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Right Ventricular Enlargement on Chest Computed Tomography

Prognostic Role in Acute Pulmonary Embolism

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Background—We investigated the prognostic role of right ventricular enlargement on multidetector-row chest CT in acute pulmonary embolism (PE).

Methods and Results—We studied 63 patients with CT-confirmed PE who underwent echocardiography within the ensuing 24 hours. Adverse clinical events, defined as 30-day mortality or the need for cardiopulmonary resuscitation, mechanical ventilation, pressors, rescue thrombolysis, or surgical embolectomy, were present in 24 patients. We performed off-line CT measurements of right and left ventricular dimensions (RV_D, LV_D) with axial and 2-dimensional reconstructed 4-chamber (4-CH) views. The proportion of patients with $RV_D/LV_D>0.9$ on the axial view was similar in patients with (70.8%) and those without adverse events (71.8%; $P=0.577$). In contrast, $RV_D/LV_D>0.9$ on the 4-CH view was more common in patients with (80.3%) than without (51.3%; $P=0.015$) adverse events. The area under the curve of RV_D/LV_D from the axial and 4-CH views for predicting adverse events was 0.667 and 0.753, respectively. Sensitivity and specificity of $RV_D/LV_D>0.9$ for predicting adverse events were 37.5% and 92.3% on the axial view and 83.3% and 48.7% on the reconstructed 4-CH view, respectively. $RV_D/LV_D>0.9$ on the 4-CH view was an independent predictor for adverse events (OR, 4.02; 95% CI, 1.06 to 15.19; $P=0.041$) when adjusted for age, obesity, cancer, and recent surgery.

Conclusions—Right ventricular enlargement on the reconstructed CT 4-CH views predicts adverse clinical events in patients with acute PE. Ventricular CT measurements obtained from 4-CH views are superior to those from axial views for identifying high-risk patients. **(*Circulation*. 2004;109:2401-2404.)**

Key Words: tomography ■ embolism ■ prognosis ■ thrombosis

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Rapid risk assessment is paramount in selecting the appropriate treatment strategy in patients with acute pulmonary embolism (PE) because high-risk patients may benefit from thrombolysis or embolectomy in addition to anticoagulation.[1] When cardiac biomarkers such as troponin or B-type natriuretic peptide are elevated, additional evaluation of right ventricular (RV) size and function is warranted.[2] Echocardiography has emerged as an important prognostic tool for risk stratification,[3] with RV dysfunction serving as an independent predictor of 30-day mortality.[4,5] Disadvantages of echocardiography include limited around-the-clock availability, incremental cost, and occasional poor imaging quality of the RV.

Contrast opacification of the heart during a standard chest CT protocol to detect PE allows visualization of RV and left ventricular (LV) endocardial borders.[6] We investigated the prognostic role of cardiac measurements obtained from axial views and from 2-dimensional reconstructed 4-chamber (4-CH) views by multidetector-row chest CT.

Methods

Patients

We retrospectively identified 67 consecutive patients between April 1999 and June 2001 who had a PE-positive multidetector-row chest CT, with a time interval of <24 hours between CT and echocardiographic studies. Sixty-three patients were eligible for the present analyses, after excluding 3 patients because of incomplete visualization of the endocardial borders by CT and 1 patient who received thrombolysis between the CT and echocardiographic studies. The Institutional Review Board at Brigham and Women's Hospital approved the study.

Multidetector-Row Chest CT

Standard contrast-enhanced PE protocols[7] were performed with a 4-slice multidetector-row CT scanner (VolumeZoom, Siemens Medical Solutions) with acquisition of 1.25-mm-thick sections of the

