

The Predictive Value of MAP and ETCO₂ Changes After Emergency Endotracheal Intubation for Severe Cardiovascular Collapse

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Abstract

Objective: To analyze the changes in mean arterial pressure (MAP) and end-tidal CO₂ (ETCO₂) in patients after emergency endotracheal intubation (ETI). To explore the values of MAP and ETCO₂ monitoring in the early prediction of severe cardiovascular collapse (CVC).

Methods: The clinical data of patients who underwent ETI were collected. The values of both MAP and ETCO₂ were observed and recorded at 5 minutes, 10 minutes, 30 minutes, 60 minutes and 120 minutes post intubation. According to whether severe CVC occurred after ETI, the patients were divided into a severe CVC group and a non-severe CVC group. The values of MAP and ETCO₂ were compared at the same time points. The correlation between MAP and ETCO₂ after ETI was also analyzed. receiver operating characteristic curves(ROC curves) were used to analyze the ability of MAP and ETCO₂ at 5 minutes and 10 minutes after ETI to predict severe CVC.

Results: A total of 116 patients were enrolled in this study; among them, 75 (64.7%) had severe CVC after ETI. The majority of subjects in the severe CVC group were male and elderly patients. The values of MAP and ETCO₂ at 5 minutes, 10 minutes, 30 minutes, 60 minutes and 120 minutes after ETI in the severe CVC group were significantly lower than those in the non-severe group. Both MAP and ETCO₂ in the two groups showed simultaneous decreases from 5 minutes to 30 minutes after ETI, reaching their lowest values at 30 minutes after ETI. After ETI, the changes in MAP were correlated with those in ETCO₂ ($r_s = 0.653, P < 0.001$). At 5 minutes after ETI, MAP could predict severe CVC (AUC = 0.86, $P < 0.001$), MAP ≤ 72 mmHg was the best cutoff value (sensitivity 78.7%, specificity 87.8%), and ETCO₂ could also predict severe CVC (AUC = 0.85, $P < 0.001$). ETCO₂ ≤ 35 mmHg was the best cutoff value for predicting severe CVC (sensitivity 77.3%, specificity 85.4%). At 10 minutes after ETI, MAP could predict severe CVC (AUC = 0.90, $P < 0.001$), MAP ≤ 67 mmHg was the best cutoff value (sensitivity 89.3%, specificity 85.4%), and ETCO₂ could also predict severe CVC (AUC = 0.87, $P < 0.001$). ETCO₂ ≤ 33 mmHg was the best cutoff value for predicting severe CVC (sensitivity 81.3%, specificity 78%). There was no significant difference in the predictive ability between any two cutoff values of MAP or ETCO₂ at 5 minutes and 10 minutes after ETI ($P > 0.05$).

Conclusion: Both MAP and ETCO₂ values of the patients with severe CVC were significantly lower than those of patients without severe CVC from 5 minutes to 120 minutes after ETI, reaching their lowest values at 30 minutes after ETI. MAP and ETCO₂ values changed synchronously with the time after intubation. There was a positive correlation between MAP and ETCO₂ after ETI. MAP and ETCO₂ values in the early stage after ETI have high accuracy in predicting severe CVC.

Introduction

One of the most common and serious fatal complications after emergency tracheal intubation (ETI) is severe circulatory collapse (CVC) [1]. It is reported that severe hemodynamic instability after emergency

ETI is not uncommon[2]; for every 1,000 hospitalized patients, there are 110 cases of emergency intubation [3]. Severe CVC after ETI is the main risk factor for adverse events and increased mortality in emergency tracheal intubation patients [4, 5, 6]. Therefore, predicting the occurrence of severe CVC early after tracheal intubation and taking immediate intervention measures are the primary prerequisites to avoid adverse events. However, the current clinical understanding of CVC is still at the stage of emergency intervention after severe CVC[7]. There is no research report on the occurrence and development of severe CVC after emergency tracheal intubation or how to find it early. Because severe CVC after ETI mainly manifests as a significant decrease in blood pressure, and this obvious decrease in blood pressure does not occur suddenly, the decrease in blood pressure may occur before the severe CVC. Therefore, whether blood pressure changes before severe CVC occurs, and if so, how it changes, the relationship between the decline and the severity of CVC, and whether there is an ability to predict CVC and a critical value for early warning are still not clear. In addition, end-expiratory carbon dioxide (ETCO₂) is a commonly used monitoring index in emergency departments, and its monitoring is convenient and widely used [8, 9]. In terms of cycle monitoring, ETCO₂ has long been found to be closely related to cycle status [10]. In emergency airway management, ETCO₂ is often used to monitor whether the tracheal tube is located in the trachea. However, to date, no research has evaluated the value of ETCO₂ in predicting the occurrence of severe CVC after emergency ETI[11,12]. Therefore, this study explored the value of MAP and ETCO₂ monitoring in the early prediction of severe CVC by analyzing the changes in MAP and ETCO₂ in patients with severe CVC and non-severe CVC after emergency ETI.

