Axial and Reformatted Four-Chamber Right Ventricle–to–Left Ventricle Diameter Ratios on Pulmonary CT Angiography as Predictors of Death After Acute Pulmonary Embolism

Michael T. Lu[1,2]
Shadpour Demehri[1]
Tianxi Cai[3]
Layla Parast[3]
Andetta R. Hunsaker[1]
Samuel Z. Goldhaber[4]
Frank J. Rybicki[1]

OBJECTIVE. The purpose of this article is to retrospectively compare right ventricular–to–left ventricular (RV/LV) diameter ratios measured on the standard axial view versus the reformatted four-chamber view as predictors of mortality after acute pulmonary embolism (PE).

MATERIALS AND METHODS. Six hundred seventy-four consecutive patients (mean age, 58 years; 372 women) with a diagnosis of acute PE on pulmonary CT angiography were considered. The axial and reformatted four-chamber RV/LV diameter ratios were compared as predictors of 30-day all-cause and PE-related mortality.

RESULTS. Ninety-seven patients (14%) died within 30 days; 39 deaths were PE related. There was no significant difference in the univariate hazard ratios (HRs) of axial and four-chamber RV/LV diameter ratios greater than 0.9 for both all-cause (HR, 2.13 [95% CI, 1.29–3.51] vs HR, 1.95 [95% CI, 1.22–3.14]; $p = 0.74$) and PE-related (HR, 19.6 [95% CI, 2.70–143] vs HR, 21.8 [95% CI, 2.99–158]; $p = 1.0$) mortality. Axial and four-chamber multivariate HRs accounting for potential confounders such as age and cancer were also similar for all-cause (HR, 1.79 [95% CI, 1.07–2.99] vs HR, 1.54 [95% CI, 0.95–2.49]; $p = 0.62$) and PE-related (HR, 16.3 [95% CI, 2.22–119] vs HR, 17.7 [95% CI, 2.43–130]; $p = 1.0$) mortality. There was no significant difference in sensitivity, specificity, negative predictive value, or positive predictive value. Axial and four-chamber measurements were well correlated (correlation coefficient, 0.857), and there was no significant difference in overall accuracy for predicting all-cause (area under the curve [AUC], 0.582 vs 0.577; $p = 0.72$) and PE-related (AUC, 0.743 vs 0.744; $p = 1.0$) mortality.

CONCLUSION. The axial RV/LV diameter ratio is no less accurate than the reformatted four-chamber RV/LV diameter ratio for predicting 30-day mortality after PE.

Keywords: CT, multiplanar reformation, pulmonary embolism

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[1]Applied Imaging Science Laboratory, Department of Radiology, Brigham and Women's Hospital and Harvard Medical School, 75 Francis St, Boston, MA 02115. Address correspondence to F. J. Rybicki (frybicki@partners.org).

[2]Department of Radiology and Biomedical Imaging, University of California, San Francisco, San Francisco, CA.

[3]Department of Biostatistics, Harvard School of Public Health, Boston, MA.

[4]Cardiovascular Division, Brigham and Women's Hospital and Harvard Medical School, Boston, MA.

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Acute pulmonary embolism (PE) is a common disease with a high mortality rate [1]. However, prognosis after PE varies widely, and thus rapid risk stratification is essential to optimize patient management [2]. PE increases right ventricular (RV) afterload, and prognosis depends on whether the right ventricle can compensate. As RV pressure increases, the right ventricle dilates. RV hypokinesis, overt RV failure, systemic hypotension, and death may ensue.

Echocardiography is the established imaging modality to evaluate the right ventricle after PE [3]. RV dilatation, as assessed by an elevated right–to–left ventricular (RV/LV) diameter ratio in the four-chamber view, is associated with short-term mortality and is commonly used to assess prognosis after PE [4–6]. However, echocardiography has poor sensitivity for the diagnosis of PE, and thus is usually performed to assess prognosis after the diagnosis has been made with CT.

Pulmonary CT angiography (CTA) is the first-line imaging study for the diagnosis of PE [7–9]. The cardiac chambers are included on standard pulmonary CTA, and thus there has been considerable interest in evaluating whether RV dilatation on the diagnostic pulmonary CTA is also associated with short-term mortality. The RV/LV diameter ratio, an established sign of RV dilatation on echocardiography, is among the most studied parameters on pulmonary CTA [10–13].

