A novel echocardiographic parameter for assessment of right ventricular function in acute pulmonary embolism: an experimental study

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Abstract

Background Right ventricular (RV) dysfunction played a decisive role in clinical management and associated with poor prognosis in acute pulmonary embolism (PE). It still remains challenging to estimate RV function accurately for the reason of complex structure and geometry. The present study aimed to determine the value of right ventricular outflow tract systolic excursion (RVOT-SE) in evaluating RV function in an animal model with acute PE. Methods Thirty-three healthy New Zealand rabbits were randomly assigned to massive thrombus group, sub-massive thrombus group and control group, 11 rabbits per group. The acute PE model was established by intravenous infusion of autologous blood clots. After 1h of thrombus injection, transthoracic echocardiography was performed to assess RV function in all rabbits. Results The acute PE model was successfully made in 18 rabbits (massive thrombus group, n = 8; sub-massive thrombus group n = 10). Right/left ventricular end-diastolic diameter (RV/LV) ratio and RV myocardial performance (Tei) index were significantly increased, while RV fractional area change (RVFAC), tricuspid annular plane systolic excursion (TAPSE) and RVOT_SE were reduced in massive thrombus group. The value of RVOT-SE and RVFAC in sub-massive thrombus group decreased significantly compared with control group (P < 0.05). But there was no significant difference in RV/LV, TAPSE and Tei index (P > 0.05). ROC analysis showed that RVOT-SE had high sensitivity (94.4%) and specificity (72.7%) in identifying RV dysfunction in acute PE. The area under the ROC curve (AUC) for combined TAPSE and RVOT-SE was greater than that of TAPSE or RVOT-SE alone (AUC= 0.962, P < 0.01). Conclusion RV function in acute PE is significantly decreased, which is closely related to the size of embolus. RVOT_SE is a simple and highly distinctive parameter in identifying RV dysfunction and tends to be superior to conventional parameters in acute PE. The combination of RVOT-SE and TAPSE can further improve the diagnostic accuracy of acute PE.

Background

Acute pulmonary embolism (PE) is one of the most serious complications of venous thromboembolism associated with a high incidence of morbidity, hospitalization and mortality [1]. In the United States, the incidence of PE is expected to reach 11.2%, and about 100,000 people die of PE per year[2]. In Europe, 34% of the 370,000 VTE-related deaths were due to acute PE, of which only 7% were diagnosed before death [3]. Despite the high morbidity, delay in diagnosis of PE occurs frequently in the absence of typical clinical features or when thrombus located in distal pulmonary artery, which will delay treatment and increase the mortality of PE.

Right ventricular (RV) dysfunction played a decisive role in clinical management and a well-established prognostic marker in patients with acute PE [4]. Although many imaging modalities have been applied to detect RV dysfunction, echocardiography is a frequent diagnostics method in clinical practice by its ability to determine RV shape and systolic function noninvasively. It still remains challenging to estimate RV function accurately for the reason of the complex structure and geometry [5]. RV dysfunction has been evaluated according to different echocardiographic findings, such as fractional area change (FAC), tricuspid annular plane systolic excursion (TAPSE), and RV index of myocardial performance (Tei) index.
However, consensus on how to determine RV dysfunction in patients with acute PE is still absence. Right ventricular outflow tract (RVOT) is an important compartment of RV, which contribute to RV systolic function by some extent. RVOT has superficial circumferential muscle fibers, which causes radial RVOT contraction during the ejection phase. As the movement of RVOT measured by M-mode echocardiography is easy to access under different cardiac ultrasound systems. Measurement of RVOT movement was recommended as an additional tool for assessment of RV function by various studies in this reproducible and simple way [6, 7].

In the present study, we sought to determine the values of RVOT movements in evaluating RV function in an animal model with acute PE and compared the accuracy between this method and other established measurements of systolic function in the diagnosis of acute PE.

**Methods**

The study protocol was approved by Institutional animal care of Guangxi Medical University and conformed to Chinese guidelines on research animal experiments. A total of 33 healthy male New Zealand white rabbits (Animal Laboratory of Guangxi Medical University, Nanning, Guangxi Zhuang Autonomous Region, China) aged 4 months, with a weight of 2.5-3.0 kg were used in this study. All rabbits were acclimatized for three days under standard conditions before experiments. Then the rabbits were randomly assigned into three groups (n = 11 in each group).