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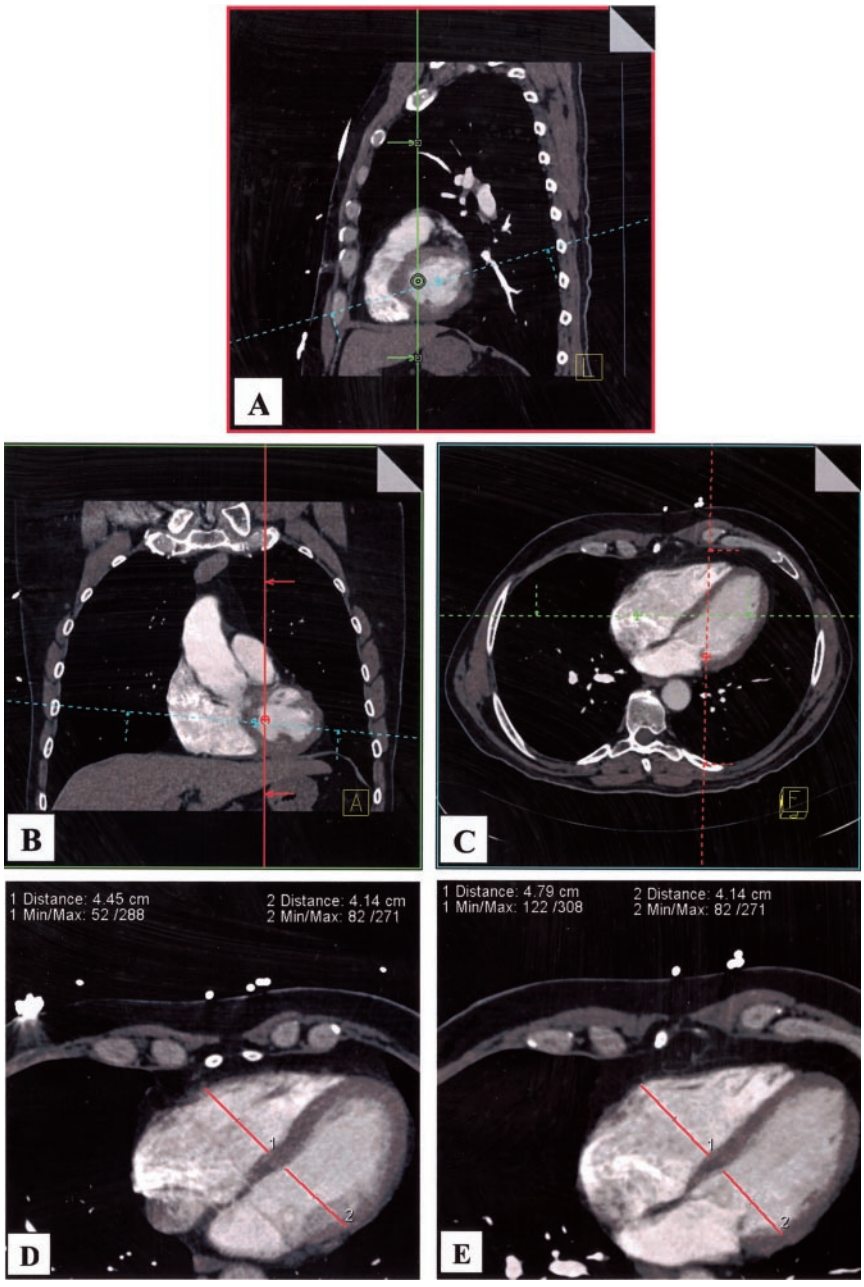


Figure 1. Measurement of RV and LV dimensions in axial and reconstructed CT 4-CH views. Multiplanar reconstruction of 4-CH view is shown (A through C). In sagittal view (A), viewport (dashed line) was rotated counterclockwise to obtain craniocaudal axis. After tilting the viewport (dashed line) slightly clockwise in coronal view (B), the 4-CH view (C) was obtained. Measurement of RV and LV dimensions in the nonreconstructed axial view is shown (D). Measurement of RV and LV dimensions in the reconstructed 4-CH view is shown (E). In both the axial and the 4-CH views, RV and LV dimensions were measured by identifying the maximal distance between the ventricular endocardium and the interventricular septum perpendicular to the long axis. In this patient, RV to LV dimension ratio was 1.07 in the axial view and 1.16 in the reconstructed 4-CH view.

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entire chest. All CT studies were available in standard Digital Imaging and Communications in Medicine (DICOM) format and were analyzed off-line with the use of a stand-alone image processing workstation (Leonardo, Siemens). This workstation allows 2-dimensional reconstruction of standardized cardiac views, with direct measurement of dimensions (Figure 1, A through C). Two independent observers, unaware of clinical, echocardiographic, or laboratory data, reconstructed 4-CH views by using 2-dimensional multiplanar reformats (MPRs) of the original axial source data.

Right and left ventricular dimensions (RV_D and LV_D) were measured by identifying the maximal distance between the ventricular endocardium and the interventricular septum, perpendicular to the long axis. Both CT readers independently performed these measurements in the axial view (Figure 1D) and the reconstructed 4-CH view (Figure 1E).