One of the largest early studies to investigate the RV/LV diameter ratio on pulmonary CTA used standard axial images [10]. Each RV and LV diameter was measured on the axial slices that best approximated the four-chamber view. However, the axis of the heart is not oriented along the axis of the patient, and thus no axial slice will provide the true four-chamber view.

Because isotropic voxels are generated from MDCT volumes, there is enhanced availability of multiplanar reformatted four-chamber views from pulmonary CTA data. This has prompted the hypothesis that the four-chamber RV/LV diameter ratio may be more accurate than the axial RV/LV diameter ratio for the prediction of death after PE [14], triggered by a study [15] that compared four-chamber and axial RV/LV diameter ratios as predictors of outcome in 63 patients with PE. A follow-up study by the same group found that an elevated four-chamber RV/LV diameter ratio was a significant predictor of 30-day all-cause mortality in 431 patients with PE. Although axial and four-chamber RV/LV diameter ratios were not compared, that study has remained the largest to date to support the RV/LV diameter ratio as a predictor of all-cause mortality in either the axial or four-chamber view [16].

The reformatted four-chamber view provides a potentially more accurate assessment of the cardiac chambers, but at a cost. Four-chamber images must be reformatted from the standard axial images using a workstation capable of 3D postprocessing. Even when this capability is available, generating the four-chamber view requires additional time and expertise. Prototype algorithms for automatically generating the four-chamber view have also been described [17], but also require a dedicated workstation and are not widely available.

To justify this additional cost, the four-chamber RV/LV diameter ratio should be superior to the standard axial RV/LV diameter ratio for predicting prognosis after PE. Studies by Kamel et al. [18] (88 patients), Wittenberg et al. [17] (120 patients), and Stein et al. [19] (152 patients) showed no statistically significant difference between four-chamber and axial measurements. Although clinical outcomes were not assessed, it follows that the four-chamber RV/LV diameter ratio is unlikely to be more accurate than the axial diameter ratio for predicting mortality after PE.

A direct comparison between RV/LV diameter ratio measurements made on the axial and reformatted four-chamber views with death as the primary outcome has not been previously investigated, to our knowledge. If the four-chamber RV/LV diameter ratio is a more accurate predictor of outcome, then its additional cost may be justified. If it is not, then the RV/LV diameter ratio should be measured on the simpler more widely available axial view. The purpose of this study was to retrospectively compare RV/LV diameter ratios measured on the standard axial versus the reformatted four-chamber view as predictors of mortality after acute PE.

Materials and Methods

Study Population

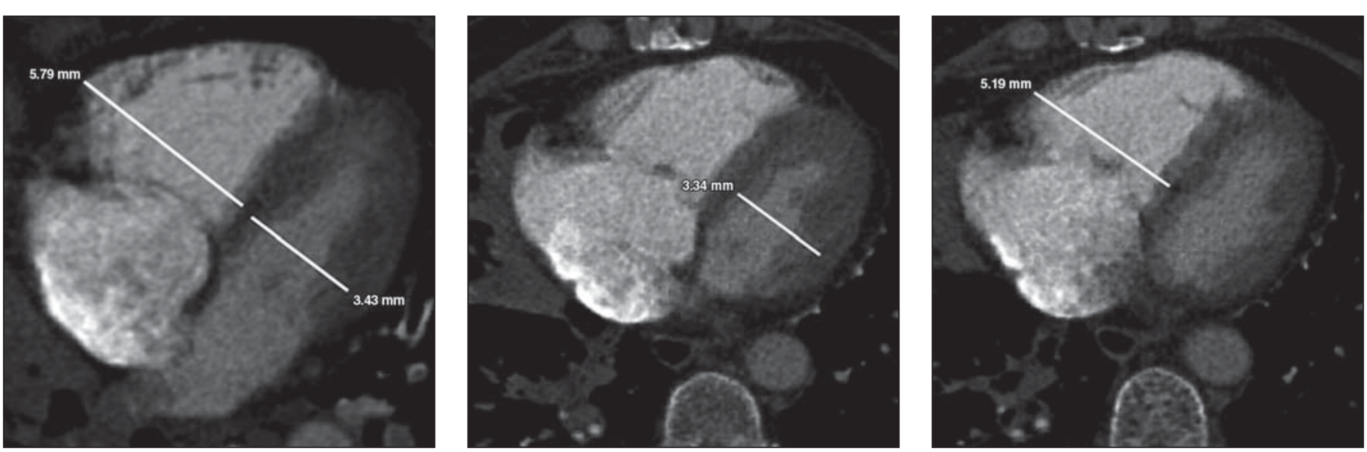
Institutional review board approval was obtained, and informed consent was not required for this retrospective study. The reports of 7162 consecutive pulmonary CTA cases (August 2003 through May 2006) were divided among three authors and were retrospectively reviewed, yielding 706 patients hospitalized with a CT diagnosis of acute PE. For patients with more than one CT diagnosis of PE within the study period, only the first diagnosis was considered. Thirty-two patients were excluded; in 26 cases, the heart was incompletely imaged, and thus cardiac chamber size measurements could not be reliably determined. Two patients with D-transposition of the great arteries were excluded. In four cases, poor contrast opacification of one or both ventricles precluded an accurate measurement of ventricular dimensions. The remaining 674 patients were included in the analyses.