**Autologous Blood Clots Preparation**

After anesthesia via ear marginal venous, a total of 2 ml of venous blood collected from another ear marginal venous were injected into a rubber tube (10 cm long with a 1-mm or 2-mm inner diameter). Then we put it into a thermostatic water bath at 37℃ for 30 minutes. Long cylindrical clots were removed from the rubber tube and washed three times with saline solution. Blood clots were then cut into four segments with 6-mm length by operating knife blade and drawn back into the tubes which were filled up with saline solution for later injection (Fig. 1).

**Establishment of acute PE model**

The acute PE model was established in this study by intravenous infusion of autologous blood clot[8]. Rabbits were anaesthetized using intravenous injection of pentobarbital sodium (Sigma-Aldrich) at a dosage of 30 mg/kg via ear marginal venous. The right jugular vein of the rabbit was cannulated by a 6F catheter after iodophor disinfection. Acute PE model was created by intravenous injection of autologous blood clots and normal saline, which was followed by bolus injection of 5-mL saline to ensure that the blood clots have entered the pulmonary circulation. Sub-massive PE was induced by injecting 4 autologous blood clots measuring 1 mm×1 mm×6 mm, while the size of autologous blood clots in massive PE is 2 mm×2 mm×6 mm (Figure 1). Control animals received normal saline at an equivalent
volume. All rabbits received intravenous injection of Benzylpenicillin (2.5U/kg) to prevent infection. At the end of the experiment, rabbits were anticoagulated by intravenous injection of 5-ml heparin (100U/ml), then euthanized by a lethal injection of potassium chloride for euthanasia under deep anesthesia. The lungs were immediately explanted to keep into 10% formalin for 72h. Pathological sectioning at 1mm intervals was performed to determine the presence and location of the thrombosis, which were then processed by conventional histology with hematoxylin and eosin staining.

**Imaging Evaluation**

After 1h of thrombus injection, transthoracic echocardiography was performed in all rabbits using a Philips EPIQ 7C ultrasound system equipped with S12-4 probe. All echocardiographic examinations were performed by a single clinician experienced in ultrasound who was blinded to each other’s interpretations. Echocardiographic data were obtained in the left lateral decubitus utilizing standard views according to established guidelines [9]. Five consecutive cardiac cycles were stored in cine loop formation for further analysis. RV basal diameter (RVD1), mid diameter (RVD2) and RV length (RVD3) were measured from the four-chamber view at end-diastole. Right/left ventricular end-diastolic diameter (RV/LV) ratio was defined as the ratio of end-diastolic diameters of the right to left ventricles in relation to a line perpendicular to left ventricular long axis from the apical 4-chamber view. RV area was measured from the apical 4-chamber view by tracing endocardial borders at end-diastole and end-systole. Tricuspid leaflets, chords and tabeculation are included in the chamber. Fractional area change (FAC) was calculated using the formula: Percentage FAC = 100% × (end-diastolic RV area – end-systolic RV area) / end-diastolic RV area. TAPSE was measured as the distance of longitudinal movement of RV annular segment using M-mode curves from the four-chamber view. RV myocardial performance (Tei) index was defined as the ratio of isovolumic contraction time and isovolumic relaxation time divided by ejection time of the RV and was obtained by doppler tissue imaging at the lateral tricuspid annulars from the apical 4-chamber view.

M-mode echocardiography was used to detect right ventricular outflow tract systolic excursion (RVOT-SE) at the level of the aortic valve when the RVOT diameter is maximum from the parasternal short-axis view [6]. Imaging was performed with the sampling line perpendicular to the RVOT anterior walls, after optimization of gain and focus. RVOT-SE is defined as the excursion of the RVOT anterior wall during the systolic phase (Fig. 2). Each data point was measured by averaging the testing values of repeated measurements. Reproducibility of RVOT-SE was evaluated by repeating the measurements in fifteen random rabbits by the same observer at 1 month interval and by a second observer blind to the results.

**Statistical analysis**

Continuous variables are presented as means ± standard deviation and categorical variables were expressed as numbers and percentages. Three groups were compared using a one-way analysis of variance (ANOVA). When ANOVA showed statistically significant differences among groups, differences among three groups were further detected by post hoc analysis with the Student-Newman–Keuls test.
Receiver operating characteristic (ROC) curve analyses were used to detect the optimal cut-off points of RV dysfunction as an indicator for diagnosis of acute PE. Bland–Altman plots were used to determine inter-observer and intra-observer variability. SPSS version 17.0 for Windows (SPSS, Inc., Chicago, IL, USA) was used for Statistical analyses and ROC curve analyses were performed using MedCalc 15.2.2 Software (Mariakerke, Belgium). P-values of < 0.05 were considered statistically significant.

