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Original Contribution

NEW ELECTROCARDIOGRAPHIC CHANGES IN PATIENTS DIAGNOSED WITH PULMONARY EMBOLISM

Ivan Co, MD,* Wesley Eilbert, MD,† and Terry Chiganos, MD, PHD‡

*Division of Critical Care, Department of Emergency Medicine and Department of Internal Medicine, University of Michigan Health System, Ann Arbor, Michigan, †Department of Emergency Medicine, University of Illinois College of Medicine, Chicago, Illinois, and ‡Department of Emergency Medicine, Lutheran General Hospital, Park Ridge, Illinois

Reprint Address: Wesley Eilbert, MD, Department of Emergency Medicine, University of Illinois College of Medicine, Chicago, IL 60612

□ **Abstract—Background: The electronic medical record is a relatively new technology that allows quick review of patients' previous medical records, including previous electrocardiograms (ECGs). Previous studies have evaluated ECG patterns predictive of pulmonary embolism (PE) at the time of PE diagnosis, though none have examined ECG changes in these patients when compared with their previous ECGs. Objective: Our aim was to identify the most common ECG changes in patients with known PE when their ECGs were compared with their previous ECGs. Methods: A retrospective chart review of patients diagnosed with PE in the emergency department was performed. Each patient's presenting ECG was compared with their most recent ECG obtained before diagnosis of PE. Results: A total of 352 cases were reviewed. New T wave inversions, commonly in the inferior leads, were the most common change found, occurring in 34.4% of cases. New T wave flattening, also most commonly in the inferior leads, was the second most common change, occurring in 29.5%. A new sinus tachycardia occurred in 27.3% of cases. In 24.1% of patients, no new ECG changes were noted, with this finding more likely to occur in patients younger than 60 years. Conclusions: The most common ECG changes when compared with previous ECG in the setting of PE are T wave inversion and flattening, most commonly in the inferior leads, and occurring in approximately one-third of cases. Approximately one-quarter of patients will have a new sinus tachycardia, and approximately one-quarter will have no change in their ECG.** © 2016 Published by Elsevier Inc.

□ **Keywords—pulmonary embolism; electrocardiographic changes; electrocardiographic changes with pulmonary embolism; ECG changes with pulmonary embolism**

INTRODUCTION

Pulmonary embolism (PE) is the third most common cause of death from cardiovascular disease after heart attack and stroke (1). The annual incidence of PE in the United States has been estimated at 600,000 cases, with an acute fatality rate ranging from 7% to 11% (2). Despite new diagnostic methods and technology, the diagnosis of PE is frequently missed, with 10% to 30% of cases not diagnosed until autopsy (3).

McGinn and White were the first to describe electrocardiographic (ECG) changes with PE in 1935 (4). Since then, >20 different ECG changes with PE have been described (5). ECG is typically one of the first diagnostic procedures performed in the emergency department (ED) patient presenting with chest pain or dyspnea. However, the ECG has poor sensitivity and specificity for diagnosing PE, and its main value in this setting is its ability to identify other potentially life-threatening diagnoses, such as myocardial ischemia or infarction and pericarditis (3).

The advent of the electronic health record in the 21st century has allowed for rapid retrieval of previously

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unavailable medical data, including previous ECGs. This new resource has proven to be valuable when interpreting ECGs in those patients with chest pain of possible cardiac origin, because many of them will have pre-existing nonspecific ECG changes. In light of this fact, the purpose of this study was to report the dynamic ECG changes found in those patients with known PE when their ECGs were compared with their previous ones.

METHODS

This was a retrospective study conducted at two university-affiliated teaching hospitals with a combined annual census of approximately 120,000. Approval from each hospital's Institutional Review Board was granted before the implementation of the study. During the study period, from January 1, 2008 through December 31, 2013 at one hospital, and from January 1, 2012 through May 31, 2015 at the other, the records of all patients with an ED diagnosis of PE were reviewed.

