# Regional Right Ventricular Dysfunction Detected by Echocardiography in Acute Pulmonary Embolism

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**This study analyzed the regional pattern of right ventricular (RV) dysfunction on transthoracic echocardiograms in patients with and without acute pulmonary embolism. Quantitative (centerline) and qualitative (wall motion score) analyses of segmental RV free wall motion were performed on a "training" cohort of 41 patients (group 1), including 14 patients with acute pulmonary embolism, 9 patients with primary pulmonary hypertension, and 18 normal subjects. Patients with acute pulmonary embolism had a distinct regional pattern of RV dysfunction, with akinesia of the mid–free wall (centerline excursion: −0.2 ± 0.8 mm, p = 0.0001 vs normal) but normal motion at the apex (centerline excursion: 5.7 ± 0.8 mm, p=NS vs normal). In contrast, patients with primary pulmonary hypertension had abnormal wall motion in all regions (p <0.03 vs normal). This echocardiographic finding of normal wall motion at the apex and abnormal wall motion in the mid–free wall in acute pulmonary embolism was then tested in a "validation" cohort of 85 patients (group 2), consisting of hospitalized patients with RV dysfunction from any cause, including 13 patients with acute pulmonary embolism. The finding had a 77% sensitivity and a 94% specificity for the diagnosis of acute pulmonary embolism, with a positive predictive value of 71% and a negative predictive value of 96%. Thus, a distinct echocardiographic pattern of regional RV dysfunction, in which the apex is spared, occurs in acute pulmonary embolism. This finding should raise the level of clinical suspicion for the diagnosis of acute pulmonary embolism.**

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Acute pulmonary embolism is an important cause of morbidity and mortality, but it is often unsuspected and underdiagnosed.[1,2] Right ventricular (RV) dysfunction is a frequent consequence of pulmonary embolism and correlates with larger pulmonary emboli and increased risk for recurrence.[3–5] The finding of RV dysfunction is not specific, because it may be observed in a variety of cardiovascular diseases. Prior echocardiographic studies of RV function in pulmonary embolism have focused on global measures of RV dysfunction, such as qualitative hypokinesia or changes in RV dimensions.[3–5] More specific echocardiographic findings would be clinically useful to increase the clinical suspicion of acute pulmonary embolism.[6] Based on clinical observations in several patients, we hypothesized that RV dysfunction in acute pulmonary embolism may have a regional pattern on echocardiography. This study analyzes segmental RV wall motion in patients with acute pulmonary embolism and tests this pattern for its diagnostic sensitivity and specificity in a separate cohort.

## METHODS

**Patients:** A total of 126 patients were studied retrospectively: a "training" cohort of 41 patients (group 1) and a separate "validation" cohort of 85 patients (group 2). Group 1 included 14 hemodynamically stable patients studied within 24 hours of the diagnosis of acute pulmonary embolism (part of 2 multicenter randomized trials[4,7]) with RV dysfunction, 9 patients with a diagnosis of primary pulmonary hypertension and RV dysfunction, and 18 patients referred for atypical chest pain with normal echocardiograms. RV dysfunction was based on prior clinical echocardiographic assessment (excluding mild dysfunction due to variability in this interpretation). Echocardiograms had to have good quality images of the entire RV free wall in the apical 4-chamber view for ≥3 cardiac cycles.

Group 2 patients were identified by a search of all clinical echocardiographic studies at our institution over a 14-month period for RV systolic dysfunction (excluding mild dysfunction) by prior clinical assessment. Ninety-five hospitalized patients were identified and 10 were excluded because of inadequate images of the RV free wall on the apical 4-chamber view. Causes of RV dysfunction in the remaining 85 patients were obtained from review of hospital records and included acute pulmonary embolism (n = 13) (hemodynamically stable patients studied within 36 hours of high probability lung scanning and/or pulmonary angiography), ischemic cardiomyopathy (n = 15), dilated (nonischemic)