Results

Results of acute PE model

There were 22 rabbits in the experimental group, of which one case died of anesthesia accident and three rabbits died of acute right heart failure immediately after thrombus injection. Consequently, 18 rabbits were included in the analyses of RV function, including 10 rabbits in the sub-massive thrombus group and 8 rabbits in the massive thrombus group. The success rate of model establishment was 81.8% (18/22), among which sub-massive emboli and massive emboli were 90.9% (10/11) and 72.7% (8/11) respectively. After thrombus injection, some rabbits developed respiratory symptoms, including respiratory acceleration, lip cyanosis, restlessness, wheezing, snoring and so on. During the observation period, no deaths were identified in both the experimental group and the control group. At the end of experiment, 18 rabbits were involved in the result analysis.

Lung Histomorphology

Isolated lung tissues of 18 rabbits with acute PE were observed by histopathology, and the blood vessels were cut along the pulmonary artery to look for thrombus. A total of 32 blood clots were injected into the large thrombus group (n = 8). The incidence of massive PE was 100% (8/8). A total of 32 blood clots were detected in lobar or segmental pulmonary arteries, including 27 blood clots in the pulmonary vascular trunks of pulmonary lobes and 5 blood clots in pulmonary segmental arteries. A total of 40 thrombus were injected into the small thrombus group (n = 10), and the incidence of submassive PE was 100% (10/10). A total of 40 blood clots were detected in the pulmonary vessels, including 31 blood clots in the pulmonary segmental arteries and 9 blood clots in distal pulmonary arteries. Cylindrical thrombus was observed in the pulmonary artery of acute PE rabbits by a microscope, and the integrity of the thrombus was maintained. Alveolar exudate of red cells and thickened alveolar septa was observed. Among them, large emboli were mostly embolized in the pulmonary lobar artery, local alveolar tissue atrophy and interstitial edema, regular thrombus. Most of the small blood clots were embolized in the segmental pulmonary artery and distal pulmonary arteries (Fig. 3).

Results of echocardiography

At 1h after thrombus injection, rabbits in acute PE had different extent of RV dilation and systolic dysfunction compared with the control group (Table 1). The difference of RV/LV ratio, RVFAC, TAPSE, Tei
index and RVOT_SE between massive thrombus group and the control group was statistically significant ($P < 0.01$). Contrasted with the control group, the value of RVFAC and RVOT-SE in sub-massive thrombus group decreased significantly ($P < 0.05$), there was no significant difference in RV/LV ratio, TAPSE and Tei index between control group and sub-massive thrombus group ($P > 0.05$). The RVFAC, RV/LV ratio, Tei index showed a significant difference between sub-massive thrombus group and massive thrombus group ($P < 0.01$). However, submassive thrombus group suggested a slightly decreased TAPSE, showing no significant difference compared with massive thrombus group ($P > 0.05$). ROC analysis showed that RVOT-SE had a high sensitivity (94.4%) and specificity (72.7%) in the assessment of RV dysfunction in acute PE (Table 2). The area under the ROC curve (AUC) for combined TAPSE and RVOT-SE was greater than that of TAPSE or RVOT-SE alone (AUC= 0.962, $P < 0.01$). The sensitivity and specificity of TAPSE with RVOT-SE for detecting acute PE were 83.3% and 100.0% respectively. The result was presented in Fig. 4.

**Reproducibility**

Bland–Altman plots were used to determine intraobserver reproducibility and interobserver reproducibility of RVOT-SE. A total of 15 rabbits were randomly selected from all groups for assessment of intraobserver reproducibility and interobserver variability of RVOT-SE. According to Bland–Altman analysis, RVOT-SE showed a good reproducibility of measurements. Intra-observer variability was -0.04 to 0.40 mm and inter-observer variability was -0.29 to 0.34 mm. The results were shown in Fig. 5.

**Discussion**

Our study demonstrated that RV function in acute PE was significantly decreased, which was closely related to the size of embolus. In the present study, we determined the value of RVOT_SE in the assessment of RV function in rabbits with acute PE, and found it to be a quick, simple, highly distinctive and reproducible parameter that is associated with RV dysfunction in acute PE. In addition, RVOT-SE tends to be superior to conventional parameters of RV function in identifying acute PE, The combination of RVOT-SE and TAPSE can be used to detect RV systolic dysfunction and further improve the diagnostic accuracy of acute PE.