Subjects And Methods

Research subjects

Adult patients who underwent emergency endotracheal intubation in the emergency department of Peking Union Medical College Hospital from March 2015 to May 2017 were included in this study in chronological order. Patients with hemodynamic instability before emergency ETI, such as shock or cardiac arrest; patients who used vasoactive drugs; or those who did not agree to participate in the study were excluded.

Ethics and informed consent

Due to the observational, noninvasive design of this study, the local ethics committee, namely, the Peking Union Medical College Hospital Ethics Review Committee, approved the study design (protocol number: S-559). All patients signed an informed consent form for endotracheal intubation.

Research methods

This study was a prospective observational study. The clinical data of patients before tracheal intubation were collected and recorded. The clinical data before tracheal intubation included sex, age, the cause of acute medical treatment, underlying disease, the cause of emergency tracheal intubation and vital signs.

Tracheal intubation adopts the procedure of rapid sequence intubation (RSI) [8]. In the case of intubation, the patient was first preoxygenated, and analgesic, sedative, and muscle relaxant drugs were given according to the procedure. Tracheal intubation was performed after direct or visual laryngoscope exposure of the glottis. If the glottis was not visible, the difficult airway management process was followed. After endotracheal intubation, if the patient had an MAP <65 mmHg, 500-1000 ml supplemental crystal fluid was given; if blood pressure could not be maintained, vasoactive drugs were given.

An IntelliVue MP50 (Philips, Netherlands) was used to monitor noninvasive blood pressure, with a measurement interval of 5 minutes. A BeneView T8 (Mindray, Shenzhen) equipped with a bypass ETCO₂ monitoring module was used to continuously monitor ETCO₂ after intubation. The values of MAP and ETCO₂ at 5, 10, 30, 60 and 120 minutes after emergency tracheal intubation were observed and recorded. According to whether patients had severe CVC after emergency ETI, they were divided into a severe CVC group and a nonsevere CVC group. Severe CVC was defined as hemodynamic instability (systolic blood pressure \leq 65 mmHg recorded at least once and/or despite supplementary blood volume of 500–1000 ml and/or systolic blood pressure \leq 90 mmHg for \geq 30 minutes in the case of vasoactive drugs). The values of MAP and ETCO₂ at 5 minutes, 10 minutes, 30 minutes, 60 minutes and 120 minutes after tracheal intubation in the two groups were analyzed and compared at the same time points between groups and at consecutive time points within groups, and all patients underwent correlation analysis of MAP and ETCO₂ after tracheal intubation. The ROC curve was used to analyze the ability of MAP and ETCO₂ to predict severe CVC at 5 and 10 minutes after intubation.

Statistical Analysis

Statistical analysis was performed using the IBM SPSS 19 software package (SPSS Inc., Chicago, Illinois, United States). The analyses calculated the number of patients and related percentages according to the classification parameters. The chi-squared test or Fisher's exact test was used to compare the categorical variables between independent groups. All continuous variables were tested for normal distribution. Continuous variables that conformed to the normal distribution were described by the mean \pm the standard deviation. The independent-sample T test was used for comparisons between groups. Continuous variables that did not conform to a normal distribution are represented by the median (interquartile range). The Wilcoxon signed rank test was used for within-group comparisons, and the Mann-Whitney U test was used for comparisons between groups. For the correlation analysis, a bivariate correlation model was used. Normally distributed data were analyzed by Pearson correlation analysis, and nonnormally distributed data were analyzed by Spearman correlation analysis. ROC curves were drawn based on relevant parameters relatively analyzed and compared to the area under the curve. P <0.05 was considered statistically significant.