Pulmonary CTA

Pulmonary CTA was performed with 4-, 16-, and 64-MDCT scanners (Sensation 4, 16, 64, all from Siemens Healthcare) with the following parameters [20]: section thickness, 1.0–1.25 × 0.75–1.0 mm; pitch, 1.0–1.5; 120 kV; and effective milliampere–second level of approximately 200. A 125-mL bolus of iodinated contrast material (370 mg I/mL) was timed with bolus tracking on the main pulmonary artery. The contrast injection rate was 3 mL/s with a power injector (Empower, E-Z-Em). Pulmonary CTA was performed without ECG gating.

Image Postprocessing and Measurements

Two observers (with 2 and 11 years of cardiothoracic CT experience) blinded to clinical presentation and outcomes performed all image postprocessing and measurements using a dedicated 3D workstation (Vitrea using Vitrea 3.9 software, both from Vital Images). The authors responsible for image analysis were not involved in the clinical care of the study patients or primary interpretation of their images. For each patient, cardiac measurements were made from both the axial and the reformatted four-chamber views. The four-chamber view was generated using standard methods [15]. In both views, ventricular diameters were measured as the maximum distance from the interventricular septum to the endocardial border perpendicular to the long axis of the heart (Fig. 1). The



A B C

Fig. 1—50-year-old man with thoracic malignancy and acute pulmonary embolism on pulmonary CT angiography.
A–C, Right ventricular (RV) and left ventricular (LV) diameter measurements (*lines*) are illustrated for both four-chamber reformation (**A**) and standard axial images (**B** and **C**). Four-chamber RV/LV ratio equaled 1.69 (5.79 / 3.43 cm, **A**). Using axial images, individual slices represent largest diameter of LV (3.34 cm, **B**) and RV (5.19 cm, **C**). Axial RV/LV ratio equaled 1.55.

four-chamber measurements were made on the single reformatted image comprising the four-chamber view. Each axial ventricular diameter was measured on the axial slice where it was largest [10].

Outcomes, Comorbidities, and Patient Mortality

Thirty-day all-cause mortality and 30-day PE-related mortality were the primary outcomes and reference standards. Additional clinical information, including demographics, comorbidities (e.g., cancer, diabetes mellitus, hypertension, congestive heart failure, chronic lung disease, coronary artery disease, peripheral arterial disease, and chronic renal insufficiency), and recent events preceding PE within 30 days (e.g., major surgery, pneumonia, sepsis, stroke, hemorrhage, and myocardial infarction) were assessed via the hospital electronic medical record by four authors. No patient was lost to follow-up before 30 days.

Data Analysis

Hazard ratios—Univariate hazard ratios (HRs) of axial and four-chamber RV/LV diameter ratios greater than 0.9 for all-cause and PE-related mortality were calculated using the Cox proportional hazards model. An RV/LV threshold of 0.9 was chosen to define a normal versus abnormal RV/LV diameter ratio [16].