Only those patients with PE confirmed by computed tomography angiography (CTA), a ventilation-perfusion (VQ) scan with a high probability result, and patients in whom PE was suspected with right ventricular dysfunction noted on echocardiography (ECHO) were included in the study. Furthermore, only patients with an ECG performed in the ED at the time of PE diagnosis and an available previous ECG were included. ECGs obtained at the time of PE diagnosis were compared with the patients' most recent previous ECGs by a single board-certified emergency physician. Ten percent of the ECG comparisons were also assessed by a second board-certified emergency physician and inter-rater agreement was measured. Changes in rate, rhythm, axis, and interval/morphology, as well as new ischemic changes were recorded on a structured data form.

RESULTS

Data from 352 patient records was included in the study. Mean patient age was 68 years, with a range from 23 to 96 years. Seventy percent of patients were aged 60 years or older. The majority (62.5%) of patients were female. Two hundred and eighty-five (80.9%) of the PEs were diagnosed by CTA, 64 (18.2%) were diagnosed by high-probability VQ scan, and 3 (0.9%) were diagnosed by clinical suspicion with right ventricular dysfunction found on ECHO. Of those PEs diagnosed by CTA, 173 (60.7%) were in a segmental pulmonary artery, 85 (29.8%) were in a main pulmonary artery, and 28 (8.0%) were saddle emboli straddling the bifurcation of the main pulmonary arterial trunk.

Table 1 summarizes patient clinical characteristics and ECG abnormalities found on their most recent ECGs obtained before the diagnosis of PE. Dyspnea was the most common presenting symptom, present in more than half of the cases. An active malignancy was the most common predisposing condition for thromboembolic disease, present in 13.9% of cases. T wave flattening was the most common abnormality found on previous ECGs, noted in 12.5% of cases.

Mean duration of time between previous ECG and ECG at the time of PE diagnosis was 14.2 months, with a median of 10 months and range of 1 to 96 months. Table 2 summarizes the new ECG abnormalities found. There was 94.3% inter-rater agreement between the two emergency physicians in those ECG comparisons reviewed by both. The majority of patients had some notable change in their ECG, with only 24.1% having no change at all. Analysis of this subgroup of patients with no ECG change noted at the time of PE diagnosis revealed that this finding was more likely to occur in patients younger than 60 years than in older patients ($p = 0.05$). A new right axis deviation (RAD) occurred in 11.1% of cases, and a new right bundle branch block (RBBB) appeared in 5.7%. Only 3.7% of ECGs had a new S1Q3T3 pattern. Subanalysis comparing ECGs of patients with saddle emboli with those of patients with non−saddle emboli found that the ECGs of saddle emboli patients were more likely to show new T wave inversions ($p = 0.001$), T wave flattening ($p = 0.04$), sinus tachycardia ($p = 0.006$), ST segment depression ($p = 0.05$), RBBB ($p = 0.002$), and S1Q3T3 pattern ($p = 0.0001$).

Table 1. Patient Clinical Characteristics and Previous Electrocardiogram Abnormalities

Presenting Symptoms	n (%)	Associated Conditions	n (%)	Previous ECG Abnormalities	n (%)
Dyspnea	196 (55.7)	Malignancy (current)	49 (13.9)	T wave flattening	44 (12.5)
Chest pain	102 (29.0)	Previous DVT or PE	36 (10.2)	Sinus tachycardia	26 (7.4)
Unilateral leg swelling	21 (6.0)	Limb immobilization	34 (9.7)	T wave inversions	24 (6.8)
Upper abdominal pain	16 (4.5)	Obesity (BMI > 35)	33 (9.4)	Right bundle branch block	12 (3.4)
Altered mental status	10 (2.8)	Pregnancy	1 (0.3)	Left bundle branch block	9 (2.6)
Back pain	9 (2.6)				
Hemoptysis	8 (2.3)				
Syncope	5 (1.4)				
Cardiac arrest	2 (0.6)				

BMI = body mass index; DVT = deep venous thrombosis; ECG = electrocardiogram; PE = pulmonary embolism.