Results

A total of 116 patients were enrolled in the study. Among them, 75 (64.7%) patients had severe CVC after endotracheal intubation. The majority of subjects in the severe CVC group were male and elderly patients,

as shown in Table 2. The values of MAP and ETCO₂ in the severe CVC group were significantly lower than those in the nonsevere CVC group 5 minutes after emergency tracheal intubation [mmHg: 64 (57, 72) vs. 80 (75.5, 89.5); 33 (30, 35) vs. 41 (37, 44), $p < 0.001$]; see Table 3. After that, the MAP and ETCO₂ values of the two groups showed a synchronous downward trend with time, as shown in Figures 1 and 2, and the decline was obvious. The values of MAP and ETCO₂ in the two groups significantly decreased and indicated severe CVC at 10 minutes after intubation. The values of the severe CVC group were significantly lower than those in the nonsevere CVC group at 30 minutes after tracheal intubation, reaching their lowest values compared with 10 minutes after intubation, and the values of the severe CVC group were still significantly lower than those of the nonsevere CVC group [mmHg: 48 (41, 55) vs 70 (67, 79); 26 (25, 27) vs. 37.5 (35, 40.75), $p < 0.001$]. The MAP and ETCO₂ values of the two groups showed a gradual recovery trend afterwards, with significant recovery 60 minutes after intubation compared with 30 minutes after intubation, and the values of the severe CVC group were still significantly lower than those of the nonsevere CVC group. The values of MAP and ETCO₂ were significantly increased at 120 minutes and 60 minutes after intubation, and the values of the severe CVC group were still significantly lower than those of the nonsevere CVC group [mmHg: 65 (59, 76) vs. 80 (72.5, 89); 34 (32, 36) vs. 38.5 (37, 40), $p < 0.001$]. After endotracheal intubation, the changes in MAP and ETCO₂ were correlated ($r_s = 0.653$, $p < 0.001$); see Figure 3. Five minutes after endotracheal intubation, MAP accurately predicted severe CVC (AUC=0.86, $p < 0.001$), as shown in Figure 4. MAP ≤ 72 mmHg was the best cutoff value for predicting severe CVC (sensitivity 78.7%, specificity 87.8%); see Table 3. ETCO₂ can accurately predict severe CVC 5 minutes after endotracheal intubation (AUC=0.85, $p < 0.001$). ETCO₂ ≤ 35 mmHg was the best cutoff value for predicting severe CVC (sensitivity 77.3%, specificity 85.4%). Ten minutes after endotracheal intubation, MAP could accurately predict severe CVC (AUC=0.90, $p < 0.001$), as shown in Figure 5. MAP ≤ 67 mmHg was the best cutoff value for predicting severe CVC (sensitivity 89.3%, specificity 85.4%); see Table 3. ETCO₂ could accurately predict severe CVC 10 minutes after endotracheal intubation (AUC=0.87, $p < 0.001$). ETCO₂ ≤ 33 mmHg was the best cutoff value for predicting severe CVC (sensitivity 81.3%, specificity 78%). There was no statistically significant difference in the predictive power of either MAP or ETCO₂ at 5 and 10 minutes after intubation in the ED ($p > 0.05$).

Discussion

In this study, by observing the changes in MAP and ETCO₂ in patients after emergency tracheal intubation, 64.7% of emergency tracheal intubation patients had severe CVC. The values of MAP and ETCO₂ at 5 minutes, 10 minutes, 30 minutes, 60 minutes, and 120 minutes after intubation in such patients were significantly lower than those in patients without severe CVC and reached their lowest values 30 minutes after intubation. The MAP and ETCO₂ values of the two groups showed a simultaneous decline from 5 minutes to 30 minutes after emergency tracheal intubation and then showed a simultaneous rebound to 120 minutes after tracheal intubation. The changes in MAP and ETCO₂ after tracheal intubation were positively correlated. Both MAP and ETCO₂ at 5 and 10 minutes after tracheal intubation could accurately predict severe CVC.

In this study, the MAP and ETCO₂ values of severe CVC patients at 5 minutes, 10 minutes, 30 minutes, 60 minutes, and 120 minutes after emergency tracheal intubation were significantly lower than those of patients without severe CVC and reached their lowest value 30 minutes after tracheal intubation. The changes in MAP and ETCO₂ after emergency tracheal intubation have not been reported before. Our study found that patients with severe CVC had lower blood pressure and lower ETCO₂ than those without severe CVC early after tracheal intubation (5 minutes after tracheal intubation). Although the MAP at this time may still be slightly higher or lower than the minimum threshold of the normal range, it still does not reach the standard of severe CVC. The consequence is that the discovery and intervention of severe CVC is delayed, and the patient is exposed to too low blood pressure for a long duration. The results of this study also confirmed this, and we can see that the blood pressure gradually decreased after 5 minutes of tracheal intubation and reached its lowest value 30 minutes after intubation (median less than 50 mmHg). After that, blood pressure slowly recovered and was still significantly lower than that of patients without severe CVC 120 minutes after intubation. This long-term average blood pressure of less than 65 mmHg will lead to the hypoperfusion of vital organs, and persistent hypotension is associated with higher mortality [13]. When coronary perfusion pressure drops severely, leading to insufficient blood and oxygen supply to the heart, even the most serious complication of cardiac arrest may occur [14]. Therefore, to avoid the occurrence of the abovementioned serious complications, the early prediction of severe CVC after emergency tracheal intubation is particularly important. This study found that MAP at 5 and 10 minutes after intubation can accurately predict the occurrence of severe CVC, and the optimal cutoff values for MAP at 5 and 10 minutes after intubation were 72 mmHg and 67 mmHg, respectively, which were above 65 mmHg. These findings indicate that early prevention and treatment of severe CVC after intubation is recommended.

