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Original Contribution

A novel ECG parameter for diagnosis of acute pulmonary embolism: RS time
RS time in acute pulmonary embolism

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ABSTRACT

Objectives: Pulmonary embolism (PE) is one of the leading causes of cardiovascular mortality worldwide. Electrocardiography (ECG) may provide useful information for patients with acute PE. In this study, we aimed to investigate the diagnostic value of the QRS duration and RS time in inferolateral leads in patients admitted to the emergency department, and pre-diagnosed with acute PE.

Methods: We retrospectively enrolled 136 consecutive patients, admitted to the emergency department, pre-diagnosed with the clinical suspicion of acute PE, and underwent computerized tomographic pulmonary angiography (CTPA) to confirm the PE diagnosis. The study subjects were divided into two groups according to the presence or absence of PE, and the independent predictors of PE were investigated.

Results: Sixty-eight patients (50%) had PE. Patients with PE had a longer RS time. Among the ECG parameters, only RS time was an independent predictor of PE (OR: 1.397, 95% CI: 1.171–1.667; $p < 0.001$). The ROC curve analyses revealed that the cut-off value of RS time for predicting acute PE was 64.20 ms with a sensitivity of 85.3% and a specificity of 79.4% (AUC: 0.846, 95%CI: 0.749–0.944; $p < 0.001$). In the correlation analyses; the RS time was correlated with RV end-diastolic diameter ($r = 0.422$; $p < 0.001$), RV/left ventricle (LV) ratio ($r = 0.622$; $p < 0.001$), and systolic pulmonary artery pressure (SPAP) ($r = 0.508$; $p < 0.001$).

Conclusion: As a novel ECG parameter, RS time could be measured for each patient. A longer RS time can be a very useful index for diagnosing acute PE as well as for estimating the RV end-diastolic diameter and SPAP.

1. Introduction

Pulmonary embolism (PE) is one of the leading causes of cardiovascular mortality worldwide [1]. PE, which presents itself with various symptoms and clinical severities, sometimes is detected incidentally, while other times may cause sudden death [2]. Several postmortem studies consistently show a high percentage of PE going undiagnosed in the antemortem period: 55.2% in a study conducted in 2001 [3], 60% in a study conducted in 2007 [1], and 68% in a study conducted in 2013 [4]. The heterogeneous clinical presentation of PE may lead to difficulties in recognition, and thus delays in the initiation of life-saving treatments. In order to overcome these difficulties, several risk scoring systems and diagrams have been developed, based on history, physical examination, and laboratory findings, to assess the clinical probability of PE. [5,6]. However, considering the missed rate of diagnosis, it appears the management of the diagnostic process is not satisfactory, and most likely due to nonspecific nature of the symptoms.

Electrocardiography (ECG) is known to provide useful information for diagnosis of acute PE, as well as several ischemic, inflammatory, and arrhythmic heart diseases. In patients with acute PE, several ECG changes can be observed [7]. Although the most common findings are tachycardia (including atrial tachyarrhythmias) (42.2%) and any ST-segment and/or T-wave changes (68.2%) [8], the literature on prognostic effect of tachycardia and nonspecific ST-T wave changes is contradictory [9]. A less common ECG finding, the right axis deviation (RAD), is found in 3% of the low risk PE patients, but in 27.8% of the high risk PE patients [10]. Both complete and incomplete right bundle branch

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block (RBBB) are more commonly seen in severe acute PE patients. These parameters have a good specificity (99% and 97%, respectively) for predicting which patients are likely to have severe acute PE, however, they have a poor sensitivity for overall acute PE patients [11]. S1Q3T3 pattern, which is considered as the pathognomonic and specific (97%) ECG finding for acute PE, may not be seen in all acute PE patients. However, as previously shown, this pattern may have a predictive value for RV strain or other cardiovascular events in acute PE patients [11].

Right ventricle overloading and dilatation due to embolus may lead to a late QRS vector directed towards the right and posterior, and delay in electrical conductivity. Even through the RBBB, the RAD, S1Q3T3 pattern, and clock-wise rotation on the horizontal axis are an indirect sign of the right and posterior direction of QRS vector due to the right ventricular dilatation and the increase in duration of QRS in the ECG in acute PE patients [12]; an ECG parameter that directly measures this delay has not been demonstrated yet.

The delay in electrical conductivity exhibits itself in stretching the S-wave in inferolateral leads, causing an increase in the elapsed time from the beginning of QRS to the peak of the S-wave (RS time). We hypothesized that RS time could be quantified to provide insight into PE diagnosis. In this study, we assessed the relationship between diagnosis of acute PE with QRS duration and prolonged RS time measured from the inferolateral leads.

