff value of FTc was 323.42 milliseconds, 326.69 milliseconds, and 312.03 milliseconds, respectively (Table 4, Fig. 3).

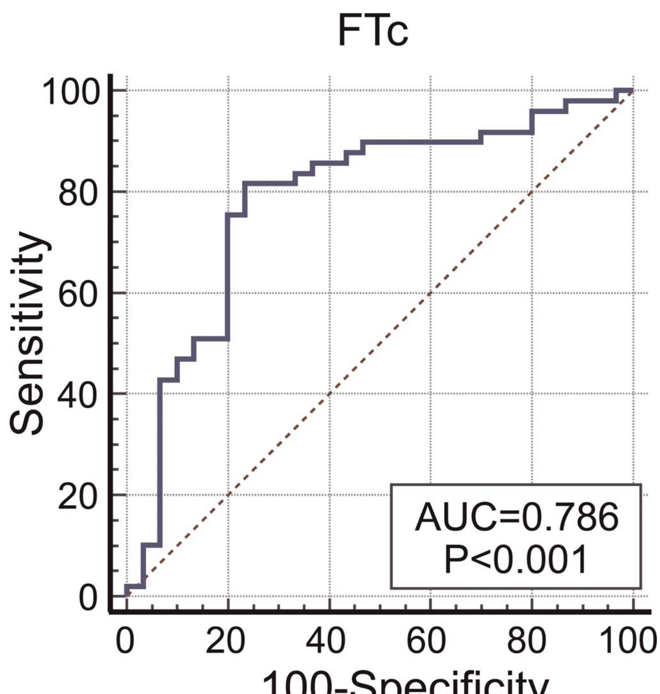

Fig. 2. **Receiver operating characteristic curve of FTc in predicting the volume responsiveness of patients.**

DISCUSSION

With the wide application of perioperative echocardiography, screening an indicator with high predictive power and robust measurements to predict volume responsiveness has become an urgent requirement for doctors to guide perioperative fluid therapy. Corrected flow time has attracted increasing attention in recent years. Some studies suggested measuring the FTc in descending aorta by transoesophageal echocardiography to guide fluid therapy and found that it could reduce the complications, improve the outcomes, and shorten the length of hospital stay (6). However, transoesophageal echocardiography has high requirements for patients, and the results are highly dependent on the operators; these factors restrict the clinical application of this technique. The common carotid artery is a major branch artery with hemodynamic characteristics similar to that of the aorta. Recent clinical studies demonstrated that FTc in the common carotid artery could be used to predict volume responsiveness in patients in shock (12), patients with autonomous respiration (13), and patients under cesarean delivery (14). These studies were performed in patients with autonomous respiration; however, whether FTc in the common carotid artery could be used to guide the fluid therapy in patients under mechanical ventilation is yet unclear. The present study aimed to investigate whether FTc in the common carotid artery could be used to predict the volume responsiveness of patients receiving mechanical ventilation. The PICCO hemodynamics monitoring system uses transpulmonary thermodilution technique technique to measure CO (15). Several studies demonstrated that CO measured by PICCO hemodynamic monitoring system is associated with and consistent to pulmonary artery catheter but is not influenced by mechanical ventilation (16). These findings indicated that PICCO hemodynamics monitoring system predicts the CO accurately. Therefore, we selected PICCO as the reference to explore whether FTc in the common carotid artery can predict volume responsiveness under mechanical ventilation.

Table 3. **Comparison of hemodynamic indicators at different PEEPs**

Indicator	PEEP	Before volume load test	After volume load test	F_{time}	P_{time}	F_{group}	P_{group}	$F_{time \times group}$	$P_{time \times group}$
MAP	0	81.86 ± 11.83	83.24 ± 14.15	0.220	0.643	0.393	0.656	0.773	0.462
	5	80.97 ± 11.89	83.97 ± 14.22						
	10	81.48 ± 14.00	81.24 ± 10.53						
HR	0	66.44 ± 11.72	65.20 ± 10.58	1.348	0.255	0.144	0.847	0.788	0.436
	5	66.28 ± 11.92	64.93 ± 9.96						
	10	67.59 ± 12.44	64.48 ± 9.76						
FTc	0	320.79 ± 67.06	329.14 ± 70.16	9.381	0.005	1.930	0.157	1.465	0.240
	5	314.02 ± 54.61	357.40 ± 53.93						
	10	315.29 ± 66.96	364.28 ± 80.77						

HR, heart rate; MAP, mean arterial pressure.

The current study suggested that FTc before fluid infusion predicts volume responsiveness of patients undergoing major surgeries in the general surgery department, and the best cutoff value was 323.42 milliseconds. These findings provided an objective, quantitative indicator for early, accurate administration of fluid therapy. This method was noninvasive and easy to perform and could be completed in most operations. The CO of patients with volume responsiveness increased after fluid infusion, and also, the FTc in the common carotid artery was increased. The equation for calculating the FTc in the common carotid artery showed that FTc in the common carotid artery is associated with the systolic phase of the heart. If the patients had insufficient volume and the CO was insufficient, the compensation of the heart rate could shorten the systolic phase of the heart, thereby decreasing the FTc value. After sufficient fluid infusion, the volume sensor of the heart could inhibit the heart rate through feedback and thus increase the FTc (17). For patients without volume responsiveness, the flow time in the common carotid artery was long, which reduced after fluid infusion, and was associated with reduced transduction of cardiac vagus nerve signals induced by the inhibition of Bezold-Jarisch reflex (18). In this study, patients were divided into R group and NR group according to whether there was volume responsiveness or not. The results showed that the basal FTc of the NR group was higher than that of the R group. At the same time, we found that the number of patients in the R group who underwent preoperative intestinal preparation and fasting time of more than 15 hours was higher than that of the NR group, suggesting that FTc can indeed reflect volume capacity. On the other hand, it also suggests that patients who have undergone intestinal preparation or who have been fasting for a long time have obvious volume deficiency before surgery, which needs to be corrected by infusion therapy or oral carbohydrate drinks.