RV dysfunction is a determining factor in the risk assessment and a well-known prognostic marker in acute PE [4]. It is recommended that patients with hemodynamically stable acute PE should be examined by transthoracic echocardiography to determine RV dysfunction[10]. Many echocardiographic parameters were used for quantitative evaluation of RV function, but accurately assessment of RV function still remains challenging owing to the complex geometry and underlying anatomy. For patients with suspected acute PE with hemodynamic stability, it is critical to risk stratification according to evaluation of RV function[11]. However, the potential benefits of echocardiography in the evaluation of RV function in patients with moderate and low risk acute PE were unclear[10]. This is due partly to the lack of consensus regarding evaluation of RV function in acute PE. Furthermore, the morphological and functional changes in RV caused by moderate and low risk acute PE were not obvious because of the
good compensation ability of pulmonary vascular bed. A simple and easily reproducible method for the assessment of RV function is therefore needed.

Several echocardiographic methods were used to identify RV dysfunction that may be conducive to the risk assessment of patients with acute PE. Some research suggests that RV/LV ratio is related to the severity of acute PE [11-13]. When the right ventricle is obviously enlarged, the interventricular septum shifts to the left ventricle, showing the "D" sign with the increased proportion of RV/LV ratio. Our results showed that RV/LV ratio is less reliable for predicting RV dysfunction in submassive acute PE, and it cannot be used as a major method in diagnosis of acute PE. FAC is associated with thrombus load in patients with acute PE, which can reflect the severity of pulmonary vascular obstruction [14]. In a clinical study to evaluate the changes of RV function in acute PE, the researchers found that there was a good correlation between FAC and Tei index, RV systolic strain and other indicators reflecting the prognosis of acute PE patients[15]. Similar to other indexes of RV function, FAC is also closely related to the prognosis of acute PE. Our results showed that FAC was significantly decreased in massive acute PE group compared the control group, no significant difference was found in FAC between small thrombus group and control group. Because FAC doesn't take into account the RV outflow tract, which results in an underestimation of the RV area by 20% to 30%[16]. Besides, it is easily affected by the RV preload, and the repeatability is poor. Park et al[17] found that TAPSE can be used to detect RV dysfunction in acute PE patients. This method is simple and has a good correlation with the traditional index of RV function. In a study evaluating echocardiography parameters to predict acute PE mortality, the lower the TAPSE, the more serious the RV systolic function was damaged. TASPE was associated with the long-term mortality of acute PE, and its clinical predictive value was better than the RV/LV ratio [18, 19]. Previous studies have confirmed that TAPSE reflects the global long-axis movement of free wall and is of great value in risk stratification and prognosis evaluation of acute PE. However, TAPSE that represents the longitudinal displacement of basal segment of RV free wall cannot reflect the overall RV systolic function and is easily affected by the measuring angle. McConnell et al [20] showed that the radial motion of the apical segment of the right ventricle was normal in patients with acute PE, and the main manifestation was the systolic dysfunction of the middle segment of the free wall of the right ventricle. Therefore, the value of TAPSE in evaluating the overall RV function in patients with acute PE is limited. As a result, there is still a lack of an accurate assessment of RV function. Due to complex morphology and structure of right ventricle, conventional two-dimensional echocardiographic parameters cannot early and accurately detected RV dysfunction. The evaluation of RV dysfunction using the Tissue Doppler seems clinically useful and potentially less load dependent than other echocardiographic markers of RV myocardial performance[21]. RV Tei index was inversely correlated with the RV FAC and TAPSE. It was confirmed to be impaired in patients with acute PE and significantly improved after the treatment[15]. Therefore, RV Tei index may aid in predicting RV dysfunction and evaluating the efficacy of thrombolytic therapy following acute PE. Our study also demonstrated that the value of RV Tei index is significantly increased in rabbits with acute PE. This approach is unreliable when patients with differing R-R intervals and affected in the presence of RA pressure overload. It should not be used as the sole quantitative method for the evaluation of RV function.
The RV consists of inflow tract, apical part and outflow tract, which contribute to the overall systolic function with different extent [22]. Anatomical studies show that there are significant differences in their orientation and myocardial fiber architecture of these three RV compartments. The contribution to its overall systolic function varies in different compartments and the apex has the least contribution compared with the inflow and outflow tract. RVOT has superficial circumferential muscle fibers and therefore causes radial RVOT contraction during systole. The RVOT is a distinct part of the RV structure, which appear to be sensitive to pulmonary circulation resistance and pulmonary artery pressure. RVOT-SE is defined as the excursion of the RVOT anterior wall during systolic phase and serves as a novel, simple, and promising parameter for assessment of RV function[6]. Previous study demonstrated that RVOT-SE is not only extremely useful but also practicable in identifying acute PE and may aid in the differential diagnosis of chronic pulmonary hypertension[23]. More importantly, the lowest values of RVOT-SE are only seen in acute PE patients. Compared to other parts of the right ventricle, the RVOT-SE is less affected by myocardial ischemia and abnormal regional wall motion, which can accurately reflect the changes of RV function.