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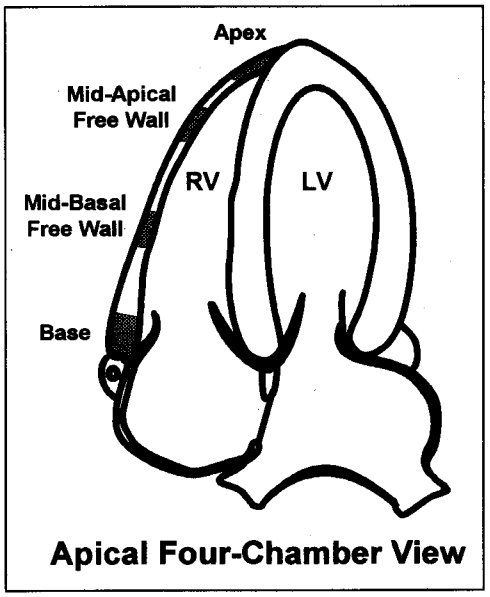


**FIGURE 1. Schematic diagram of the apical 4-chamber view from a transthoracic 2-dimensional echocardiogram. Qualitative wall motion scores were assigned at 4 locations of the right ventricular free wall *(shaded areas)*. LV = left ventricle; RV = right ventricle.**

cardiomyopathy (n = 15), chronic pulmonary hypertension (n = 11), valvular heart disease (n = 9), congenital heart disease (n = 7), RV infarction (n = 6), cardiac transplant rejection (n = 2), postoperative cardiac transplantation (n = 2), postoperative cardiac tamponade (n = 1), acute respiratory distress syndrome (n = 1), and amyloid heart disease (n = 1).

**Quantitative analysis:** A custom-designed computer program was used for quantitative RV free wall motion analysis of the 41 patients in the initial training cohort. Video images from a videocassette recorder were displayed on a computer screen (with no patient information), and a "mouse" device was used to trace the RV free wall endocardium in the apical 4-chamber view by an investigator blinded to patient diagnosis. Only the apical 4-chamber view was displayed, without Doppler information, and studies were analyzed in random sequence. End-diastolic images were identified by the onset of the R wave on the simultaneously recorded electrocardiogram. End-systolic images were identified at the terminal portion of the T wave. The RV free wall was traced from base to apex (Figure 1) at end-systole and end-diastole for 3 separate cardiac cycles. For each tracing, no prior tracings were displayed on the monitor screen. The excursion of the RV free wall from end-diastole to end-systole was measured by the centerline method.[8] A centerline was defined midway between the diastolic and systolic curves, and chord lengths were then defined perpendicular to the centerline extending from the diastolic to the systolic curve. The chord lengths were averaged for 3 cardiac cycles.

**Qualitative analysis:** A qualitative wall motion analysis of group 1 was also performed because quantitative off-line analysis is not a routine clinical tool. RV wall motion from the apical 4-chamber view was assessed independently by 2 experienced echocardiographers blinded to the patient diagnosis. Echocardiograms were evaluated in random sequence without Doppler information or other views.