2. Materials and methods

2.1. Study population

This is a retrospective study over the records of 145 consecutive patients that have come to the emergency department between the dates of January 2016 and March 2017, that were preliminarily diagnosed with PE by the emergency department physician, and subsequently were referred to the computerized tomographic pulmonary angiography (CTPA) for confirmation of PE. CTPA of all patients had been evaluated by an experienced radiologist blinded to the patients' characteristics.

As part of our study, the ECGs of these patients were evaluated by two experienced cardiologists, who were also blinded to the patients CTPA. Two of the files were excluded due to the radiologist deeming the CTPA results as non-conclusive, leaving 143 patients. Of these 143 patients, seven were excluded due to poor quality ECG images. Finally, the remaining 136 patients constituted our study population (Fig. 1).

Demographic features, clinical features such as heart rate, blood pressure, respiration rate, mental status, oxygen saturation under noninvasive monitoring, as well as biochemical and hematological values, such as complete blood count, blood biochemical parameters, troponin-I, and d-dimer that had been measured on admission were obtained from patients' records. All the patients already had their revised Geneva and Wells scores calculated in their files, to assess the clinical likelihood of acute PE. We obtained these scores from patients' records as well. We also obtained left ventricle (LV) ejection fraction, RV dilatation, degree of tricuspid regurgitation (TR), and systolic pulmonary artery pressure (SPAP) which had been recorded by the consulting cardiologist at the time of arrival to the emergency department, through bedside echocardiography.

Multislice CTPA (SOMATOM Sensation 64; Siemens, Erlangen, Germany) had been performed in all patients using a standard CTPA protocol for PE. PE had been defined as a partial and/or complete endoluminal filling defect in the pulmonary artery system in at least two consecutive computed tomography (CT) sections.

The study protocol was reviewed and approved by the Local Ethics Committee of Kafkas University in accordance with the principles of the Declaration of Helsinki.

2.2. Electrocardiography

Digital 12-lead standard ECGs with paper speed of 25 mm/s and 10 mm/mV had been performed on each patient, upon admission to the emergency department, and the strips had been added to each patient's record. As part of our study, these ECG strips were obtained from patients' records, scanned, and were subjected to analysis using digital image processing software (imagej.nih.gov/ij/). All these measurements were performed by two experienced cardiologists blinded to other information of the patients. As a result of these measurements heart rate, rightward deviation of frontal QRS axis, complete or incomplete RBBB, QRS fragmentation on at least two contiguous leads, T-wave inversion on precordial leads, ST-segment depression on at least two contiguous leads, ST-segment elevation (STE) on at least two contiguous leads, STE in V1 (STEV1), STE in AVR (STEAVR) leads, prominent S-wave in D1 lead, presence of Q/q wave, T-wave inversion in D3 lead, and S1Q3T3 pattern were investigated.

The QRS duration was defined as the interval from the start of the QRS complex until the J-point, and was measured from the lead with the longest duration. As part of QRS, the RS time was defined as the interval from the beginning of the QRS complex until the nadir of S or S' wave (Fig. 2). In our study RS time was calculated from the inferolateral leads, which is represented by leads D1, AVL, D2, D3, AVF, V4, V5, and V6. Similar to QRS, the RS time was measured from the lead with the longest duration from among the above-mentioned leads. All durations are presented in milliseconds (msec).

2.3. Statistical analyses

Statistical analyses were performed using the SPSS version 22.0 (IBM, Chicago, Illinois). Normality of the data was analyzed using the Kolmogorov-Smirnov test. Numerical variables with a normal distribution are presented in terms of mean ± standard deviation (SD) values, while the non-normally distributed variables are presented as median and interquartile range values. Frequencies were calculated for the categorical variables (numbers and percentages [%]). The continuous variables of both the groups were compared using the Student *t*-test or the Mann Whitney *U* test. The categorical data were compared using the Chi-Square test or the Fisher exact test. Statistical significance was defined as a P value <0.05. The correlation of RS time with RV dimension, RV/LV ratio, and SPAP was assessed using Pearson correlation analyses. Multivariate logistic regression analyses were performed to identify the independent predictors of acute PE using the variables with marginal association with it in the univariate analyses. The RS time with the best specificity and sensitivity for predicting acute PE was calculated using receiver-operating characteristic (ROC) curve analysis. Effect size (Cohen's d) and power value (1-β) of RS time comparison between patients with and without PE were calculated using G*Power software (version 3.1.9.2). The alpha level used for this analysis was <0.05.

