

Developing a scoring tool to estimate the risk of deterioration for normotensive patients with acute pulmonary embolism on admission

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Research

Keywords: pulmonary embolism, computerized tomography, nomogram, right ventricular

Posted Date: August 3rd, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-50644/v1>

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Version of Record: A version of this preprint was published on January 6th, 2021. See the published version at <https://doi.org/10.1186/s12931-020-01602-x>.

Abstract

Background: It is important to identify deterioration in normotension patients with acute pulmonary embolism (PE). This study aimed to develop a tool for predicting deterioration among normotensive patients with acute PE on admission.

Methods: Clinical, laboratory, and computed tomography parameters were retrospectively collected for normotension patients with acute PE who were treated at a Chinese center from January 2011 to May 2020 on admission into hospital. The endpoint of the deterioration was any adverse outcome within 30 days. The eligible patients were randomized 2:1 to training and validation datasets. A nomogram was developed and validated by training and validation datasets respectively. The areas under the receiver operating characteristic curves (AUCs) and 95% confidence intervals (CIs) were calculated. A risk-scoring tool for predicting deterioration was applied as a web-based calculator.

Results: The 845 eligible patients (420 men, 425 women) had an average age of 60.05 ± 15.43 years. Adverse outcomes were identified for 81 patients (9.6%). The nomogram for adverse outcomes included heart rate, systolic pressure, N-terminal-pro brain natriuretic peptide, and ventricular/atrial diameter ratios at 4-chamber view, which provided AUC values of 0.925 in the training dataset (95% CI: 0.900–0.946, $p < 0.001$) and 0.900 in the validation dataset (95% CI: 0.883–0.948, $p < 0.001$). A risk-scoring tool was published as a web-based calculator (<https://gaoyzcmu.shinyapps.io/APE9AD/>).

Conclusions: We developed a web-based scoring tool that may help predict deterioration in normotensive patients with acute PE.

Background

In 2019, the European Society of Cardiology (ESC) revised the risk stratification system for patients with acute pulmonary embolism (PE) by adding a simple PE severity index based on the 2014 ESC guideline [1, 2]. However, it remains important to predict a poor prognosis among normotensive patients with acute PE, as mortality still occurs in this patient population [3–5]. Furthermore, the illusion of security at the patient's admission may mask the risk of rapid deterioration and death [6, 7]. Unfortunately, there is no universally recognized tool for predicting deterioration and guiding clinical decision-making [1].

Various combinations of clinical, laboratory, and imaging parameters may be useful for addressing this issue [1]. Computed tomography (CT) pulmonary angiography can be used to diagnose PE, although there remains controversy regarding whether it can identify patients with acute PE who have a poor prognosis [8–11]. Furthermore, CT parameters can be used to identify right ventricular (RV) dysfunction in the ESC guideline [1, 2]. Moreover, most models for predicting a poor short-term prognosis among normotensive patients with acute PE have not incorporated CT parameters [6, 8, 12, 13]. In this context, the principle pathophysiological mechanism in acute PE involves increased resistance in the pulmonary circulation [14], which might lead to changes in cardiac size parameters that can be evaluated during CT. For example, the extremely elevated resistance in the pulmonary circulation explains the poor short-term

outcomes in acute PE [14], which can dramatically increase the ratio of right-to-left heart parameters. Thus, the ratio of right-to-left heart size parameters from CT findings might be useful for predicting short-term outcomes among normotensive patients with acute PE.

Although CT parameters regarding cardiac size can reflect the increased resistance in the pulmonary circulation [15], individual responses to this increased resistance vary broadly. Furthermore, these broad variations can be manifested in clinical and laboratory parameters. Therefore, the present study aimed to develop tools that combined clinical, laboratory, and simple CT parameters to predict the short-term prognosis of normotensive patients with acute PE.

Methods

Study design

This retrospective study evaluated clinical, laboratory, and simple CT parameters from the admission of normotensive patients with acute PE. The Bova score and 2019 ESC algorithm were used for risk stratification. The outcomes of interest were defined as the occurrence of adverse outcomes within 30 days after admission into hospital. Eligible patients were randomized 2:1 into training and validation dataset. Training dataset were used to develop and evaluate multivariable logistic regression models for predicting the outcomes of interest. The discriminatory power was evaluated by comparing the nomogram to the established risk stratification systems. The consistency of the nomograms was evaluated using the validation dataset. The investigators independently collected the data regarding the clinical, laboratory, and CT parameters as well as data regarding the risk stratification scores and outcomes of interest. This research was approved by the Institutional review board of Shengjing Hospital of China Medical University (No.2020PS522K) and informed consent was exempted due no intervention to patient's treatment.