Transthoracic Echocardiography

Echocardiography was performed within 24 hours after PE diagnosis. Digitized echocardiographic studies were analyzed off-line in a core laboratory. Echocardiographic measurements were performed by an observer who was blinded to clinical, laboratory, and CT data. End-diastolic RV_D and LV_D were measured in the 4-CH view by identifying the maximal distance between the ventricular endocardium and the interventricular septum perpendicular to the long axis at the beginning of the QRS complex.

Adverse Clinical Events

Adverse clinical events were defined as death within 30 days or escalation of therapy according to the Management Strategies and Prognosis in Pulmonary Embolism Trial-3 (MAPPET-3) criteria:[8] cardiopulmonary resuscitation, mechanical ventilation, administration of catecholamines for systemic arterial hypotension (except for dopamine infused at a rate of ≤ 5 μg/kg per minute), rescue thrombolysis, or surgical embolectomy. Thrombolysis or surgical embolectomy was considered in the presence of cardiogenic shock or preserved arterial systemic pressure plus RV dysfunction by echocardiography. CT scan findings did not affect the treatment strategy.

Statistical Analysis

Spearman's rank correlation was used to determine interobserver agreement between two CT readers for RV_D and RV_D/LV_D on 4-CH views and to determine agreement for RV_D and RV_D/LV_D between CT and end-diastolic echocardiographic measurements.

We performed univariate nominal comparisons between patients with and without adverse clinical outcome by using Fisher's exact test. Continuous data were compared with Student's *t* test. We calculated area under the curve by using receiver operating characteristic (ROC) analyses of RV_D/LV_D on CT and echocardiography for predicting adverse clinical events. Using ROC analyses for predicting adverse events, we identified RV_D/LV_D of 0.9 as high-sensitivity cutoff for both the reconstructed CT 4-CH view and echocardiography. Sensitivity and specificity of $RV_D/LV_D>0.9$ on CT and echocardiography for predicting adverse events were calculated. We performed multivariate analysis to calculate the odds ratio of $RV_D/LV_D>0.9$ on the CT 4-CH view for predicting adverse events within 30 days, adjusting for age, obesity, cancer, and recent surgery.

Results

Overall, there were 63 patients: 27 (43%) men and 36 (57%) women. The mean age was 58.2±14.9 years. Twenty-four (38%) patients had adverse clinical events. Fourteen patients died within 30 days, including 4 who required mechanical ventilation, 3 who were treated with pressors, and 1 who received thrombolysis. The remaining 6 patients who died were treated with intravenous unfractionated heparin alone. Of 10 surviving patients with adverse events, 5 underwent surgical embolectomy, 4 received thrombolysis, and 1 required mechanical ventilation and pressors. Hemodynamic instability at presentation, defined as systolic arterial pressure <90 mm Hg, was present in 46% patients with and 5% without adverse events ($P<0.001$). Cancer was more common in patients with adverse events (50% versus 20%; $P=0.025$). Coronary artery disease was present in 17% of patients with and 18% without adverse events ($P=1.0$), chronic pulmonary disease in 17% and 15% ($P=1.0$), and congestive heart failure in 4% and 13% ($P=0.394$), respectively. Recent surgery was present in 17% and 21% of patients and trauma in 0% and 3% of patients with and without adverse events, respectively ($P=1.0$ for both comparisons). Obesity, defined as body mass index ≥30 kg/m^2, was present in 29% patients with and 38% without adverse events ($P=0.588$).

The correlation coefficients between the two CT readers were 0.83 for RV_D and 0.74 for RV_D/LV_D ($P<0.001$ for both correlations). The correlation coefficients between CT and echocardiography were 0.64 for RV_D and 0.72 for RV_D/LV_D ($P<0.001$ for both correlations).

The proportion of patients with $RV_D/LV_D>0.9$ on the axial view was similar in patients with (70.8%) and those without adverse events (71.8%; $P=0.577$). However, $RV_D/LV_D>0.9$ on the reconstructed 4-CH view was more common in patients with (80.3%) than without (51.3%; $P=0.015$) adverse events. After exclusion of 2 deaths associated with terminal cancer, $RV_D/LV_D>0.9$ on 4-CH view was present in 81.8% patients with and 53.7% without adverse events ($P=0.031$). $RV_D/LV_D>0.9$ on echocardiography was also more common in patients with adverse events (70.8% versus 43.6%; $P=0.042$).