The distribution of age, sex, comorbidities, and recent events between those patients who did and did not die within 30 days from any cause was compared using Fisher exact test for binary variables and the Wilcoxon rank sum test for continuous variables. A multivariate analysis was then performed accounting for the variables with p values less than 0.05 and a prevalence greater than 2%. For all-cause mortality, these variables included age, cancer, coronary artery disease, major surgery, and stroke. For PE-related mortality, these variables included age, cancer, and peripheral arterial disease.

Test characteristics—Point estimates of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for axial and four-chamber RV/LV diameter ratios greater than 0.9 were obtained and compared using nonparametric methods. Calculations of 95% CIs were based on the bootstrap method.

Correlation and receiver operating characteristic analysis—Correlation between the axial and four-chamber RV/LV diameter ratios was assessed with Pearson correlation coefficient. The receiver operating characteristic (ROC) plots of the axial and four-chamber RV/LV diameter ratios were then compared for the prediction of 30-day all-cause and PE-related mortality. The specificity, NPV, and PPV of the axial and four-chamber RV/LV diameter ratios were compared at a fixed sensitivity of 0.80. A fixed sensitivity was used because it allows comparison without choosing an arbitrary RV/LV threshold. A sensitivity of 0.80 was chosen because it is comparable to the previously published sensitivity of a four-chamber RV/LV diameter ratio for all-cause mortality [16].

The statistical analysis was performed using R (version 2.0.0 2004, The R Foundation). p values for hypothesis testing were based on the Wald test. p values less than or equal to 0.05 were considered significant.

Results

Outcomes and Measurements

Among the 674 patients, the mean (± SD) age was 58 ± 17 years, and 372 patients (55%) were women. Baseline patient characteristics

TABLE 1: Characteristics of Study Patients With Pulmonary Embolism (PE)

Characteristic	All-Cause Mortality ($n = 97$)	No All-Cause Mortality ($n = 577$)	p	PE-Related Death ($n = 39$)	No PE-Related Death (n = 635)	p
Age (y), mean ± SD	65 ± 13	57 ± 17	< 0.001	65 ± 11	58 ± 17	0.009
Female sex	56 (58)	316 (55)	0.66	18 (46)	354 (56)	0.25
Comorbidities						
Cancer	86 (89)	254 (44)	< 0.001	34 (87)	306 (48)	< 0.001
Diabetes mellitus	14 (14)	66 (11)	0.40	6 (15)	74 (12)	0.45
Hypertension	39 (40)	230 (40)	1.0	15 (38)	254 (40)	1.0
Congestive heart failure	9 (9.3)	33 (5.7)	0.18	4 (10)	38 (6.0)	0.29
Chronic lung disease	12 (12)	58 (10)	0.47	5 (13)	65 (10)	0.59
Coronary artery disease	20 (21)	72 (12)	0.037	8 (21)	84 (13)	0.23
Peripheral arterial disease	5 (5.2)	10 (1.7)	0.051	3 (7.7)	12 (1.9)	0.050
Chronic renal insufficiency	3 (3.1)	10 (1.7)	0.41	0 (0)	13 (2.0)	1.0
Events 30 days before PE						
Major surgery	20 (21)	216 (37)	0.001	8 (21)	228 (36)	0.057
Pneumonia	4 (4.1)	59 (10)	0.059	1 (2.6)	62 (9.8)	0.16
Sepsis	4 (4.1)	14 (2.4)	0.31	0 (0)	18 (2.8)	0.62
Stroke	8 (8.2)	20 (3.5)	0.048	2 (5.1)	26 (4.1)	0.67
Hemorrhage	2 (2.1)	28 (4.9)	0.29	0 (0)	30 (4.7)	0.41
ST-elevation myocardial infarction	2 (2.1)	5 (0.87)	0.27	0 (0)	7 (1.1)	1.0
Non-ST-elevation myocardial infarction	1 (1.0)	4 (0.69)	0.54	1 (2.6)	4 (0.63)	0.26
Measurements						
Axial RV/LV > 0.9	78 (80)	374 (65)	0.002	38 (97)	414 (65)	< 0.001
Four-chamber RV/LV > 0.9	75 (77)	361 (63)	0.006	38 (97)	398 (63)	< 0.001

Note—Except where noted otherwise, data are no. (%) of patients. Mortality was assessed 30 days after PE. p values were calculated using Fisher exact test for binary variables and the Wilcoxon rank sum test for continuous variables. RV/LV = right ventricular–to–left ventricular diameter ratio.