In addition, this study also found that ETCO₂ and MAP changed synchronously after emergency tracheal intubation, and changes in MAP and ETCO₂ were correlated. ETCO₂ at 5 and 10 minutes after endotracheal intubation can also accurately predict severe CVC, and the prediction performance is not lower than that of MAP. End-tidal carbon dioxide (ETCO₂) is the partial pressure measured at the end of exhaled carbon dioxide (CO₂) in exhaled air. Carbon dioxide is produced in the aerobic metabolism of perfused tissue. It diffuses from the cells into the blood, flows back into the lungs through veins and is cleared by ventilation in the lungs. The main determinants of ETCO₂ include CO₂ production, cardiac output (CO), pulmonary perfusion blood flow, and alveolar ventilation. Therefore, ETCO₂ can comprehensively evaluate the three main functions of the human body: metabolism, circulation and ventilation. If two of the functions are in a relatively stable state, the change in ETCO₂ can reflect a change in the third function [15]. After a period of emergency endotracheal intubation mechanical ventilation, if there is no carbon dioxide accumulation in the body, and the metabolism and lung ventilation in the body are in a relatively stable state, then the change in ETCO₂ reading can reflect the change in cardiac output. Cardiac output is also an important factor influencing blood pressure. Therefore, under the condition that other factors are relatively stable, ETCO₂ and MAP should change simultaneously, and ETCO₂ and MAP should have a certain correlation. Our research results also

confirmed this. This suggests that the decrease in cardiac output after emergency tracheal intubation may be the main reason for the drop in blood pressure. Because of this, some studies have reported that ETCO₂ can be used as a noninvasive monitoring method for shock patients [16,17], and our study also found that ETCO₂ 5 minutes and 10 minutes after endotracheal intubation can also accurately predict severe CVC, and the prediction performance is not less than that of MAP. ETCO₂ and MAP are also noninvasive monitoring methods, but their advantage over noninvasive cuff blood pressure measurement is that they can be continuously monitored in real time and are easy to use[18,19]. However, it should be noted that when there are other factors that affect ETCO₂, the value of ETCO₂ should be interpreted with caution. For example, after tracheal intubation in patients with type II respiratory failure, ETCO₂ is significantly increased due to the accumulation of carbon dioxide in the body. At this time, the value of ETCO₂ may not truly reflect the changes in circulation[20].

This study also has some shortcomings. First, this study is a single-center prospective study. The overall sample size is small, and the results may not reflect responses in all emergency tracheal intubation patients. Second, for purely observational studies, clinical interventions such as fluid replacement and vasoactive drugs may have an impact on MAP and ETCO₂. Again, some patients have intubation due to pulmonary respiratory failure, which may have an impact on ETCO₂ values.

Conclusion

MAP and ETCO₂ values of patients with severe CVC from 5 minutes to 120 minutes after tracheal intubation in the emergency department were significantly lower than those without CVC, and MAP and ETCO₂ values reached their lowest values 30 minutes after intubation. With the elapsed time after tracheal intubation, MAP and ETCO₂ showed synchronous trend variations, both with positive correlations. Early MAP and ETCO₂ values after tracheal intubation have high accuracy in predicting severe CVC. Five minutes post intubation, MAP≤72 mmHg, ETCO₂≤35 mmHg, and 10 minutes post intubation, MAP≤67 mmHg and ETCO₂≤33 mmHg indicated the possibility of severe CVC.