3. Results

The study population comprised 136 patients who had underwent CTPA to confirm the diagnosis of acute PE (mean age: 60 ± 17 years; 52.9% [$n = 72$] women). Sixty-eight (50%) patients had been diagnosed with acute PE, whereas PE had been excluded in the remaining 68 (50%). Characteristics of the study population are summarized in two tables: Baseline demographics, and clinical characteristics are in Table 1, and laboratory characteristics are in Table 2.

Patients with acute PE had an increased respiratory rate, higher d-dimer and troponin-I levels, and decreased oxygen saturation than those without PE. There was no statistical difference in the age and sex of the patients with and without acute PE. Although the median revised Geneva score was significantly higher in acute PE patients than in those without PE (3.0 [3.0–4.5] vs. 3.5 [1.0–6.0]; $p = 0.002$), there was

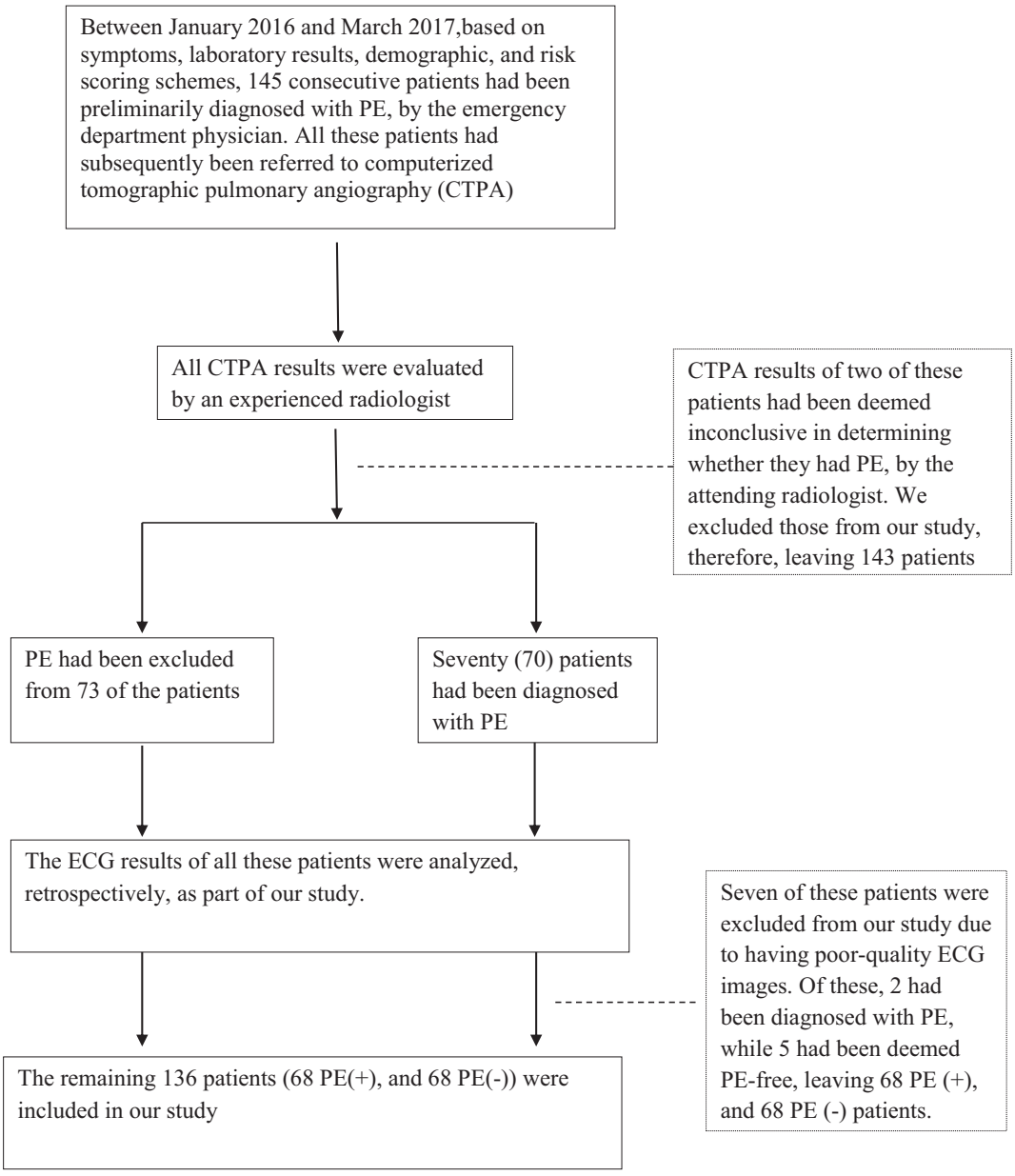

Fig. 1. Flow chart. Enrollment of study patients.

no statistical difference between the two groups in terms of the Wells score. While more of the patients with PE had underwent surgery, or were immobilized within the previous four weeks; had more symptoms of deep vein thrombosis; and had a history of hypertension than those without PE, these differences did not reach statistical significance.