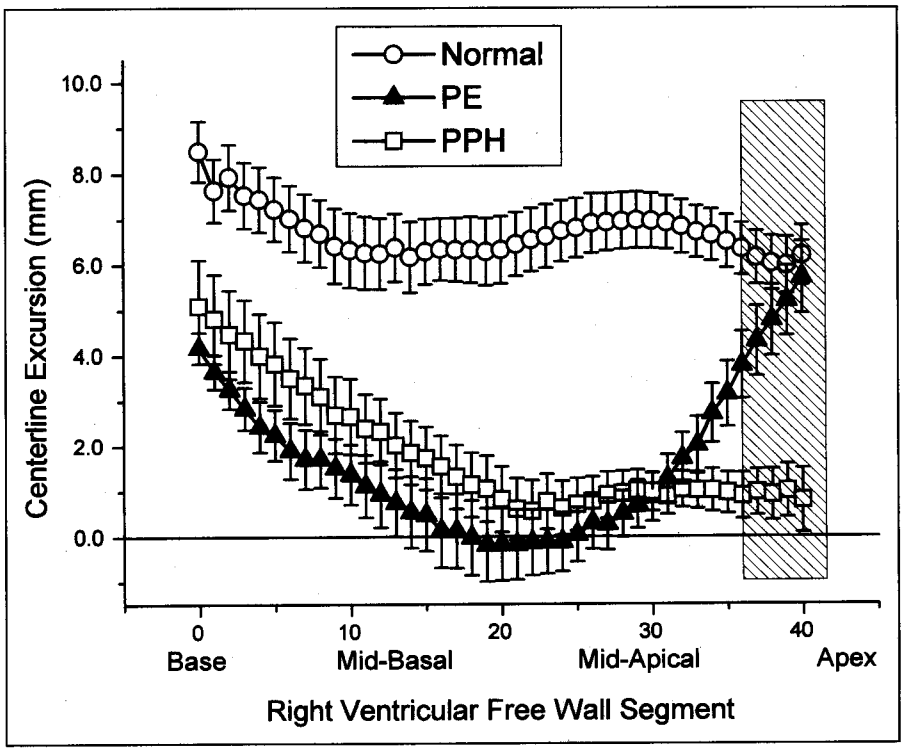


**FIGURE 2. Segmental right ventricular free wall excursion (mean ± SEM) by centerline analysis in group 1 patients as a function of right ventricular free wall segment. Centerline excursion in patients with acute pulmonary embolism (PE) was near normal (p = NS vs normal, p <0.03 vs primary pulmonary hypertension [PPH]) at the apex (*hatched area*), but abnormal at the mid-free wall and base (p <0.02 vs normal). Centerline excursion in patients with primary pulmonary hypertension was reduced compared with that in normal subjects in all segments (p <0.03).**

A qualitative wall motion score (0 = normal, 1 = hypokinesia, 2 = akinesia or dyskinesia) was assigned to 4 locations along the RV free wall in the apical 4-chamber view: apex, midapical free wall, midbasal free wall, and base (Figure 1). After independently assigning wall motion scores, discrepancies between the 2 observers were resolved by consensus. Interobserver agreement was 90% (group 1 analysis) and 92% (group 2 analysis).

**Statistics:** For quantitative analysis, centerline RV free wall excursion was compared for the 3 patient groups at 40 RV segments by analysis of variance. Post-hoc testing between pairs of patient groups at each RV segment was performed using a Student's *t* test with Bonferroni's correction. For qualitative analysis in group 1, wall motion scores were compared for the 3 patient groups at the 4 RV locations by the Kruskal-Wallis test for equality of populations. Then, direct comparisons between pairs of patient groups at each RV location were subject to the 2-sample Wilcoxon rank-sum test for equality.

## RESULTS

**Quantitative analysis:** Centerline analysis of group 1 revealed a distinct pattern of segmental RV wall motion in acute pulmonary embolism (Figure 2). Patients with pulmonary embolism had near-normal RV free wall excursion at the most apical segments (5.7 ± 0.8 mm [mean ± SEM] for pulmonary embolism vs 6.2 ± 0.7 mm for normal at segment 40, p = NS). However, wall motion was markedly decreased in the mid–free wall segments (−0.2 ± 0.8 mm for pulmonary embolism vs 6.3 ± 0.7 mm for normal at segment 20, p = 0.0001). Abnormal wall motion persisted at the base (4.2 ± 0.3 mm for pulmonary embolism vs 8.5 ± 0.7 mm for normal at segment 1, p = 0.001). In contrast, patients with primary pulmonary hypertension had decreased RV free wall excursion in all regions (p <0.03 vs normal for all segments). Segmental wall motion at the apex was significantly greater in pulmonary embolism than in primary pulmonary hypertension (p <0.03 for segments 36 to 40). Thus, quantitative analysis showed marked regional changes in RV function in acute pulmonary embolism, with a pattern of normal wall motion at the apex and absent wall motion in the mid–free wall.