Abbreviations

CVC: cardiovascular collapse

ETI: endotracheal intubation

Emergency Department: ED

PEEP: positive end-expiratory pressure

ETCO₂: end-tidal carbon dioxide

COPD: chronic obstructive pulmonary disease

MAP: mean arterial pressure

ROC: receiver-operating characteristic

ORs: odds ratios

CI: confidence interval

FiO₂: inspired oxygen concentration

Declarations

Ethics and consent

Because of the observational, noninvasive design of this study, the need for written consent was waived. The local ethics committee, the PUMCH Institutional Review Board, approved the study design (PROTOCOL NUMBER:S-559).

Consent for Publication

All authors read and approved the final manuscript and agree to be accountable for all aspects of the work for publication.

Availability of data materials

All the original data was available.

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Conflicts of interest

None of the authors received funding for any portion of this work.

Authors' contributions

Dai Jiayuan and Xu Jun conceived of and designed the study, interpreted the data, and helped to draft the manuscript. Yin Lu and Song Xiao were involved with data acquisition and provided critical revisions to the manuscript. Yin Lu and Gu Ming performed the statistical analysis and provided critical revisions to the manuscript. Yu Xuezhong and Zhu Huadong contributed to interpretation of the data and provided critical revisions to the manuscript. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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No.

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Tables

Table 1 Characteristics of patients

	Total (n=116)	No CVC (n=41)	Yes CVC (n=75)	p- value
Number	116	41	75	
Age in years □ median [IQR]	63.50 [54.75, 71.00]	56.00 [49.00, 67.00]	65.00 [57.00, 72.00]	0.005
Gender,n(%)				
Male,n(%)	59 (50.9)	15 (36.6)	44 (58.7)	0.038
Female,n(%)	57 (49.1)	26 (63.4)	31 (41.3)	
Reasons for Emergency Room admission:				
Acute respiratory failure,n(%)	71(61.2)	24 (58.5)	47 (62.7)	0.324
Consciousness disorder,n(%)	32 (27.6)	13 (31.7)	19 (25.3)	0.427
Twitch,n(%)	5	3	2	0.662
Trauma □n(%)	10 (8.6)	3 (7.3)	7 (9.3)	0.571
Past medical history				
Tobacco,n(%)	53 (45.7)	16 (39.0)	37 (49.3)	0.384
COPD,n(%)	19 (16.4)	6 (14.6)	13 (17.3)	0.91
Diabetes,n(%)	65 (56.0)	18 (43.9)	47 (62.7)	0.08
Hypertension,n(%)	63 (54.3)	23 (56.1)	40 (53.3)	0.928
Drink wine,n(%)	33 (28.4)	11 (26.8)	22 (29.3)	0.944
Reasons for intubation				
Hyoxemia, n(%)	81 (69.8)	26 (63.4)	55 (73.3)	0.368
Respiratory distress,n(%)	36 (31.0)	11 (26.8)	25 (33.3)	0.607
Airway protection, n(%)	27 (23.3)	12 (29.3)	15 (20.0)	0.368
Obstruction by spurum,n(%)	6 (5.2)	2 (4.9)	4 (5.3)	0.693

Table2 Comparison of MAP and ETCO₂ between CVC group and non-CVC group after ETI

	Total [n=116]	Yes CVC (n=75)	No CVC (n=41)	p-value
MAP [mmHg]				
5min,	70 (62, 80.75)	64 (57, 72)	80 (75.5, 89.5)	<0.001
10min	62 (53, 73)	55 (51, 63)	75 (70, 82)	<0.001
30min	55 (45.25, 68)	48 (41, 55)	70 (67, 79)	<0.001
60min	66 (55.25, 76)	59(52, 68)	77 (72, 81)	<0.001
120min	72 (61.25, 81)	65 (59, 76)	80 (72.5, 89)	<0.001
ETCO₂ [mmHg]				
5min	34 (31.5, 39)	33 (30, 35)	41 (37, 44)	<0.001
10min	32 (29, 37.5)	30(28, 33)	39.5 (34, 41)	<0.001
30min	27 (26, 35.5)	26(25, 27)	37.5 (35, 40.75)	<0.001
60min	34 (29.5, 37.5)	31(29, 34)	38 (36, 41)	<0.001
120min	36 (33, 38)	34(32, 36)	38.5 (37, 40)	<0.001

Table3 Comparison of the ability of MAP and ETCO₂ to predict severe CVC at 5 and 10 minutes after ETI

Time	Cut-off	AUC (95% CI)	Sensibility [%]	Specificity [%]	PPV [%]	NPV [%]
5min						
MAP	≤72mmHg	0.86 [0.80-0.93]	78.7	87.8	92.2	69.3
ETCO ₂	≤35mmHg	0.85 [0.77-0.93]	77.3	85.4	90.6	67.3
10min						
MAP	≤67mmHg	0.90 [0.83-0.96]	89.3	85.4	91.8	81.4
ETCO ₂	≤33mmHg	0.87 [0.81-0.94]	81.3	78	87.1	69.5