Regional RV dysfunction is a distinctive echocardiographic feature in acute PE, which is characterized by preserved apical function contrasting with RV free wall dysfunction [20, 24]. Notably, although excursion of the apex appears to be preserved in acute PE, global and segmental RV strains decreased significantly. In the present study, RV free wall and RVOT function are lower in it compared with normal controls. The combination of RVOT-SE and TAPSE can be used to detect RV systolic dysfunction more accurately in patients with acute PE and tends to be superior to conventional parameters of RV function in identifying acute PE with higher sensitivity and specificity. More importantly, these values can be easily acquired by beside ultrasound to early detect RV systolic dysfunction and may be valuable in the diagnosis of acute PE.

There were some limitations in this study. Firstly, the sample size of this study is small, which needs to be verified by expanding the sample size in the future research. Secondly, the size and amount of thrombus are closely related to the RV dysfunction in acute PE. However, only the effect of thrombus size on RV function was discussed in this study. Further research is needed to assess the effects of clot burden. Thirdly, no single echocardiographic parameter could be precise enough to evaluate RV function due to RV complex geometry and contractile pattern. Although RVOT-SE has certain advantages in the evaluation of RV systolic function, multiple echocardiographic parameters are needed to accurately assessment of RV dysfunction in acute PE. Fourthly, we cannot rule out the possibility that myocardial performance may be influenced by general anesthesia, thus affecting the accuracy of echocardiographic indices. Fifthly, the right cardiac catheter is the gold standard for evaluating hemodynamic changes of right heart, which is not available in this study; this will be performed in our subsequent studies. At last, emerging echocardiographic techniques such as strain and three-dimensional echocardiography should be considered to assess RV function in future studies, which will add more insight into changes of RV function in acute PE.
Conclusions

In this study, RV function is significantly decreased in acute PE, which is closely related to the size of embolus. RVOT_SE is a quick, simple, reproducible and highly distinctive parameter that is associated with RV dysfunction in acute PE. In addition, RVOT-SE tends to be superior to conventional parameters of RV function in identifying acute PE. The combination of RVOT-SE and TAPSE can be useful in the detection of RV systolic dysfunction and further improve the diagnostic accuracy of acute PE.

Abbreviations

AUC: Area under ROC curve; PE: Pulmonary embolism; Tei index: Myocardial performance index; ROC: Receiver operating characteristics; RV: Right ventricular; RV/LV ratio: Right/left ventricular end-diastolic diameter ratio; RVOT-SE: Right ventricular outflow tract systolic excursion; RVFAC: Right ventricular fractional area change; TAPSE: Tricuspid annular plane systolic excursion.

Declarations

Acknowledgements

Not applicable.

Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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Authors’ contributions

DCZ and JW designed the experimental protocol. DCZ and HC raised and managed rabbits. DCZ, JW, HC, YT, TZ and XYC conducted the experiments. DCZ, JW and HC contributed to data collection. DCZ and JW performed statistical analyses. DCZ and JW wrote the manuscript. DCZ, JW and HC reviewed the manuscript. All authors read and approved the manuscript.
Ethics approval and consent to participate

The study protocol was approved by Institutional animal care of Guangxi Medical University and conformed to Chinese guidelines on research animal experiments.

Consent for publication

Not applicable.

Competing interests

The authors have no potential conflicts of interest to declare.