Patient Selection

Normotensive patients with acute PE were evaluated if they were treated at the Shengjing Hospital of China Medical University between January 2011 and May 2020. The diagnosis and management of acute PE was based on the 2019 ESC guidelines [1]. The inclusion criteria were age of ≥ 18 years and diagnosis of PE based on CT pulmonary angiography. The exclusion criteria were pregnancy, reception of reperfusion treatment before admission, and missing data regarding CT parameters, echocardiography, cardiac troponin I (c-Tn I), and N-terminal-pro brain natriuretic peptide (NT-pro BNP).

Clinical Data And Risk Stratification

The patients' medical records were reviewed to collect their demographic characteristics and baseline data from their admission regarding heart rate, systolic pressure, history of disease, c-Tn I concentration,

and NT-pro BNP concentration. RV dysfunction was diagnosed by a transthoracic echocardiography within 24 hours after admission as anyone or more of the following parameters: RV dilation, an increased RV-left ventricle (LV) diameter ratio (> 0.9), hypokinesia of the free RV wall, increased tricuspid regurgitant jet velocity, and/or decreased tricuspid annular plane systolic excursion [2].

The risk stratification was based on the 2019 ESC algorithm [1] and Bova scores [13], with classifications as “low risk,” “intermediate-low risk,” and “intermediate-high risk” (Additional file 1:Table S1 and Additional file 2:Table S2). The 2019 ESC algorithm evaluated c-Tn I (cutoff: $0.04 \mu\text{g/L}$), NT-pro BNP (cutoff: 600 pg/mL), RV dysfunction, and simple PE severity index [1]. The Bova scores were calculated based on c-Tn I (cutoff: $0.05 \mu\text{g/L}$), RV dysfunction, heart rate (cutoff: 110 beats/min), and systolic pressure (cutoff: $90\text{--}100 \text{ mmHg}$).

Outcomes Of Interest

The outcomes of interest were defined as the occurrence of adverse outcomes within 30 days after admission. Adverse outcomes were defined as PE-related death, the need for mechanical ventilation, the need for cardiopulmonary resuscitation, and the need for life-saving vasopressor and reperfusion treatment [12, 16].

Measurement Of Ct Parameters

Three simple CT parameters were selected for the analysis. The first factor was thrombus location, which was categorized as within the central pulmonary artery (CPA embolism) [16, 17], spanning both sides of the bifurcation (saddle-CPA embolism) [18], and outside the CPA (non-CPA embolism) (Additional file 3:Figure S1 a, b and c). The second factor was the RV and LV diameters in the short-axis plane, which were measured as the maximal diameter from the cardiac intima to the interventricular septum [19], as well as the relative ratio of the RV/LV short-axis diameters (Additional file 4:Figure S2 a). The third factor was the maximum chamber diameters, which were measured using a 4-chamber view perpendicular to the atrial and interventricular septum (Additional file 4:Figure S2 b) [10, 20], as well as the relative ratios of the RV/LV and right atrium (RA)/left atrium (LA) 4-chamber diameters. All CT parameters were measured using Mimics Medical software (version 19.0, Mimics Medical software, Leuven, Belgium).

Development Of The Models And Risk-scoring Tools

The models were developed based on three steps: (a) identifying relevant prognostic factors, (b) developing and validating the models, and (c) evaluating the models' discriminatory power relative to the 2019 ESC algorithm and Bova score. To prevent over-fitting and simplification, classification and regression tree (CART) analysis was used to identify relevant prognostic factors. The optimal cutoff

points for significant prognostic factors were determined based on the optimal separation from a penalized discriminant analysis [21, 22].

In the second step, eligible patients were randomized 2:1 into training and validation datasets based on the TRIPOD standard [23]. Univariate and multivariate logistic regression analyses were used to investigate independent prognostic factors using the training dataset, and a nomogram was created by converting each regression coefficient from the multivariate logistic regression onto a scale of 0 points (low) to 100 points (high). The total scores for all variables were summed [24], and the different risk groups were separated based on their total nomogram scores via CART analysis.

In the third step, the validation dataset was used to evaluate the models' consistency relative to the observed outcomes [22]. The models' abilities to predict adverse outcomes were also compared to the 2019 ESC algorithm [1] and the Bova score [13] based on receiver operating characteristic curve (ROC) and decision curve analysis (DCA). The final risk-scoring tools were published as free web-based calculators.