The area under the curve (AUC) of RV_D/LV_D on CT axial and 4-CH views for predicting adverse events was 0.667 and 0.753 (Figure 2), respectively. The AUC of RV_D/LV_D on echocardiography was 0.691. With 0.9 used as the cutoff for RV_D/LV_D, sensitivity and specificity for predicting adverse events were 37.5% and 92.3% on the CT axial view and 83.3% and 48.7% on the reconstructed 4-CH views, respectively. Sensitivity and specificity of $RV_D/LV_D>0.9$ on echocardiography were 70.8% and 56.4%, respectively.

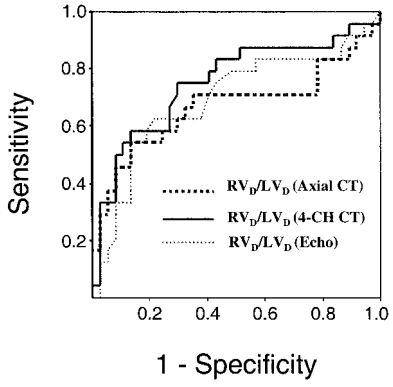


Figure 2. Receiver operating characteristic curves for predicting adverse clinical events with RV to LV dimension ratio on axial CT view, 4-CH CT view, and echocardiographic 4-CH view.

The univariate odds ratio of $RV_D/LV_D>0.9$ on the CT 4-CH view for predicting adverse events within 30 days was 4.75 (95% CI, 1.37 to 16.47; $P=0.014$). Multivariate analysis yielded the following odds ratios for predicting adverse events: OR, 4.02 (95% CI, 1.06 to 15.19; $P=0.041$) for $RV_D/LV_D>0.9$ on the CT 4-CH view; OR, 2.74 (95% CI, 0.83 to 9.07; $P=0.097$) for cancer; OR, 1.02 (95% CI, 0.98 to 1.06; $P=0.331$) for age; OR, 0.58 (95% CI, 0.17 to 1.91; $P=0.368$) for obesity; and OR, 0.64 (95% CI, 0.15 to 2.78; $P=0.553$) for recent surgery.

Discussion

Detection of RV enlargement on multidetector-row chest CT helped identify patients with PE at risk for adverse clinical events. Ventricular CT measurements obtained from 2-dimensional reconstructed 4-CH views were superior to those from axial views and comparable to echocardiography for predicting adverse events. The test performance, best described as the AUC from ROC analyses, was highest for ventricular dimension ratios on the CT 4-CH view. Four fifths of patients with adverse events had RV enlargement on the CT 4-CH view ($RV_D/LV_D>0.9$), with a true positive rate of 83.3%. In contrast, only half of the patients without adverse events had RV enlargement on the CT 4-CH view, with a true negative rate of 48.7%. Although half of the patients with adverse events had cancer, the prognostic information obtained from an increased $RV_D/LV_D>0.9$ on the CT 4-CH view persisted when adjusted for age, obesity, cancer, and recent surgery.

The prognostic role of ventricular dimension measurements on the reconstructed 4-CH views on multidetector-row CT has not previously been investigated. In a study of 25 patients with PE, CT signs of RV pressure overload were closely correlated to the presence of echocardiographic RV dysfunction.[9] Reid and Murchison[10] used nonstandardized

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(axial) CT images and found that RV dilation correlated with clinical severity. In our study, the identified RV_D/LV_D cutoff of 0.9 for predicting adverse events was similar to the RV_D/LV_D cutoff of 1.0 used in the MAPPET-2 Trial.[11]

A potential limitation of the present study is that image acquisition by CT was not ECG gated. This might have attenuated the correlation between echocardiographic and CT measurements. However, considering the substantial increase in patient radiation exposure with only limited incremental diagnostic improvement over standard protocols, ECG-gated techniques for routine PE imaging are not generally recommended.[12]

We found valuable prognostic information by detecting RV enlargement on reconstructed CT 4-CH views. These measurements were comparable to echocardiographic measurements for identifying patients at high risk for adverse events. Measurement of ventricular dimensions on the reconstructed 4-CH view appears to be a promising risk stratification tool. Future prospective studies should validate the predictive value of CT-derived ventricular measurements for identifying patients at increased risk for PE-related death.

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