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**Tables**
Table 1 Comparison of the morphological and functional indexes of right heart at 1h after acute pulmonary embolism

| Parameters       | Control group (n=11) | Submassive PE (n=10) | Massive PE (n=8) | F     | p     |
|------------------|----------------------|----------------------|------------------|-------|-------|
| RAD (cm)         | 0.91±0.10            | 0.93±0.12            | 1.06±0.24*#      | 6.444 | 0.005 |
| RAA (cm²)        | 0.77±0.17            | 0.85±0.12            | 0.95±0.15*       | 3.230 | 0.056 |
| RVD1 (cm)        | 0.84±0.10            | 0.85±0.08            | 1.03±0.10*#      | 11.571| 0.01  |
| RVD2 (cm)        | 0.79±0.13            | 0.84±0.09            | 1.05±0.15*#      | 11.276| 0.01  |
| RVD3 (cm)        | 1.27±0.12            | 1.23±0.16            | 1.43±0.11*#      | 5.671 | 0.009 |
| RV/LV ratio      | 0.76±0.08            | 0.84±0.07            | 0.94±0.13*#      | 8.746 | 0.001 |
| RVFAC (%)        | 54.10±4.56           | 48.74±6.13*          | 42.05±4.23*#     | 13.005| 0.007 |
| TAPSE (cm)       | 0.57±0.04            | 0.53±0.04            | 0.49±0.05*       | 5.964 | 0.01  |
| Tei index        | 0.40±0.08            | 0.44±0.06            | 0.60±0.07*#      | 19.758| 0.01  |
| RVOT-SE (cm)     | 0.32±0.06            | 0.23±0.05*           | 0.19±0.05*       | 13.189| 0.01  |

Note: Comparison with normal control group, *P<0.05; Comparison with sub-massive group, #P<0.05

RAD: right atrial diameter; RAA: right atrial area; RVD1: right ventricular basal diameter; RVD2: right ventricular mid cavity; RVD3: RV longitudinal dimension; RV/LV ratio: right/left ventricular end-diastolic diameter ratio; RVFAC: right ventricular fractional area change; TAPSE: tricuspid annular plane systolic excursion; Tei index: right ventricular myocardial performance index; RVOT_SE: Right ventricular outflow tract systolic excursion
Table 2 Receiver operator curve analysis of the morphological and functional indexes of right ventricle at 1h after acute pulmonary embolism

| Parameter          | Cut-off value | Sensitivity | Specificity | AUC  | P value |
|--------------------|---------------|-------------|-------------|------|---------|
| RVD2(cm)           | 0.81          | 83.3        | 54.4        | 0.735| 0.05    |
| RV/LV ratio        | 0.83          | 77.8        | 81.8        | 0.836| 0.01    |
| RVFAC (%)          | 48.00         | 76.9        | 90.9        | 0.876| 0.01    |
| TAPSE(cm)          | 0.54          | 77.8        | 72.7        | 0.806| 0.01    |
| Tei index          | 0.45          | 72.7        | 90.2        | 0.831| 0.01    |
| RVOT_SE(cm)        | 0.28          | 94.4        | 72.7        | 0.884| 0.01    |

AUC: Area under Curve; RVD2: mid cavity; RV/LV ratio: right/left ventricular end-diastolic diameter ratio; RVFAC: right ventricular fractional area change; TAPSE: tricuspid annular plane systolic excursion; Tei index: right ventricular myocardial performance index; RVOT_SE: Right ventricular outflow tract systolic excursion

Figures

Figure 1

Preparation of autologous blood clots. (A) Two blood clots with inner diameters of 2 mm and 1 mm respectively. (B) A blood clot with a 2 mm inner diameter was cut into segments measuring 6 mm in length.
Figure 2

Right ventricular outflow tract systolic excursion (RVOT_SE) was measured using M-mode echocardiography at the level of the aortic valve from the parasternal short-axis view. Measurements of the systolic excursion of the RVOT anterior wall (white arrows). (A) A rabbit with normal right ventricular (RV) function (control group). (B) A rabbit with seriously decreased RV function (Massive thrombus group).

Figure 3

Pulmonary vascular pathological changes of rabbit with acute pulmonary embolism (A) A thrombus was found in lobar pulmonary artery (HE, Original magnification×100). (B) A thrombus was found in the distal pulmonary artery. (HE, Original magnification×400)
Figure 4

Receiver operating characteristic (ROC) curves for identification of acute pulmonary embolism. The area under the ROC curve (AUC) for right ventricular outflow tract systolic excursions (RVOT-SE) and tricuspid annular plane systolic excursion (TAPSE) was greater than that of RVOT-SE or TAPSE alone.
Figure 5

Bland–Altman analyses for intra-observer variability and inter-observer variability. (A) Intra-observer variability. Test 1 = first observation, Test 2 = second observation (B) Inter-observer variability. OB1 = first observer. OB2 = second observer.

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