Positive end-expiratory pressure has been applied widely in critical patients, which refers to the technique of maintaining specific airway pressure at the intermittent positive pressure ventilation to open small airways. It plays a critical role in treating critical diseases, such as respiratory distress syndrome and cardiac asthma (19). However, PEEP will make the evaluation of hemodynamics more complex (4). The mechanisms of previously used intrathoracic indicators, such as stroke volume variation and pulse pressure variation, which were applied to measure volume responsiveness, were based on the heart-lung interactions, namely, the changes in the stroke volume and diameter of inferior vena cava with the periodical change in intrathoracic pressure under mechanical ventilation (20). Intriguingly, PEEP can alter the intrathoracic pressure and thus influence these indicators (8). Nonetheless, additional studies are needed to investigate further whether FTc in the common carotid artery has high sensitivity and specificity in predicting volume responsiveness in patients receiving high-level PEEP.

Table 4. **Diagnostic threshold, sensitivity, and specificity of FTc at different PEEP**

	PEEP	AUROC	Diagnostic threshold	Sensitivity (%)	Specificity (%)
FTc	0	0.921	323.42	100.00	78.91
	5	0.805	326.69	66.72	100
	10	0.719	312.03	78.62	73.30

In the second stage of this study, the PEEP value was adjusted sequentially to investigate whether different levels of PEEP influence the predictive power of FTc in the common carotid artery for volume responsiveness. The findings demonstrated that FTc at different levels of PEEP was not significantly different, and the diagnostic thresholds under the ROC were >0.7, suggesting that PEEP does not have any significant influence on FTc. Therefore, FTc in the common carotid artery was suitable for patients under mechanical ventilation with different levels of PEEP, which can be associated with the fact that the common carotid artery is outside the thoracic cavity and thus is not influenced by intrathoracic pressure. In addition, FTc was associated with the systolic phase of the heart, and different levels of PEEP did not exert a significant influence on the duration of the systolic phase of the heart.

All the patients underwent laparotomy under the same anesthesia regimen. The demographic characteristics of the included patients were similar, and thus, the putative biases were ruled out. In the second stage of the study, PEEP value was sequentially adjusted. We found that PEEP <10 cmH_2O did not affect FTc in the common carotid artery, which increased the range of clinical application.

Nevertheless, the present study had several limitations. First, the sample size of the study was small. The first stage of the study included 80 patients, whereas the second stage only included 29 patients. Second, although the measurements were performed independently by two experienced investigators, and the averages were calculated, the measurement errors were inevitable. Third, to avoid injury caused by excessive volume load to elderly patients and patients with cardiopulmonary dysfunction, the patients included in this study were younger. Finally, the highest PEEP value in this study was 10 cmH_2O, and additional studies were needed to further investigate whether high levels of PEEP can influence the FTc.

In summary, FTc in the common carotid artery can accurately predict volume responsiveness under mechanical ventilation. Furthermore, it is not influenced by PEEP. Even when PEEP is 10 cmH_2O, FTc in the common carotid artery has a high

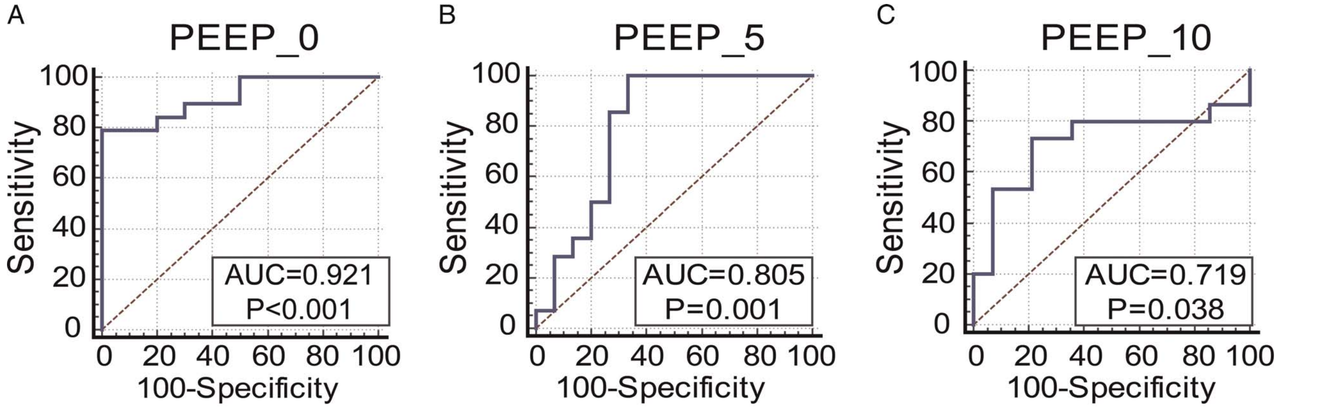

FIG. 3. **Receiver operating characteristic curve of FTc in predicting the volume responsiveness of patients under different PEEPs.** A, PEEP = 0 cmH_2O; B, PEEP = 5 cmH_2O; C, PEEP = 10 cmH_2O.

diagnostic value, which provides a theoretical basis for fluid therapy in perioperative patients.

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