**Qualitative analysis:** Qualitative wall motion analysis of group 1 also demonstrated a regional pattern of RV dysfunction in acute pulmonary embolism (Figure 3), with normal wall motion at the apex (wall motion score 0.1 ± 0.1 [mean ± SEM], p = NS vs normal) and impaired wall motion at the midapical free wall (wall motion score 1.9 ± 0.1, p = 0.0001 vs normal), midbasal free wall (wall motion score 1.4 ± 0.1, p = 0.0001 vs normal), and base (wall motion score 0.6 ± 0.1, p = 0.01 vs normal). By comparison, patients with primary pulmonary hypertension had global RV dysfunction, with abnormal wall motion at all 4 locations (p <0.0005 vs normal). Wall motion scores at the apex were significantly different between pulmonary embolism and primary pulmonary hypertension (p = 0.002). Thus, findings of qualitative analysis were similar to those of quantitative analysis, with regional RV dysfunction in acute pulmonary embolism and global RV dysfunction in primary pulmonary hypertension.

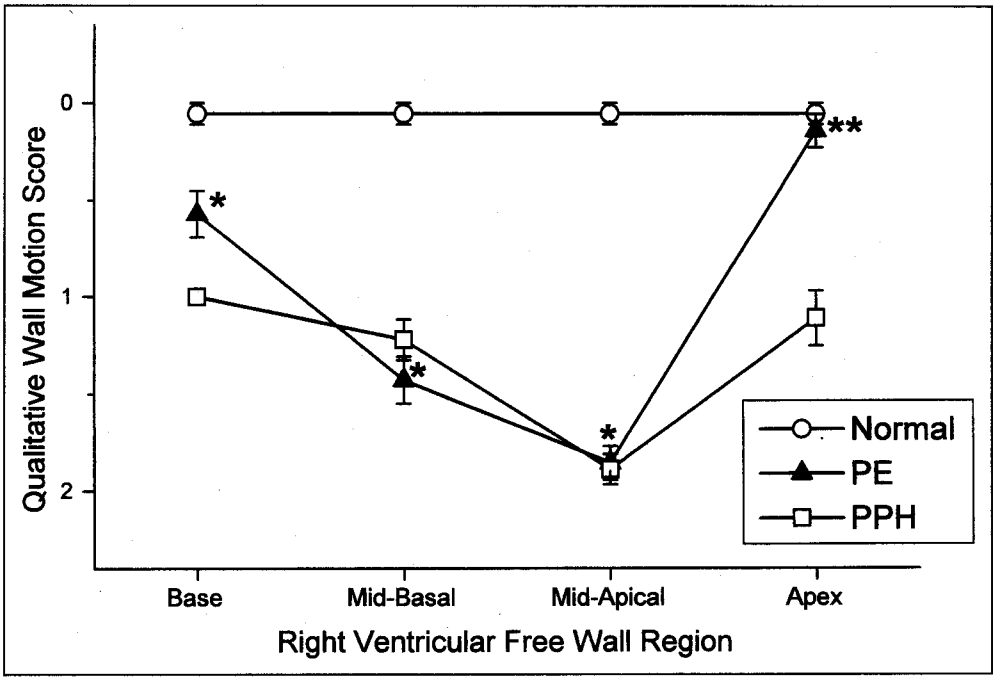


**FIGURE 3. Qualitative wall motion scores (0 = normal, 1 = hypokinesia, 2 = akinesia/dyskinesia) (mean ± SEM) in group 1 vs right ventricular free wall location. Patients with acute pulmonary embolism (PE) had normal wall motion at the apex and akinesia of the midapical free wall. Patients with primary pulmonary hypertension (PPH) had abnormal wall motion at all 4 locations. *p <0.02, PE vs normal; **p = NS, PE vs normal and p = 0.002, PE vs PPH.**