Figures

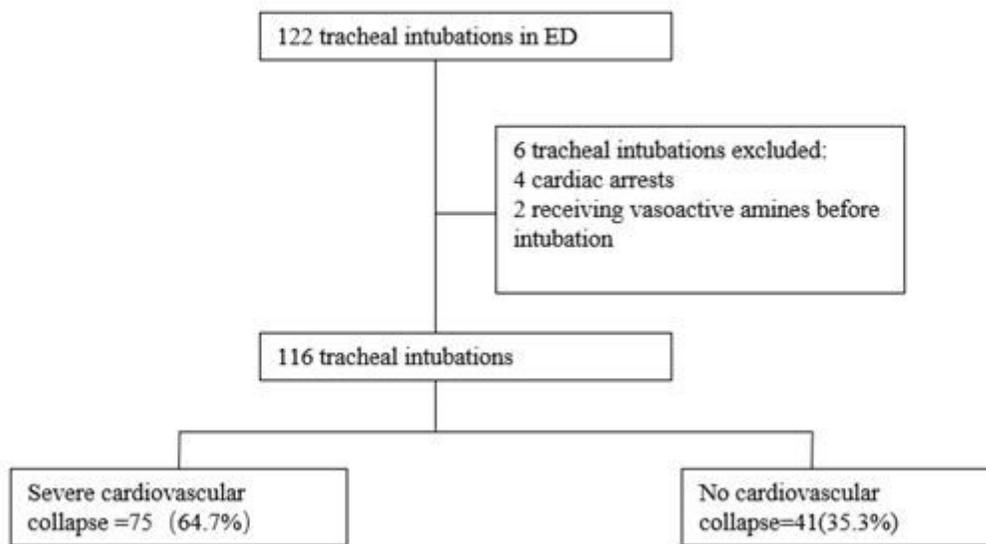


Figure 1

Study flow chart: This figure is the flow chart of our study.