Statistical analysis

Continuous variables were expressed as mean \pm standard deviation and compared using the Student's *t* test. Categorical variables were presented as number (%) and compared using the χ^2 test. Recursive partitioning analysis and the CART were used to dichotomize each variable while controlling for confounders and to divide the training dataset into different risk group according the total nomogram scores [25]. Univariate and multivariate logistic regression analyses were used to evaluate the different factors, and the results were expressed as odds ratios (ORs) with the corresponding 95% confidence intervals (CIs). The nomograms' predictive performances were evaluated based on the concordance index (C-index) and calibration with 1,000 bootstrap resampling [24]. The ROC curves were used to evaluate the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and the area under the ROC curve (AUC). Clinical utility was evaluated based on net benefits from the DCA. DeLong's test was used to compare the AUC values [26]. Differences were considered significant at *p*-values of < 0.05 and all analyses were performed using R software (version 4.0.01; R Foundation, <https://www.r-project.org>).

Results

Demographics and baseline characteristics

We evaluated 902 normotensive patients with acute PE, although 57 patients were excluded: Totally, 3 patients were excluded due to pregnancy, 5 patients were excluded due to reception of reperfusion treatment and 49 patients were excluded due to absence of CT parameters, echocardiography, c-Tn I or NT-pro BNP. The 845 eligible patients included 420 male and 425 female patients with an average age of 60.05 ± 15.43 years. Adverse outcomes were identified for 81 patients (42 male and 39 female) who had

an average age of 59.36 ± 15.74 years (Table 1). No adverse outcomes were identified for 764 patients (378 male and 386 female) who had an average age of 60.12 ± 15.40 years. Patients with adverse outcomes had significantly higher values for heart rate, systolic pressure, c-Tn I, and NT-pro BNP (all $p < 0.001$). Patients with adverse outcomes were more likely to have RV dysfunction ($p < 0.001$). Among the CT parameters, patients with adverse outcomes were more likely to have CPA embolism and saddle-CPA embolism (both $p < 0.001$). Furthermore, patients with adverse outcomes had higher values for the RV short-axis diameter, RV 4-chamber diameter, RA 4-chamber diameter, RV/LV short-axis diameter ratio, RV/LV 4-chamber diameter ratio, and RA/LA 4-chamber diameter ratio (all $p < 0.001$). However, patients with adverse outcomes also had lower values for the LV short-axis diameter, LV 4-chamber diameter, and LA 4-chamber diameter (all $p < 0.001$).

Table 1
Baseline characteristics among patients with and without adverse outcomes

	All patients	Adverse outcomes		<i>p</i> -value
	(n = 845)	Yes (n = 81)	No (n = 764)	
Sex (male/female)	420/425	42/39	378/386	0.68
Age (years)	60.05 ± 15.43	59.36 ± 15.74	60.12 ± 15.40	0.93
Heart rate (beats/min)	86.57 ± 17.81	108.64 ± 22.84	84.23 ± 15.45	< 0.001
Systolic pressure (mmHg)	124.33 ± 18.26	115.22 ± 19.64	125.30 ± 17.85	< 0.001
RV dysfunction	81(9.6%)	59(72.8%)	181(23.7%)	< 0.001
c-Tn I (μg/L)	0.11 ± 0.47	0.25 ± 0.49	0.091 ± 0.46	< 0.001
NT-pro BNP (pg/mL)	1,547.12 ± 3,652.06	131,039 ± 3,255.93	3,779.92 ± 5,832.71	< 0.001
CPA embolism	209 (24.7%)	45 (55.6%)	164 (22.0%)	< 0.001
Saddle-CPA embolism	62 (7.3%)	17 (21.0%)	45 (5.9%)	< 0.001
RV short-axis diameter (mm)	39.21 ± 7.42	44.70 ± 8.53	38.62 ± 7.05	< 0.001
LV short-axis diameter (mm)	40.76 ± 7.30	33.68 ± 6.91	41.51 ± 6.94	< 0.001
RV4-chamber diameter (mm)	36.38 ± 7.37	42.64 ± 10.28	35.72 ± 6.67	< 0.001
LV 4-chamber diameter (mm)	39.47 ± 7.36	31.63 ± 7.09	40.30 ± 6.88	< 0.001
RA 4-chamber diameter (mm)	45.44 ± 9.34	52.38 ± 11.72	44.70 ± 8.74	< 0.001
LA 4-chamber diameter (mm)	34.83 ± 8.52	29.18 ± 8.00	35.43 ± 8.35	< 0.001
RV/LV short-axis diameter ratio	1.00 ± 0.30	1.38 ± 0.40	0.96 ± 0.25	< 0.001
RV/LV 4-chamber diameter ratio	0.96 ± 0.31	1.44 ± 0.59	0.90 ± 0.20	< 0.001
RA/LA 4-chamber diameter ratio	1.39 ± 0.52	1.97 ± 0.87	1.33 ± 0.42	< 0.001
Bova score				
Low risk	681 (75.9%)	33 (40.7%)	648 (84.4%)	< 0.001

c Tn-I cardiac troponin I; *NT-pro BNP* N-terminal pro-brain natriuretic peptide; *CPA* central pulmonary artery; *RV* right ventricle; *LV* left ventricle; *RA* right atrium; *LA* left atrium, *ESC* European Society of Cardiology