A comparison of the echocardiographic and tomographic findings revealed that in acute PE patients, right ventricular dilatation, increased systolic pulmonary artery pressure, and the presence of more than a mild degree of tricuspid regurgitation were more frequent than in those without PE. Based on the thorax CT findings, patients with PE had a larger RV end-diastolic diameter and a greater RV/LV ratio than those without PE. Echocardiographic and tomographic findings of the study patients are listed in Table 3.

An analysis of the ECG parameters revealed that the patients with PE had a longer RS time (69.65 ± 7.63 vs. 59.72 ± 6.35; $p < 0.001$) and a longer QRS duration (101.38 ± 16.88 vs. 92.15 ± 18.99; $p = 0.038$). The effect size and power value of RS time comparison were 1.41 and 0.99, respectively. Also, PE patients had a more frequent prominent S wave in D1 lead than the patients without PE. Although the frequency of increased heart rate, right axis deviation of the QRS axis, complete or incomplete RBBB, atrial fibrillation, and S1Q3T3 pattern were higher in patients with acute PE, these differences were not statistically significant (Table 3). To eliminate the effect of complete and incomplete RBBB on QRS expansion or RS time, the comparison was repeated with the exclusion of patients with RBBB. While the QRS duration was similar in patients with and without PE (n: 56, 96 ± 15 vs. n: 48, 90 ± 20; $p = 0.197$); the RS time was significantly longer in patients with PE than in those without PE (66.4 ± 6.1 vs. 58.7 ± 6.2; $p < 0.001$). Ten patients were treated with thrombolytic therapy due to massive PE; even after excluding these patients from the analyses, the RS time was still longer in patients with PE than in those without PE (n: 58, 68.92 ± 7.12 vs. n: 68, 59.72 ± 6.35; $p < 0.001$).

Multivariate regression analysis was used to determine the independent predictors of acute PE, using parameters associated with acute PE in the univariate analysis (RS time, QRS duration, Geneva score, d-dimer level > 500 μg/L, troponin I level, oxygen saturation, and

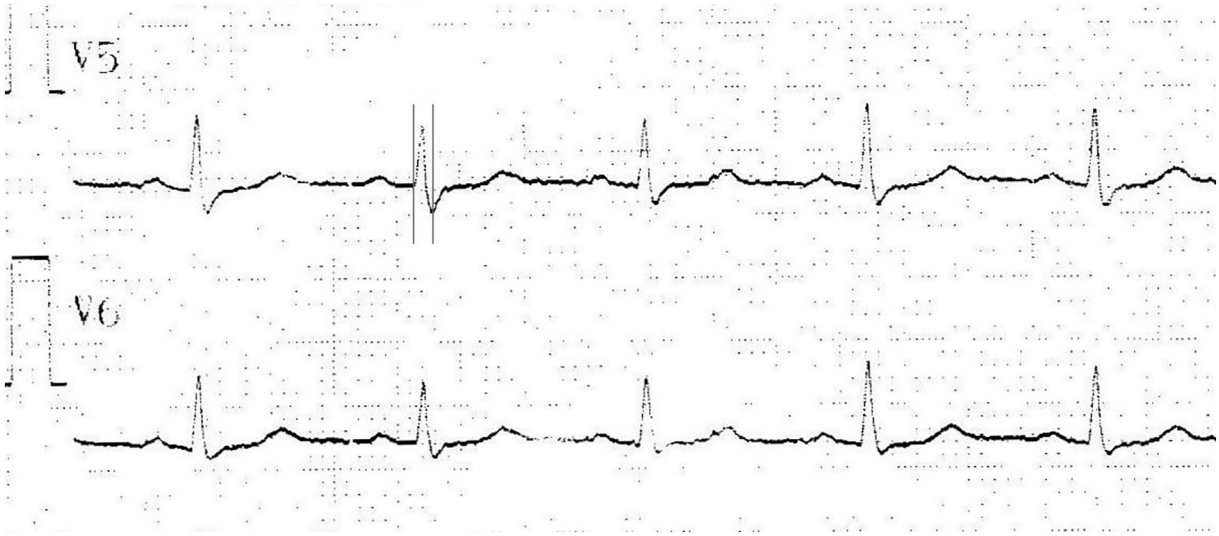

Fig. 2. Identification of RS time on ECG strip.

respiratory rate). RS time (OR: 1.397, 95%CI: 1.171–1.667; $p < 0.001$), Geneva score (OR: 1.486, 95%CI: 1.142–1.933; $p = 0.003$), and respiratory rate (OR: 1.307, 95%CI: 1.053–1.621; $p = 0.015$) were found to be independent predictors of acute PE (Table 4).