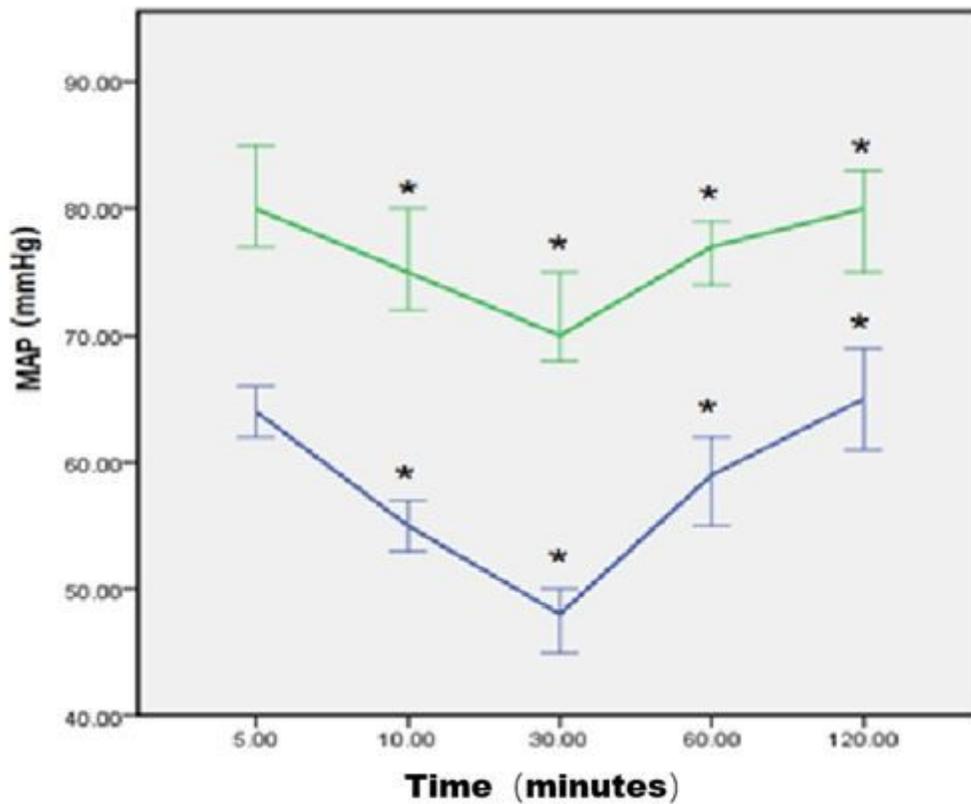


Figure 2

Changes in MAP after ETI in the CVC group and non-CVC group

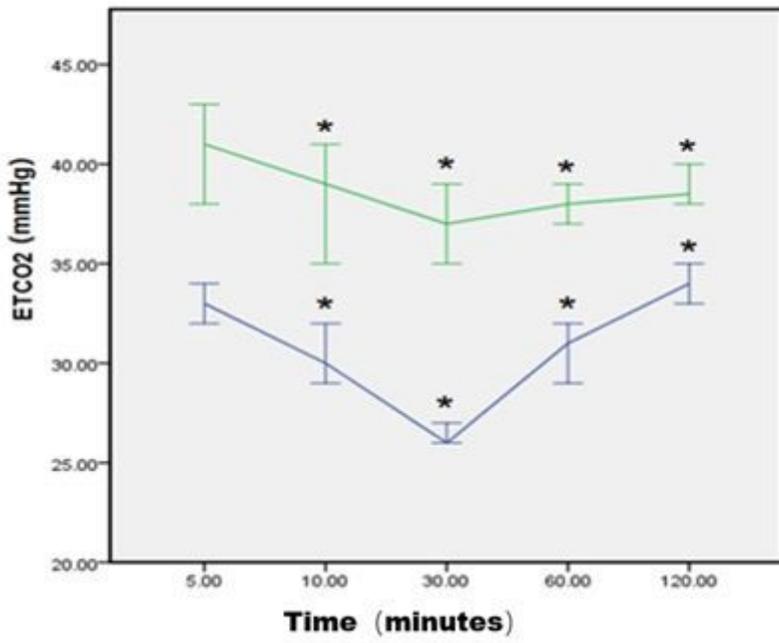


Figure 3

Changes in ETCO2 after ETI in the CVC group and non-CVC group

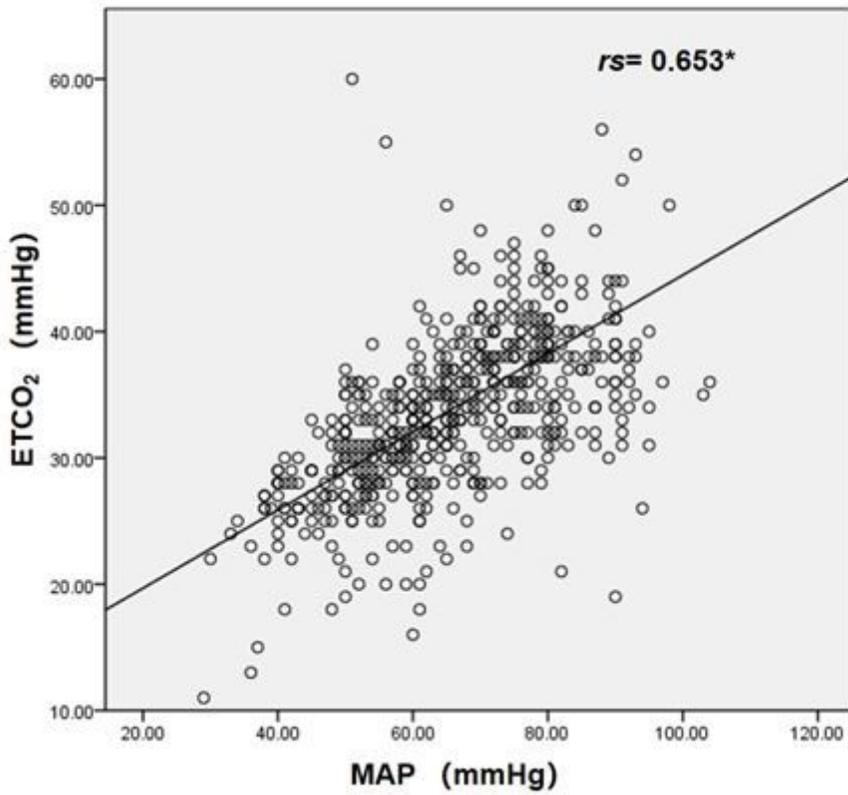


Figure 4