Table 2. New Electrocardiogram Abnormalities at Time of Pulmonary Embolism Diagnosis When Compared with Previous Electrocardiogram

Variable	n (%)
T wave inversions	
Inferior leads	53 (15.1)
Lateral leads	38 (10.8)
Anterior leads	30 (8.5)
Total	121 (34.4)
T wave flattening	
Inferior leads	54 (15.3)
Lateral leads	31 (8.8)
Anterior leads	19 (5.4)
Total	104 (29.5)
Sinus tachycardia	96 (27.3)
No change	85 (24.1)
Right axis deviation	39 (11.1)
ST segment depression	
Lateral leads	17 (4.8)
Anterior leads	11 (3.1)
Inferior leads	4 (1.1)
Total	32 (9.1)
Right bundle branch block	20 (5.7)
S1Q3T3	13 (3.7)
Atrial fibrillation/flutter	0
Left axis deviation	0
Left bundle branch block	0

No patients in our study had new-onset atrial fibrillation or flutter at the time of PE diagnosis.

T wave inversions were the most common ECG change noted, found in 34.4% of cases. These T wave inversions occurred in all lead locations, though most commonly in the inferior leads. New T wave flattening, defined as no positive deflection >1 mm above the ST segment baseline, was the second most common change, noted in 29.5% of cases. New T wave flattening also occurred most commonly in the inferior leads. A new sinus tachycardia occurred in 27.3% of cases, making it the third most common change. New ST segment depression occurred in 9.1% of patients, most commonly in the lateral leads. None of the cases reviewed had new ST segment elevation.

DISCUSSION

In the modern era, the diagnosis of PE can be made with a great degree of accuracy by CTA, VQ scan, and pulmonary artery angiography. Despite this fact, the ECG, because of its simplicity, widespread availability, and low-cost, has definite clinical advantages over these other diagnostic modalities. The utility of the ECG in this realm has been widely studied. Unfortunately, the common ECG findings with PE lack sufficient sensitivity and specificity to be of useful diagnostic value. This is reflected by the fact that none of the commonly used clinical models for determining PE risk consider ECG findings (6–8). Despite this, various ECG patterns have been shown to predict the extent of pulmonary perfusion defects, the degree of pulmonary hypertension, right ventricular dysfunction, and clinical outcome with PE (9–12).

Mean age of patients included in our study was 68 years, similar to previous population-based PE registries (13,14). At this advanced age, many patients will have baseline ECG findings reflecting chronic illnesses, such as hypertension, chronic obstructive pulmonary disease, and coronary artery disease. Many of these findings are similar to the common ECG abnormalities described with PE. Unfortunately, the large majority of previous studies describing ECG abnormalities with PE have been specific to patients with no pre-existing cardiac or pulmonary disease (3). In this study, we attempted to describe dynamic ECG changes found in individual patients diagnosed with PE.

The mechanism by which PE causes ECG changes is unclear. The changes have been attributed to hemodynamic, anatomic, ischemic, metabolic, and autonomic changes that affect the cardiac tissue (15). An acute PE causes a mechanical obstruction of the pulmonary artery, resulting in elevated right heart pressures. This change may lead to right heart dilatation with a resultant change in axis (16). In addition, right ventricular overload may result in decreased myocardial perfusion and myocardial ischemia (17,18). Hypoxia, stimulating the release of chemical mediators, including catecholamines, histamine, and serotonin, resulting in increased myocardial oxygen consumption and possibly coronary artery spasm, can also play a role (19–21). These ECG changes are often transient in nature and revert to normal within a week of anticoagulant therapy (22,23).

Only 24.1% of the ECGs reviewed in this study were unchanged from previous, with this finding more likely to occur in patients younger than 60 years. This value is similar to the 9% to 30% of “normal” ECGs that have been reported in previous studies (3,24–27). Sinus tachycardia was the only new dysrhythmia found at the time of PE diagnosis in our study, occurring in 27.3% of cases. Others have reported rates of sinus tachycardia of 8% to 69% with PE, though it is unknown if this dysrhythmia was pre-existing in those patients (25,27–30). It is noteworthy that while none of the patients in our study had new-onset atrial fibrillation or flutter, these dysrhythmias have been reported by other investigators to occur at rates ranging from 0% to 35% (22,29–33).