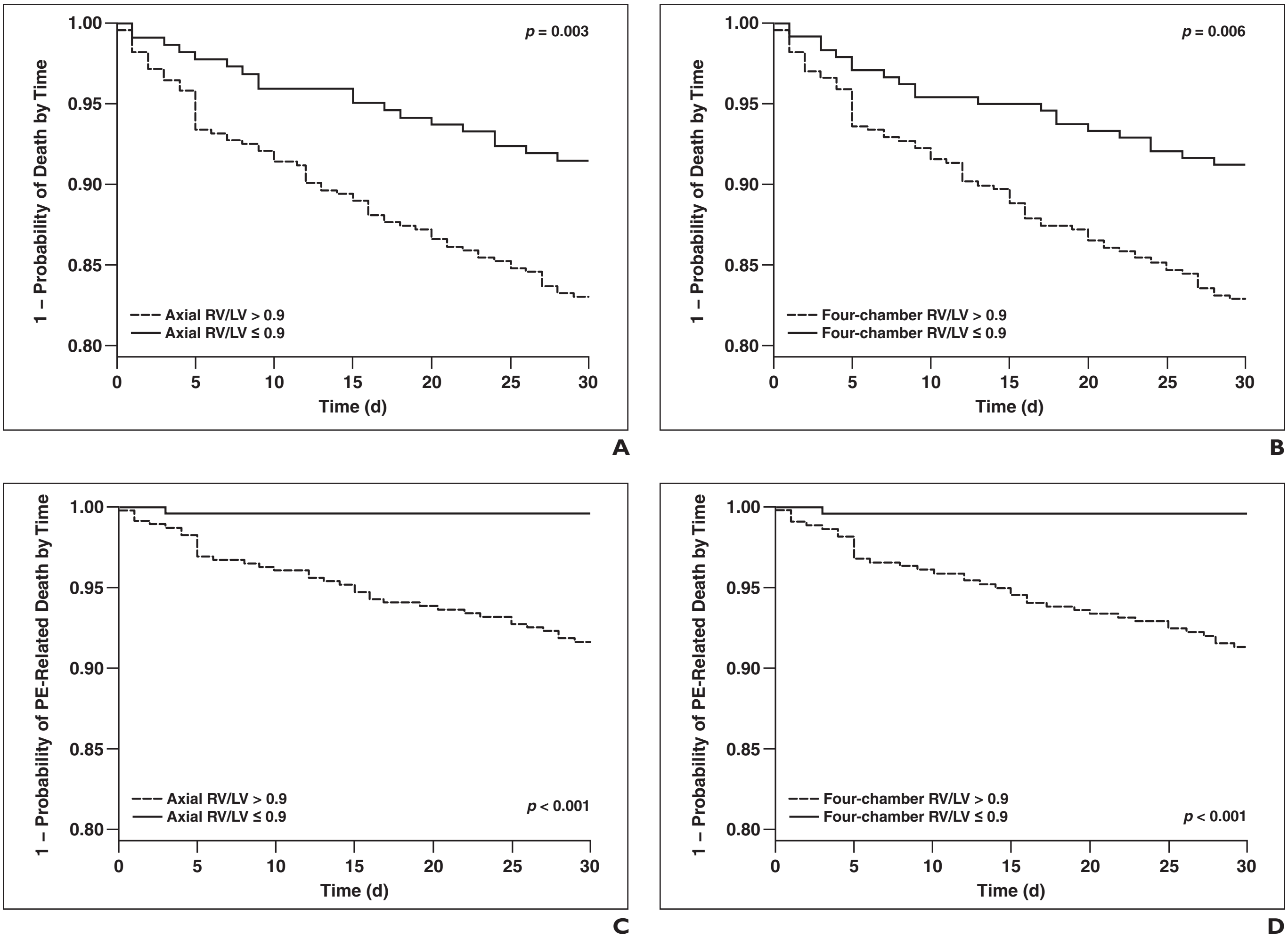


Fig. 2—Kaplan-Meier survival curves for 674 patients with pulmonary embolism (PE).
A and **B,** Survival based on axial (**A**) and four-chamber (**B**) right ventricular–to–left ventricular (RV/LV) ratio > 0.9 for all-cause mortality.
C and **D,** Survival based on axial (**C**) and four-chamber (**D**) RV/LV > 0.9 for PE-related mortality.