The ROC curve analysis revealed that the cut-off value of RS time for predicting acute PE was 64.20 msec with a sensitivity of 85.3% and a specificity of 79.4% (AUC: 0.846, 95% CI: 0.749–0.944; $p < 0.001$). The cut-off RS time value of 60 msec (1,5 mm on ECG) for predicting acute PE had a 88.2% sensitivity and a 41.2% specificity (AUC: 0.647, 95% CI: 0.522–0.759; $p = 0.004$). In the ROC curve comparison, the AUC value of RS time was higher than that of the QRS duration (AUC: 0.685 95% CI: 0.561–0.792; $p = 0.007$) (Fig. 3).

In the correlation analyses; in addition to the weak-moderate correlation between RS time and RV end-diastolic diameter ($r = 0.422$; $p < 0.001$), there was a moderate correlation between the RS time and the RV/LV ratio ($r = 0.622$; $p < 0.001$) as well as between the RS time and SPAP ($r = 0.508$ $p < 0.001$) (Table 5).

4. Discussion

This study demonstrated that a prolonged RS time was associated with acute PE. Further, to our knowledge, this is the first study to report that prolonged RS time is an independent predictor of acute PE. Furthermore, the RS time was correlated with RV end-diastolic diameter, RV/LV ratio, and SPAP.

PE is challenging to diagnose because of the non-specific nature of its clinical findings and symptoms. Patients with a suspicion of PE should be evaluated in terms of detailed history of predisposing factors and specific laboratory indices in addition to a validated risk scoring system that assesses the clinical probability [6,13]. Subjects of this study had been found to have a high percentage of d-dimer positivity and a high clinical probability of PE based on the modified Geneva and Wells score (with modified Geneva score being more distinguishing than Wells score). CTPA is recommended for patients with a high clinical probability of developing PE or those with a low or intermediate clinical

Table 1
Demographic, clinical characteristics and risk scores of all patients, patients with and without pulmonary embolism, with *p* value. Abbreviations: PE: pulmonary embolism; DVT: Deep vein thrombosis.

	All patients (n:136)		Patients without PE (n:68)		Patients with PE (n:68)	*p* value	
Age (years)	60	±17	57	±15	63	±18	0.089
Female gender, n (%)	72	(52.9)	34	(50.0)	38	(55.9)	0.627
Diabetes Mellitus, n (%)	14	(10.3)	8	(11.8)	6	(8.8)	0.689
Hypertension, n (%)	42	(30.9)	14	(20.6)	28	(41.2)	0.066
Smoking, n (%)	62	(45.6)	30	(44.1)	32	(47.1)	0.808
History of pulmonary disease, n (%)	22	(16.2)	10	(14.7)	12	(17.6)	0.742
Coronary artery disease, n (%)	26	(19.1)	10	(14.7)	16	(23.5)	0.355
Heart Failure, n (%)	14	(10.3)	8	(11.8)	6	(8.8)	0.690
History of pulmonary embolism, n (%)	4	(2.9)	4	(5.9)	0	(0.0)	0.151
History of DVT, n (%)	6	(4.4)	2	(2.9)	4	(5.9)	0.555
History of malignancy, n (%)	8	(5.9)	2	(2.9)	6	(8.8)	0.303
Surgery or immobilization within past four weeks, n (%)	28	(20.6)	10	(14.7)	18	(26.5)	0.230
DVT symptoms, n (%)	28	(20.6)	8	(11.8)	20	(29.4)	0.072
Hemoptysis, n (%)	8	(5.9)	2	(2.9)	6	(8.8)	0.303
Systolic blood pressure, mm Hg	128.82	±20.46	129.41	±19.84	128.24	±21.35	0.815
Body temperature °C	36.40	36.20–36.85	36.40	36.20–36.90	36.40	36.20–36.70	0.558
Respiratory rate (/min)	20.0	18.0–24.0	20.0	18.0–22.0	20.5	20.0–28.0	0.033
Oxygen saturation (%)	93.0	86.5–96.0	94.0	91.0–96.0	91.0	81.0–94.0	0.004
Geneva score	5.00	3.00–8.00	3.50	1.00–6.00	6.00	4.00–9.00	0.002
Geneva score >3, n (%)	96	(70.6)	34	(50.0)	62	(91.2)	<0,001
Wells score	3.50	3.00–5.75	3.00	3.00–4.50	4.50	3.00–7.00	0.170
Wells score >1, n (%)	114	(83.8)	58	(85.3)	56	(82.3)	0.742