	All patients	Adverse outcomes		p-value
Intermediate-low risk	102 (12.1%)	17 (20.7%)	85 (11.1%)	0.009
Intermediate-high risk	62 (7.3%)	31 (38.3%)	31 (4.1%)	< 0.001
2019 ESC algorithm				
Low risk	503 (59.5%)	17 (21.0%)	486 (63.6%)	< 0.001
Intermediate-low risk	172 (20.4%)	14 (17.3%)	158 (20.7%)	0.47
Intermediate-high risk	170 (20.1%)	50 (61.7%)	120 (15.7%)	< 0.001
<i>c Tn-I</i> cardiac troponin I; <i>NT-pro BNP</i> N-terminal pro-brain natriuretic peptide; <i>CPA</i> central pulmonary artery; <i>RV</i> right ventricle; <i>LV</i> left ventricle; <i>RA</i> right atrium; <i>LA</i> left atrium, <i>ESC</i> European Society of Cardiology				

The Bova scores for patients with adverse outcomes revealed low risk (33 patients), intermediate-low risk (17 patients), and intermediate-high risk (31 patients). The Bova scores for patients without adverse outcomes revealed low risk (648 patients), intermediate-low risk (85 patients), and intermediate-high risk (31 patients). The 2019 ESC algorithm for patients with adverse outcomes revealed low risk (17 patients), intermediate-low risk (14 patients), and intermediate-high risk (50 patients). The 2019 ESC algorithm for patients without adverse outcomes revealed low risk (486 patients), intermediate-low risk (158 patients), and intermediate-high risk (120 patients) (Table 1).

Variable Selection

Five variables were considered significant predictors of adverse outcomes and were dichotomized: heart rate (≥ 110 beats/min vs. <110 beats/min), systolic pressure (90–100 mmHg vs. >100 mmHg), NT-pro BNP (≥ 800 pg/mL vs. <800 pg/mL), RV/LV 4-chamber diameter ratio (≥ 1.25 vs. <1.25), and RA/LA 4-chamber diameter ratio (≥ 1.30 vs. <1.30). Multivariate logistic regression analysis using the training dataset revealed that adverse outcomes were independently predicted by heart rate (OR:7.07, 95% CI: 2.92–17.09, $p < 0.001$), systolic pressure (OR:7.68, 95% CI:1.57–37.58, $p < 0.001$), NT-pro BNP (OR: 3.35, 95% CI: 1.36–9.17, $p < 0.001$), RA/LA 4-chamber diameter ratio (OR:3.53, 95% CI: 1.27–2.85, $p < 0.001$), and RV/LV 4-chamber diameter ratio (OR: 29.86, 95% CI:11.34–78.61, $p < 0.001$)(Table 2).

Table 2

Univariate and multivariate logistic regression analyses for developing the nomogram to predict adverse outcomes in the development dataset

	Univariate analysis		Multivariate analysis	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Heart rate (≥ 110 vs. <110 beats/min)	20.58 (10.77–39.33)	< 0.001	7.07 (2.92–17.09)	< 0.001
Systolic pressure (90–100 vs. >100 mmHg)	26.11 (9.43–72.28)	< 0.001	7.68 (1.57–37.58)	0.012
NT-pro BNP (≥ 800 vs. <800 pg/mL)	7.94 (4.07–15.50)	< 0.001	3.35 (1.39–8.11)	0.0073
RV/LV 4-chamber diameter ratio (≥ 1.25 vs. <1.25)	64.66 (28.84–144.96)	< 0.001	29.86 (11.34–78.61)	< 0.001
RA/LA 4-chamber diameter ratio (≥ 1.30 vs. <1.30)	6.63 (3.17–13.85)	< 0.001	3.53 (1.36–9.17)	0.0096
<i>NT-pro BNP</i> N-terminal pro-brain natriuretic peptide; <i>RV</i> right ventricle; <i>LV</i> , left ventricle; <i>RA</i> right atrium; <i>LA</i> left atrium; <i>OR</i> odds ratio; <i>CI</i> confidence intervals				

Performance of the nomograms in the training and validation datasets

Nomograms were developed using the two multivariate logistic regression models (Fig. 1). The nomogram for predicting adverse outcomes incorporated five variables and provided good C-index values in the training dataset (C-index: 0.925, 95% CI: 0.900–0.946) and in the validation dataset (C-index: 0.900, 95% CI: 0.883–0.948) (Fig. 2). The calibration curve also revealed good agreement between the nomogram's predictions and the actual outcomes (Fig. 3).