appear in Table 1. Ninety-seven patients (14%) died within 30 days; 39 deaths (5.8%) were PE related. Four-hundred fifty-two patients (67%) had an axial diameter ratio greater than 0.9; 432 patients (64%) had a four-chamber diameter ratio greater than 0.9. The Kaplan-Meier survival curves for all-cause and PE-related mortality are depicted in Figure 2.

HRs

For all-cause mortality, the univariate HRs were 2.13 (95% CI, 1.29–3.51; $p = 0.003$) for an axial RV/LV diameter ratio greater than 0.9 and 1.95 (95% CI, 1.22–3.14; $p = 0.006$) for a four-chamber RV/LV diameter ratio greater than 0.9. The axial and four-chamber HRs were not significantly different ($p = 0.74$).

For PE-related mortality, the HRs were 19.6 (95% CI, 2.70–143; $p = 0.002$) for an axial RV/LV diameter ratio greater than 0.9 and 21.8 (95% CI, 2.99–158; $p = 0.002$) for a four-chamber RV/LV diameter ratio greater than 0.9. The axial and four-chamber HRs were not significantly different ($p = 1.0$).

A multivariate analysis was performed accounting for all of the clinical variables (Table 2) with a significant association with 30-day mortality and prevalence greater than 2%. For all-cause mortality, these variables included age, cancer, coronary artery disease, major surgery, and stroke. For PE-related mortality, these variables included age, cancer, and peripheral arterial disease. For all-cause mortality, the multivariate HRs for axial and four-chamber RV/LV diameter ratios greater than 0.9 were 1.79 (95% CI, 1.07–2.99; $p = 0.026$) and 1.54 (95% CI, 0.95–2.49; $p = 0.078$), respectively. For PE-related mortality, the multivariate HRs for axial and four-chamber RV/LV diameter ratios greater than 0.9 were 16.3 (95% CI, 2.22–119; $p = 0.006$) and 17.7 (95% CI, 2.43–130; $p = 0.005$), respectively. There was no significant difference between axial and four-chamber multivariate HRs for both all-cause ($p = 0.62$) and PE-related ($p = 1.0$) mortality.

Sensitivity, Specificity, NPV, and PPV

The test characteristics of axial and four-chamber RV/LV diameter ratios greater than 0.9 are summarized in Table 3. There was no significant difference between axial and four-chamber sensitivity, specificity, PPV, or NPV for both all-cause and PE-related mortality.

Correlation and ROC Analysis

Diameter ratios from the axial and reformatted four-chamber views were well correlated, with a correlation coefficient of 0.857 (Fig. 3). When the ROC curves were com-

TABLE 2: Multivariate Hazard Ratios (HRs) for 30-Day Death Among Patients With Pulmonary Embolism (PE)

Outcome, View, Clinical Variable	No. of Patients	HR	95% CI	*p*
All-cause mortality				
Axial RV/LV > 0.9	452	1.79	1.07–2.99	0.026
Age	—	1.02	1.00–1.04	0.016
Cancer	340	8.66	4.61–16.3	< 0.001
Coronary artery disease	92	1.93	1.16–3.21	0.012
Major surgery	236	0.49	0.30–0.80	0.003
Stroke	28	4.10	1.96–8.60	< 0.001
Four-chamber RV/LV > 0.9	436	1.54	0.95–2.49	0.078
Age	—	1.02	1.01–1.04	0.006
Cancer	340	8.45	4.49–45.9	< 0.001
Coronary artery disease	92	1.87	1.12–3.11	0.016
Major surgery	236	0.49	0.30–0.80	0.005
Stroke	28	3.80	1.82–7.93	< 0.001
PE-related mortality				
Axial RV/LV > 0.9	452	16.3	2.22–119	0.006
Age	—	1.02	0.99–1.04	0.16
Cancer	340	7.01	2.74–17.9	< 0.001
Peripheral arterial disease	15	3.67	1.12–12.0	0.032
Four-chamber RV/LV > 0.9	436	17.7	2.43–130	0.005
Age	—	1.02	1.00–1.05	0.089
Cancer	340	6.65	2.59–17.0	< 0.001
Peripheral arterial disease	15	3.56	1.08–11.7	0.036

Note—RV/LV = right ventricular–to–left ventricular ratio. Dashes indicate not applicable.