Table 2
Laboratory characteristics of all patients, patients with and without pulmonary embolism, with *p* value. Abbreviations: PE: pulmonary embolism; WBC: White Blood Cell.

	All patients (n:136)		Patients without PE (n:68)		Patients with PE (n:68)		*p* value
Blood urea nitrogen (mg/dl)	40.21	±16.38	39.62	±15.18	40.79	±17.72	0.770
Alanine transaminase (U/L)	25.68	±17.77	28.71	±20.32	22.65	±14.48	0.161
Aspartate transaminase(U/L)	27.01	±15.33	30.21	±16.71	23.82	±13.30	0.086
Potassium (mmol/L)	4.27	±0.47	4.28	±0.48	4.27	±0.47	0.894
Sodium (mmol/L)	137.63	±4.39	136.79	±5.00	138.47	±3.57	0.116
Calcium (mg/dL)	8.92	±0.54	9.03	±0.57	8.82	±0.49	0.105
WBC (/1000)	9.57	±4.40	9.34	±4.91	9.80	±3.87	0.672
Hemoglobin (g/dL)	13.79	±2.17	13.91	±1.82	13.68	±2.51	0.653
Platelet (10,000/μL)	230.22	±79.92	231.74	±74.42	228.71	±86.18	0.877
D-dimer (μg/L)	2000.50	±1444.24	1546.15	±914.72	2454.85	±1724.17	0.008
D-dimer >500 μg/L, n (%)	61	(89.7)	28	(82.4)	33	(97.1)	0.046
Troponin I level (ng/mL)	0.02	0.0–0.12	0.01	0.0–0.11	0.02	0.01–0.15	0.032
Troponin *I* > 0.04, n (%)	24	(35.3)	10	(29.4)	14	(41.2)	0.310

risk of PE with d-dimer positivity [6]. In the present study, PE diagnosis had been confirmed using CTPA, and PE had been found in 50% of the patients.

The 12-lead ECG remains one of the initial tests performed upon admission to the hospital for patients complaining of chest pain and/or dyspnea. To date, numerous ECG findings, including sinus tachycardia, S1Q3T3 pattern, atrial tachyarrhythmias, Q wave in lead III, S1Q3T3 pattern, complete or incomplete RBBB, T wave inversion, and fragmentation in QRS have been associated with PE [8,14]. Several possible underlying mechanisms have been proposed for the PE-related ECG changes, such as rapid RV pressure overload and RV enlargement, reduction in electrical conduction due to mechanical compression of the increased cavity pressure and cellular hypoxia, damage in the overall perfusion of cardiac myocardium caused by RV infarction and/or decrease in the preload of the left ventricle due to RV dysfunction, and probable cellular ischemia induced by mediators (such as catecholamines or histamine) [15-20]. However, a majority of the these ECG findings have been found not to have sufficient specificity and sensitivity for diagnosing PE [21,22]. In our study, in accordance with the aforementioned literature, ECG parameters including RAD, RBBB, clockwise rotation, S1Q3T3, and S1S2S3 patterns were also more frequent in the PE group; however, this increase in frequency did not reach statistical significance. The reason for these ECG parameters not reaching statistical significance is perhaps due to our study subjects, with and without PE, had already been deemed high-risk for the purposes of PE.

In a healthy heart, the latest portion of the QRS complex, the S-wave in leads V4–V6, occurs due to the right ventricular and the septal electrical forces being directed towards the base, while the left ventricular electrical forces have a more posterior direction [12]. In patients with chronic obstructive pulmonary disease, the spatial orientation of the heart and the insulating effect of the over-aerated lungs induce a late QRS vector oriented superiorly, and to the right; resulting in a wide, slurred S-wave in leads I, II, III, V4, V5, and V6 [23-26]. In the course of PE, some changes in the heart's position are observed. The dilatation and possible ischemia of the RV could cause delayed activation of the

Table 3
Echocardiographic, computerized tomographic and electrocardiographic characteristics of all patients, patients with and without pulmonary embolism, with *p* value. Abbreviations: PE: pulmonary embolism; LVEF: Left ventricle ejection fraction; TR: Tricuspid regurgitation; RV: Right ventricle; LV: Left ventricle; RBBB: Right bundle branch block; ECG: Electrocardiography.