**Sensitivity and specificity:** The pattern of regional RV dysfunction in acute pulmonary embolism found in group 1 was then tested in the separate validation cohort of 85 hospitalized patients with RV dysfunction from a broad range of causes (group 2) in order to assess diagnostic sensitivity and specificity. Qualitative analysis of group 2 employed the simple criterion of normal wall motion at the RV apex with abnormal wall motion at the midapical RV free wall in the apical 4-chamber view. This echocardiographic finding was present in 10 of the 13 patients in group 2 with acute pulmonary embolism (sensitivity of 77%), and absent in 68 of the 72 patients with RV dysfunction from other causes (specificity of 94%). The positive predictive value of this pattern for the diagnosis of pulmonary embolism was 71% and the negative predictive value was 96% for an overall diagnostic accuracy of 92%.

## DISCUSSION

This study demonstrates that among patients with acute pulmonary embolism and RV dysfunction, there is a distinct, regional pattern of abnormal RV wall motion. Both quantitative and qualitative analyses of 2-dimensional echocardiograms in patients with acute pulmonary embolism revealed normal wall motion of the RV apex but akinesia of the mid–RV free wall. This echocardiographic pattern was both sensitive and specific for the diagnosis of acute pulmonary embolism in hospitalized patients with RV dysfunction.

Previous investigators have shown that abnormalities of RV size and function are common in patients with pulmonary embolism. Kasper et al[3] reported that 75% of 93 patients with proven pulmonary embolism had RV dilatation. Kasper et al[9] subsequently reported that "asynergy" of the RV free wall was present in 81% of pulmonary embolism patients with pulmonary hypertension. Goldhaber et al[4] found RV hypokinesia by a qualitative global wall motion score in 46% of 101 patients with acute pulmonary embolism, and Wolfe et al[5] showed that these patients were at high risk for recurrent pulmonary embolism. These and other previously described echocardiographic findings in acute pulmonary embolism[3–6,9,10] have not been shown to be specific for this diagnosis, because they are often present in a variety of other cardiovascular conditions, including primary and secondary pulmonary hypertension, tricuspid valve disease, dilated cardiomyopathy, RV infarction, and congenital heart disease. Therefore, our finding of a distinct, regional pattern of RV dysfunction may be clinically useful in prompting further diagnostic evaluation for acute pulmonary embolism.

**Potential mechanisms:** Three mechanisms may help explain our findings. First, tethering of the RV apex to a contracting and often hyperdynamic left ventricle in acute pulmonary embolism may account for the preserved wall motion at the apex. Second, the right ventricle may be assuming a more spherical shape to equalize regional wall stress when subjected to an abrupt increase in afterload.[11,12] A more spherical shape with systolic contraction would correspond to a bulging of the mid–RV free wall relative to the apex and base. Chronic pulmonary hypertension, in contrast, causes RV hypertrophy[6] which may limit tethering effects and shape changes, resulting in a more diffuse pattern of RV dysfunction. A third potential mechanism is localized ischemia of the RV free wall due to increased wall stress.

**Study limitations:** Two-dimensional echocardiography is inherently limited in depicting the complex 3-dimensional shape and function of the right ventricle. Three-dimensional echocardiography[13] or magnetic resonance imaging[14] could yield a more precise description of segmental RV function in pulmonary embolism. Although this regional pattern of RV dysfunction was relatively sensitive and specific for acute pulmonary embolism when tested in the larger patient cohort, patients with other causes of an acute increase in RV afterload may have similar findings. For example, one of our "false positive" cases had acute respiratory distress syndrome.

This study focused on the utility of identifying a regional RV wall motion pattern in patients in whom abnormal RV function had already been identified. This study was not designed to establish the overall utility of echocardiography in the diagnosis of acute pulmonary embolism, and these data do not provide justification for performing echocardiography routinely to establish the diagnosis of pulmonary embolism. However, since completion of this study, we have found that heightened awareness of this regional RV dysfunction pattern in our echocardiography laboratory has led to the otherwise unsuspected diagnosis of acute pulmonary embolism in several patients.


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