Predicting adverse outcomes based on the nomogram, Bova score, and 2019 ESC algorithm

The AUC values for predicting adverse outcomes were 0.925 for the nomogram (95% CI: 0.900–0.946, $p < 0.001$), 0.797 for the Bova score (95% CI: 0.761–0.830, $p < 0.001$), and 0.790 for the 2019 ESC algorithm (95% CI: 0.753–0.823, $p < 0.001$). Comparison of the nomogram and Bova score revealed a difference in the AUC values of 0.128 (95% CI: 0.072–0.184, $p < 0.001$). A comparison of the nomogram and 2019 ESC algorithm revealed a difference in the AUC values of 0.136 (95% CI: 0.075–0.196, $p < 0.001$). The nomogram had a higher PPV for predicting adverse outcomes (66.5%) than did the Bova score (34.8%) or the 2019 ESC algorithm (31.3%) (Table 3).

Table 3
Comparing the nomograms for adverse outcomes and risk assessment

	AUC (95% CI)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Nomogram	0.925 (0.900–0.946)	74.1	95.1	65.5	97.2
Bova score	0.797 (0.761–0.830)	70.4	85.8	34.8	96.4
2019 ESC algorithm	0.790 (0.753–0.823)	64.8	84.6	31.3	95.7

ESC European Society of Cardiology; *AUC* area under the curve; *CI* confidence interval; *PPV* positive predictive value; *NPV* negative predictive value; *CI* confidence intervals

The DCA revealed that the nomogram had greater net benefit than did the 2019 ESC algorithm or the Bova score for predicting adverse outcomes. Using the nomogram for predicting adverse outcomes added a net benefit of 0.03–0.98 (Fig. 4).

Development Of The Risk-scoring Tool

The nomogram for predicting adverse outcomes was used to develop a web-based calculator (<https://gaoyzcmu.shinyapps.io/APE9AD/>), which assigned patients to a high-risk group (≥ 145 points) or a low-risk group (< 145 points). The QR code in the lower right corner of each calculator in Fig. 5a and b can be used to publish the results to mobile electronic equipment.

Discussion

This study developed a tool for estimating the risk of deterioration among normotensive patients with acute PE. The results revealed that the risk of adverse outcomes within the first 30 days after admission could be predicted using a nomogram that incorporated the RV/LV and RA/LA 4-chamber diameter ratios, NT-pro BNP concentration, systolic pressure, and heart rate. Furthermore, this risk-scoring tool had better discriminatory power and a greater net benefit than did the 2019 ESC algorithm and the Bova score. Finally, this tool was converted into convenient web-based calculators that could be used in clinical practice.

Our results are consistent with the Bova score, as a decreased systolic pressure (90–100 mmHg) and an elevated heart rate (≥ 110 beats/min) were risk factors for adverse outcomes. In normotensive patients with acute PE that is deteriorating, tachycardia and relative hypertension are compensatory and neurohumoral responses to a low left heart output [5, 27, 28]. However, we found that elevated NT-pro BNP concentrations were a significant risk factor, but elevated c-Tn I concentrations were not, which conflicts with the 2019 ESC algorithm and Bova score. To expand the utility of our tools, we did not consider the underlying disease, which can predict a poor prognosis in acute PE [29]. In this context, elevated NT-pro BNP and c-Tn I concentrations are caused by myocyte stretching [27]. However, NT-pro BNP can reflect the patient's current state and also underlying disease, such as chronic heart failure [28, 30], although c-Tn I concentrations do not. This difference may explain why NT-pro BNP concentrations but not c-Tn I concentrations were significantly associated with adverse outcomes in our tool.