	All patients (n:136)		Patients without PE (n:68)		Patients with PE (n:68)		*p* value
Echocardiographic findings							
LVEF	58.26	±8.77	58.50	±9.12	58.03	±8.54	0.827
TR more than mild degree, n (%)	62	(45.6)	20	(29.4)	42	(61.8)	0.007
RV dilatation, n (%)	60	(44.1)	14	(20.6)	46	(67.6)	<0.001
Pulmonary artery systolic pressure	39.60	±12.34	30.38	±6.43	48.83	±9.61	<0.001
Computerized tomography findings							
RV end-diastolic diameter (mm)	39.13	±9.00	34.49	±6.10	43.77	±9.11	<0.001
LV end-diastolic diameter (mm)	37.90	±7.21	38.95	±6.43	36.85	±7.86	0.231
RV/LV ratio	1.05	±0.27	0.89	±0.10	1.22	±0.29	<0.001
Electrocardiographic findings							
Atrial fibrillation, n (%)	18	(13.2)	4	(5.9)	14	(20.6)	0.074
Heart rate, (bpm)	90.96	±22.64	87.53	±27.18	94.38	±16.67	0.215
Right axis deviation, n (%)	16	(11.8)	4	(5.9)	12	(17.6)	0.132
Clockwise rotation, n (%)	38	(27.9)	12	(17.6)	26	(38.2)	0.059
Complete or incomplete RBBB, n (%)	32	(23.5)	12	(17.6)	20	(29.4)	0.253
Fragmentation in QRS, n (%)	30	(22.1)	10	(14.7)	20	(29.4)	0.144
Precordial T wave negativity, n (%)	52	(38.2)	22	(32.4)	30	(44.1)	0.318
ST depression in any ECG derivation, n (%)	26	(19.1)	12	(17.6)	14	(20.6)	0.758
ST elevation in two or more contiguous leads, n (%)	50	(36.8)	28	(41.2)	22	(32.4)	0.451
ST elevation in V1 lead, n (%)	24	(17.6)	14	(20.6)	10	(14.7)	0.525
ST elevation in AVR lead, n (%)	26	(19.1)	12	(17.6)	14	(20.6)	0.758
Prominent S-wave in D1 Lead, n (%)	50	(36.8)	16	(23.5)	34	(50.0)	0.024
Prominent Q-wave in D3 Lead, n (%)	38	(27.9)	16	(23.5)	22	(32.4)	0.417
T wave negativity in D3 Lead, n (%)	38	(27.9)	16	(23.5)	22	(32.4)	0.421
S1Q3T3 pattern, n (%)	10	(7.4)	2	(2.9)	8	(11.8)	0.163
S1S2S3 pattern, n (%)	24	(17.6)	6	(8.8)	18	(26.5)	0.056
Presence of ST depression in V4–6, n (%)	24	(17.6)	14	(20.6)	10	(14.7)	0.525
QRS duration (msec)	96.76	±18.38	92.15	±18.99	101.38	±16.88	0.038
RS time (msec)	64.68	±8.58	59.72	±6.35	69.65	±7.63	<0.001

Table 4
Univariate and multivariate logistic regression analysis of demographic, clinical, laboratory and electrocardiographic characteristics that predict pulmonary embolism.

	Univariate analysis of PE			Multivariate analysis of PE		
	Odds ratio	95% C.I.	*p* value	Odds ratio	95% C.I.	*p* value
RS time, msec	1.225	1.109–1.353	<0.001	1.397	1.171–1.667	<0.001
QRS duration, msec	3.436	1.025–11.520	0.045	–	–	–
Geneva score	1.266	1.072–1.495	0.005	1.486	1.142–1.933	0.003
D-dimer >500 μg/L	7.071	0.803–62.311	0.078	–	–	–
Troponin I level	3.654	0.581–22.958	0.167	–	–	–
Oxygen saturation (%)	0.914	0.846–0.986	0.020	–	–	–
Respiratory rate (/min)	1.116	1.004–1.240	0.041	1.307	1.053–1.621	0.015

Table 5
The correlation analysis between RS time and QRS duration and RV end-diastolic diameter, RV/LV ratio and systolic pulmonary artery pressure. Abbreviations: RV: Right ventricle; LV: Left ventricle.