As with many previous studies, we found a significant percentage of patients with a new RBBB or RAD at the time of PE diagnosis. Contrary to some earlier studies that found left axis deviation (LAD) more frequently than RAD in these patients, none of the cases we reviewed had a new LAD (4,22,29,34). This leads us to speculate that the LAD reported in previous studies

may have simply been present before the diagnosis of PE was made.

T wave inversion has been reported by several investigators as the most common ECG abnormality with PE, occurring in 17% to 68% of cases (20,22,29,35,36). New T wave inversions were also the most common ECG change found in our study. T wave flattening has not been studied previously in conjunction with PE. This is perhaps due to the nonspecific nature of this finding. We found T wave flattening to be a common ECG change with PE, present in approximately one-third of cases.

Less than 10% of the cases we reviewed had new ST segment depression present at the time of PE diagnosis. This is significantly less than older studies, which have reported ST segment depression rates of 14% to 50% (28,30,37,38). There were no patients in this study with new ST segment elevation, an ECG finding with PE that has been reported sporadically (39–43). Finally, we found 3.7% of patients had a new S1Q3T3 pattern at the time of PE diagnosis. While this finding by itself has been found to be nonspecific for PE, its presence as a new ECG change may make it a more specific finding (30).

The majority of the new ECG changes we found were more likely to be present in patients with saddle emboli than in those patients with non–saddle emboli. This finding is consistent with saddle emboli representing a large clot burden and a risk factor for right ventricular dysfunction and sudden hemodynamic collapse (44).

Limitations

There are several limitations to this study. For various reasons, we were unable to determine and report all of the associated conditions of the patients in the study, specifically how many patients had pre-existing coronary artery disease, were in a postoperative period, or were using exogenous estrogen. We did not examine the ECGs for all of the reported abnormalities known to occur with PE. We intentionally omitted the more esoteric ECG changes described with PE, such as P pulmonale and PR segment displacement, as we sought to describe only changes that can be identified easily. Finally, there was no control group in this retrospective study. Because many patients will have changes occur in their ECG over time, a control group of non-PE patients of similar age and medical conditions would have been helpful for comparison. Previous studies examining the ECGs of asymptomatic patients in their late 60s and early 70s, age groups similar to the mean age of the patients in this study, have reported rates of ST and T wave abnormalities ranging from 3.9% to 24.1% (45,46). However, the mean duration of time over which these changes typically develop in these age groups is unknown.

CONCLUSIONS

The ECG is a quick, inexpensive, and readily available tool used in the ED for patients with cardiovascular complaints. While nonspecific, the ECG changes that occur because of PE are easily identifiable. With the relatively new technology of the electronic medical record, ECG changes associated with PE can be compared with previous ECGs for detection of dynamic changes. This study, and hopefully more similar studies, will help define those ECG changes specific to PE.

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ARTICLE SUMMARY

1. Why is this topic important?

Many patients with pulmonary embolism (PE) present to the emergency department with symptoms that will be evaluated with an electrocardiogram (ECG). No previous studies have identified ECG changes in patients at the time of pulmonary embolism diagnosis, when their ECGs are compared with their previous.

2. What does this study attempt to show?

Our aim was to determine which ECG changes found at the time of PE diagnosis are new when compared with patients' previous ECGs.

3. What are the key findings?

New T wave inversions or T wave flattening, most commonly in the inferior leads, were the most common new ECG change, occurring in approximately one-third of cases. A new sinus tachycardia was found in approximately one-quarter of cases. Approximately one-quarter of patients had no change in their ECG, with this finding more common in patients <60 years of age.

4. How is patient care impacted?

New ECG changes noted specifically when compared with patients' previous ECGs may help identify those patients with PE.