Interestingly, the increased predictive value of our risk-scoring tool (vs. the 2019 ESC algorithm and the Bova score) was mainly related to the RV/LV and RA/LA 4-chamber diameter ratios. A previous report had described the interaction between the RV and LV via the interventricular septum [31], and the RV and pulmonary circulation are characterized by low resistance and high output [14]. Furthermore, the size of the LV is larger than the size of the RV. Thus, severe PE leads to increased pressure in the RV, which compresses the LV via the interventricular septum, and clear RV-to-LV compression can be observed in cases with severe chronic pulmonary hypertension (PH) [32]. Severe PH is also the main pathophysiological mechanism underlying the occurrence of adverse outcomes in acute PE [1]. Decreased blood return to the LV also further reduces the LV size, which leads to an increased right-to-left heart size ratio. The four-chamber view is defined as the plane perpendicular to the atrial and interventricular septum [10], which can be used to accurately evaluate the increased size of the right heart, the decreased size of the left heart, and the interaction between these factors. The threshold value in our study was an RV/LV 4-chamber diameter ratio of 1.25, rather than previously reported cutoffs of 0.9, 1.0, or 1.1 [3, 33], although differences in the definition of this threshold may explain the selection of different parameters between our study and previous studies. The RA/LA 4-chamber diameter ratio was another factor in our risk-scoring tool. The membranous structure [31] and greater pressure sensitivity of the atrium (vs. the ventricle) may explain the lower weighting of the RA/LA 4-chamber diameter ratio relative to the weighting of the RV/LV 4-chamber diameter ratio in our scoring tool.

Limitations

The present study has several limitations that should be considered. First, although we evaluated data from normotensive patients with acute PE who were treated an approximately 10-year period, the retrospective analysis is prone to bias. Second, although this scoring tool was developed using randomized training and validation datasets, external validation is also required. Third, we did not have access to data regarding respiratory rate, cardiac troponin T, and heart type fatty acid binding protein, which precluded comparisons of our tools to the fast prognostic score [12] and respiratory index [6] for predicting adverse outcomes.

Conclusions

We developed a scoring tool that was published as web-based calculators for predicting adverse outcomes among normotensive patients with acute PE. This risk-scoring tool may help improve the management of patients with acute PE in predicting deterioration.

Abbreviations

ESC, European Society of Cardiology; PE, pulmonary embolism; CT, computed tomography; c-Tn I, cardiac troponin I; NT-pro BNP, N-terminal pro-brain natriuretic peptide; RV, right ventricle; LV, left ventricle; RA, right atrium; LA, left atrium; CPA, central pulmonary artery; CART, classification and regression tree; ROC, receiver operating characteristic curve; AUC, area under the receiver operating characteristic curve; OR, odds ratio; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value; DCA, decision curve analysis; C-index, concordance index; PH, pulmonary hypertension.

Declarations

Ethics approval and consent to participate

This research was approved by the Institutional review board of Shengjing Hospital of China Medical University (No.2020PS522K). Patient confidentiality was maintained.

Conflicts of interest

All authors have no relevant conflicts of interest to disclose.

Availability of data and materials

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

Competing interests

The authors declare that they have no competing interests.

Funding

This study received funding from the 345 Talent Project of Shengjing Hospital of China Medical University and Health commission of Liaoning (LNCCC-D12-2015)

Consent for publication

Not applicable.

Authors' contributions

D J designed, performed the research and measurement CT parameters as well as wrote the manuscript; Y G evaluated the endpoints and performed statistical analysis; C J performed the statistical analysis; J H collected the clinical parameters. H Z collected the laboratory parameters; H S conducted the risk stratification.

Acknowledgments

This article accepted professional language-editing service.

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Figures

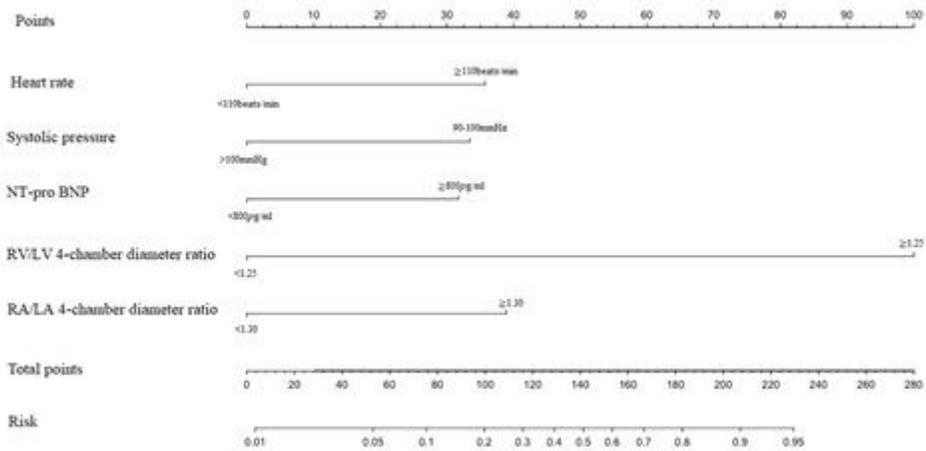


Figure 1

The nomograms for predicting the risk of adverse outcomes c Tn-I cardiac troponin I; NT-pro BNP N-terminal pro-brain natriuretic peptide; RV right ventricle; LV left ventricle; RA right atrium; LA left atrium