	RV end-diastolic diameter (mm)	RV/LV ratio	Systolic pulmonary artery pressure
RS time (msec)			
r value	0.422	0.622	0.508
p value	<0.001	<0.001	<0.001
n	136	136	136
QRS duration (msec)			
r value	0.292	0.367	0.296
p value	0.016	0.002	0.014
n	136	136	136

RV, resulting in RBBB, RAD, prominent S-wave in D1, S1S2S3 pattern, and clockwise rotation of horizontal axis [9,11,15,20]. We hypothesized that the PE induced delay in electrical conductivity, and the right and posteriorly oriented QRS vector could induce prolongation of the RS time measured from inferolateral leads, and therefore prolongation of the QRS duration. In fact, we observed that the prolongation of QRS, and the prolongation of RS intervals were significantly associated with PE; and the prolongation of RS time was an independent predictor of PE. To our knowledge, in an ECG, the RS time is the first-identified interval that shows the delay of electrical conductivity due to PE and/or RV loading.

In this study, aside from observing that the prolongation of RS time was an independent predictor of PE, we found that, RS time was longer in PE patients, even in those with no RBBB and/or massive PE. Moreover, the RS time was significantly correlated with RV's dimensions, and RV/LV ratio. Based on this result, we concluded that the prolongation of the last part of the QRS complex is present, even in patients without massive PE causing obvious RBBB, RAD, and clockwise rotation. Furthermore, the RS time could be used to quantify this observation. Given the sensitivity and specificity for predicting acute PE of defined ECG parameters that are established previously [16,27], irrespective of complete or incomplete RBBB, RS time appears to be an effective diagnostic tool.

We established a prolonged RS time has a predictive value for PE diagnosis. Our ROC curve analysis has shown an RS time of >64.20 msec has the best predictive value. However, it begs the question how a clinician would measure a time of that precise in an ECG strip. In order to simplify such evaluation by a clinician, we considered using 60 msec (width of 1.5 squares on an ECG strip) as the basis for prediction. We observed using 60 msec also had good predictive value.

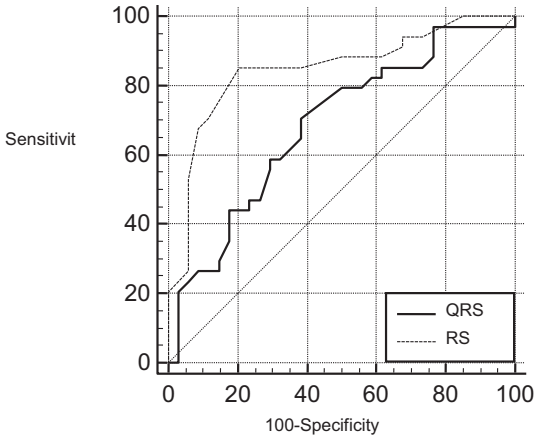

Fig. 3. ROC graphics to detect the cut-off value of RS time for pulmonary embolism prediction and ROC curves comparison between QRS duration and RS time to detect the better electrocardiographic parameter in predicting pulmonary embolism.

Our study has certain limitations. First, our study had a retrospective design and was based on patient file analyses. Second, the sample size is relatively low. Furthermore, due to the low number of in-hospital mortality, prognostic data could not be introduced. Third the bedside echocardiography that had been conducted by the consultant cardiology physician at the emergency department lacks some measurements. For instance, right ventricular dimensions were not measured, and right ventricular dilatation was reported only as present or absent. Fourth, subjects included in this study do not represent a homogeneous group, since patients with a history of various cardiovascular and/or pulmonary diseases, as well as those with no other diagnosed cardiovascular disease were included in the same study. As such, we do not know the effect of presence of (or lack thereof) other cardiovascular diseases, and how they affect the results of our study. Finally, in patients with a high clinical risk, PE might have been underdiagnosed, especially considering the sensitivity and specificity of CTPA. In these patients, conventional pulmonary angiography may be a more suitable option.

5. Conclusion

ECG is a non-invasive, fast, inexpensive, and easily accessible diagnostic tool. Recognition of specific ECG changes that may indicate presence of PE, could help lead to an earlier diagnosis of a potentially deadly disease. We are mindful of the difficulty of diagnosing PE with a single ECG parameter, and this study's premise is not that RS time alone is sufficient to diagnose PE. However, our findings indicate prolonged RS time on surface ECG is a novel and effective parameter that can be very useful index (along with other parameters) for diagnosing acute PE in the emergency room.

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Conflicts of interest

None declared.

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