Correlation analysis of MAP and ETCO2 in patients after ETI

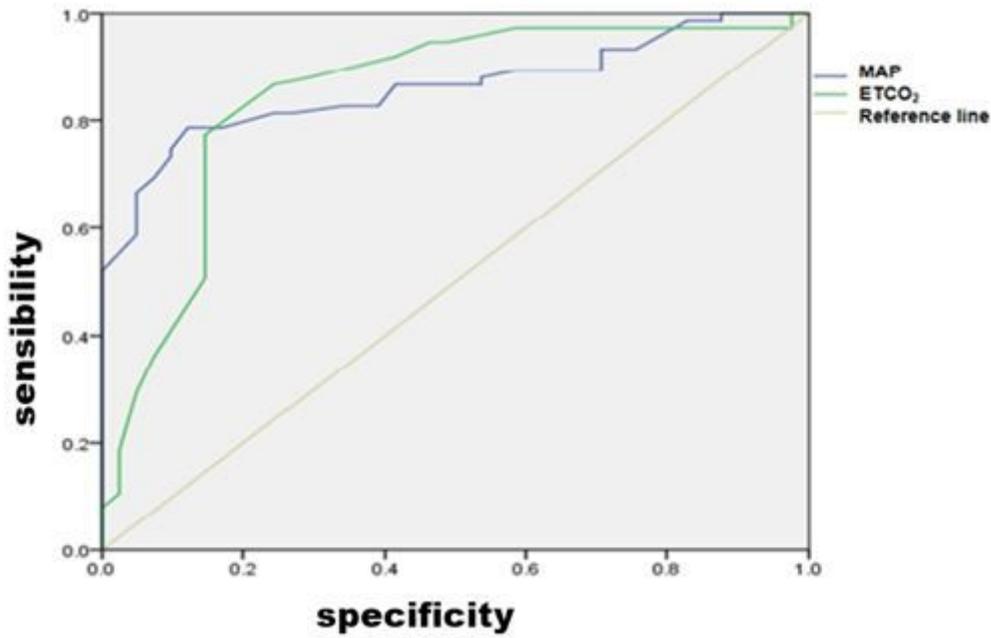


Figure 5

ROC curve of MAP and ETCO₂ for severe CVC at 5 min after ETI

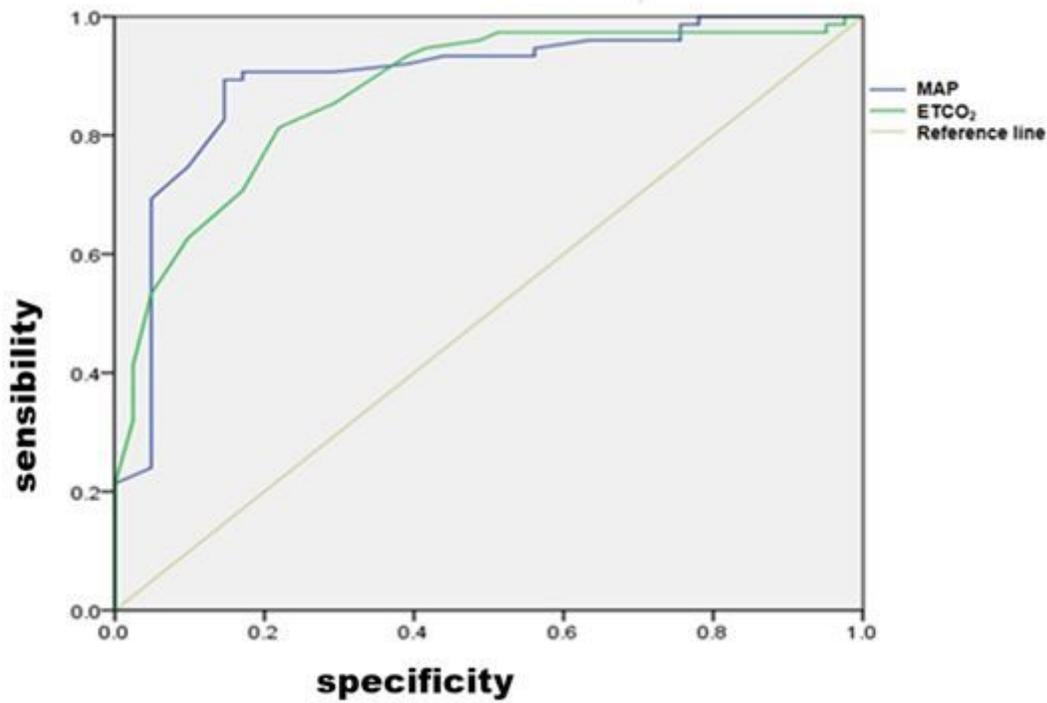


Figure 6

ROC curve of MAP and ETCO₂ for severe CVC at 10 min after ETI