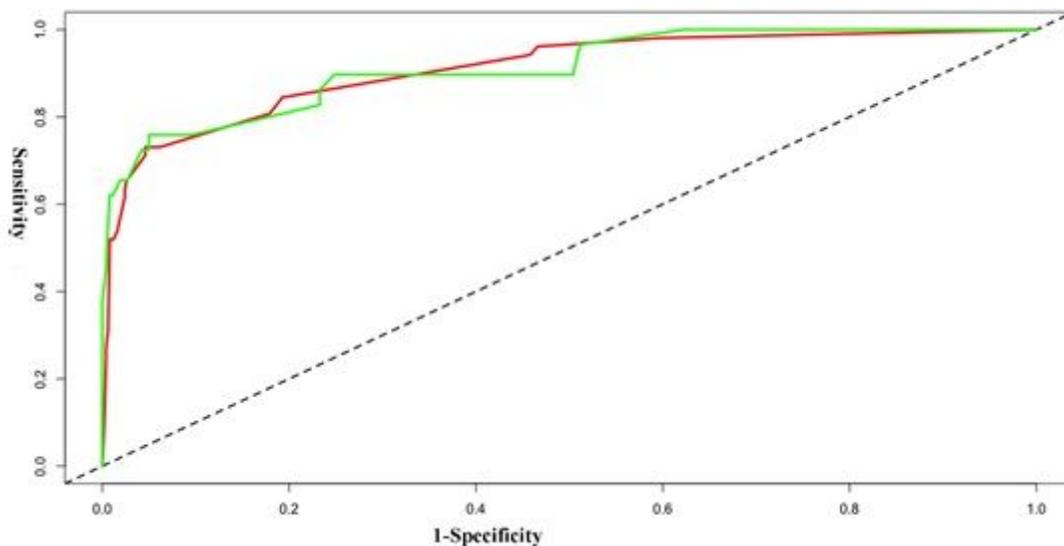


Figure 2

The receiver operating characteristic curves for predicting adverse outcomes The training dataset is shown using the red line and the validation dataset is shown using the green line. The area under the curve values for predicting adverse outcomes were 0.925 in the training dataset (95% CI: 0.900–0.946, $p < 0.001$) and 0.900 in the validation dataset (95% CI: 0.883–0.948, $p < 0.001$).

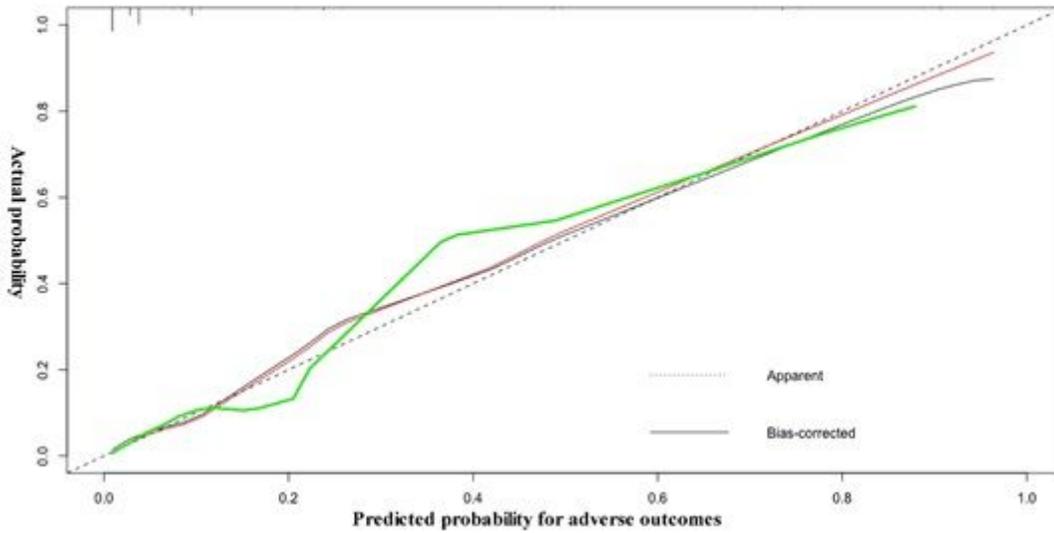


Figure 3

Calibration curves for the nomograms predicting adverse outcomes The training dataset is shown using the red line and the validation dataset is shown using the green line.

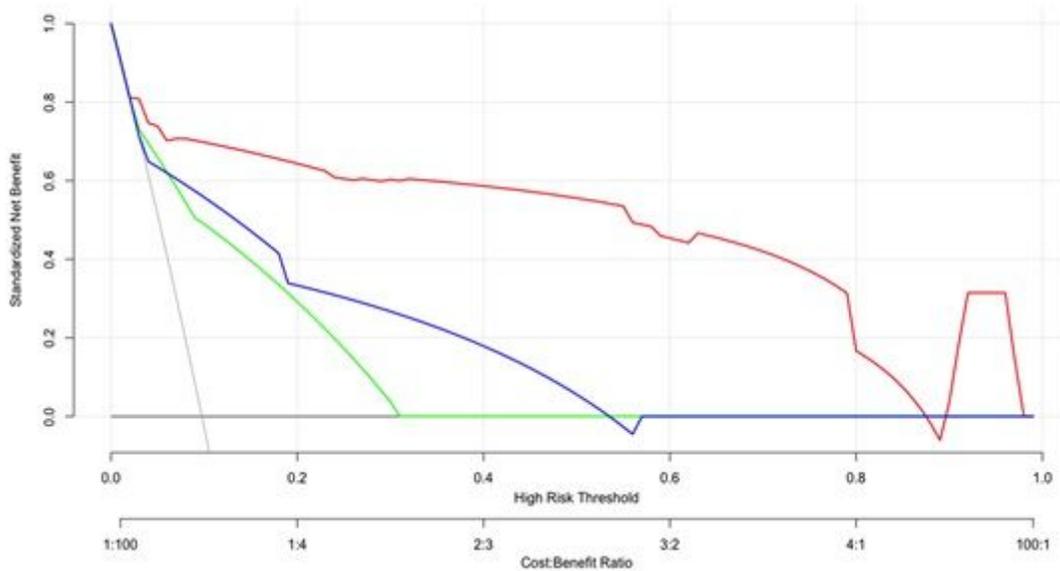


Figure 4

Decision curve analysis for the nomograms A comparing the net benefits between the nomogram, the 2019 ESC algorithm, and the Bova score, which revealed that the nomogram was better for (net benefit: 0.03–0.98) The nomogram is shown using the red line, Bova score is shown using the green line and 2019 ESC algorithm is shown using green line.

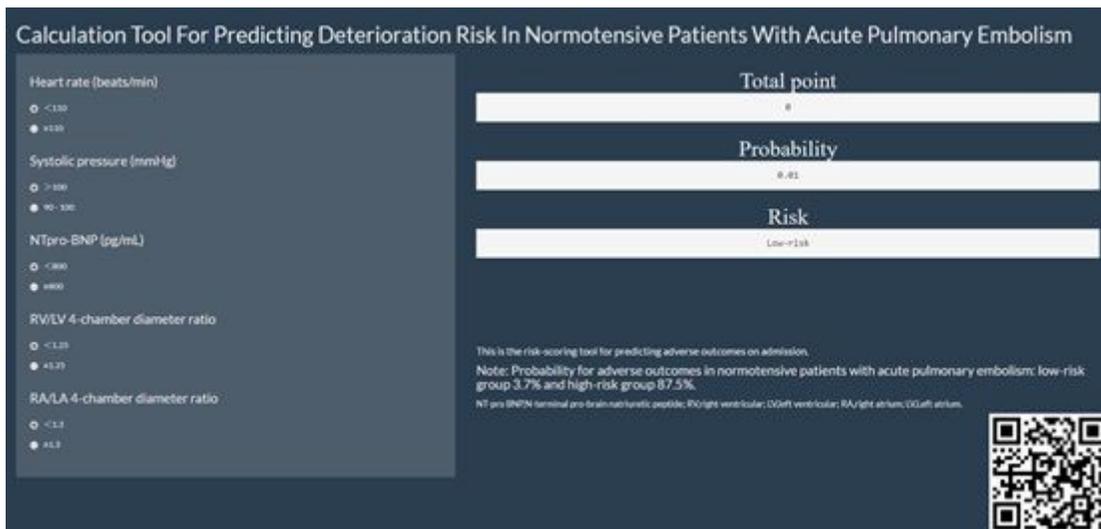


Figure 5

The web-based calculators for estimating the risks of adverse outcomes (<https://gaoyzcmu.shinyapps.io/APE9AD/>) The QR codes in the lower right corner can be used to publish the results to mobile electronic equipment. NT-pro BNP N-terminal pro-brain natriuretic peptide; RV right ventricle; LV left ventricle; RA right atrium; LA left atrium

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