TABLE 3: Test Characteristics

Outcome, Measure	Axial RV/LV > 0.9	Four-Chamber RV/LV > 0.9	*p*
All-cause mortality			
Sensitivity	0.80 (0.72–0.89)	0.77 (0.69–0.86)	0.37
Specificity	0.35 (0.31–0.39)	0.38 (0.34–0.42)	0.19
NPV	0.92 (0.88–0.95)	0.91 (0.87–0.94)	0.62
PPV	0.17 (0.14–0.21)	0.17 (0.14–0.21)	0.94
Pulmonary embolism–related mortality			
Sensitivity	0.97 (0.93–1.0)	0.97 (0.93–1.0)	0.99
Specificity	0.35 (0.31–0.39)	0.38 (0.34–0.41)	0.19
NPV	0.99 (0.99–1.0)	0.99 (0.99–1.0)	0.51
PPV	0.09 (0.07–0.12)	0.10 (0.97–0.12)	0.21

Note—Data are proportions (95% CI). There was no significant difference between axial and four-chamber sensitivity, specificity, negative predictive value (NPV), or positive predictive value (PPV). RV/LV = right ventricular–to–left ventricular ratio.

pared (Fig. 4), there was no significant difference in the overall accuracy of the two techniques for all-cause mortality (area under the curve [AUC], 0.582 vs 0.577; $p = 0.72$) or for PE-related mortality (AUC, 0.743 vs 0.744; $p = 1.0$). When axial and four-chamber diameter ratios were compared at a fixed sensitivity of 0.80, there was no significant difference in specificity, NPV, or PPV for both all-cause and PE-related mortality (Table 4).

Discussion

For 674 consecutive patients, there was no significant difference in the accuracy of axial and four-chamber RV/LV diameter ratios for predicting mortality after acute PE. Our data support that these measurements should be performed using axial images alone; this approach will simplify image interpretation and expedite the reporting of prognosis in patients with acute PE.

Our results are in keeping with those for smaller patient cohorts described by Kamel et al. [18] (n = 88), Wittenberg et al. [17] (n = 120), and Stein et al. [19] (n = 152), who found no statistical difference in axial and four-chamber RV/LV diameter ratio measurements. In contrast to our study, these earlier works did not assess clinical outcomes. Kamel et al. and Wittenberg et al. did not report mortality. Stein et al. reported only three deaths (possibly because the most seriously ill patients were excluded), and this precluded a comparison of four-chamber and axial diameter ratios as predictors of mortality [18].

Our results are discordant with those of Quiroz et al. [15], who studied 63 patients with PE and reported that the four-chamber RV/LV diameter ratio was significantly more accurate than the axial RV/LV diameter ratio. The discordance may be related to their small cohort and to the fact that this group used a composite outcome including death, cardiopulmonary resuscitation, mechanical ventilation, use of vasopressors, or thrombolysis rather than 30-day mortality.

We found that an axial RV/LV diameter ratio greater than 0.9 was significantly associated with both all-cause (multivariate HR, 1.79; p = 0.026) and PE-related (multivariate HR, 16.3; p = 0.006) mortality. To our knowledge, this study is the largest to support an enlarged axial RV/LV diameter ratio on pulmonary CTA as a significant predictor of death after PE. Our results are in keeping with the growing body of work that supports echocardiography [4–6] and pulmonary CTA [10, 14, 16] RV/LV diameter ratios as predictors of mortality. The pulmonary CTA RV/LV diameter has been included in the most recent European Society of Cardiology guidelines for the management of PE [3].

However, several studies did not find that an enlarged RV/LV diameter ratio was associated with mortality after PE [21, 22]. The largest of these was a study of 1193 patients by Araoz et al. [22], which found that the axial RV/LV diameter was not a significant predictor of death after PE. This discrepancy

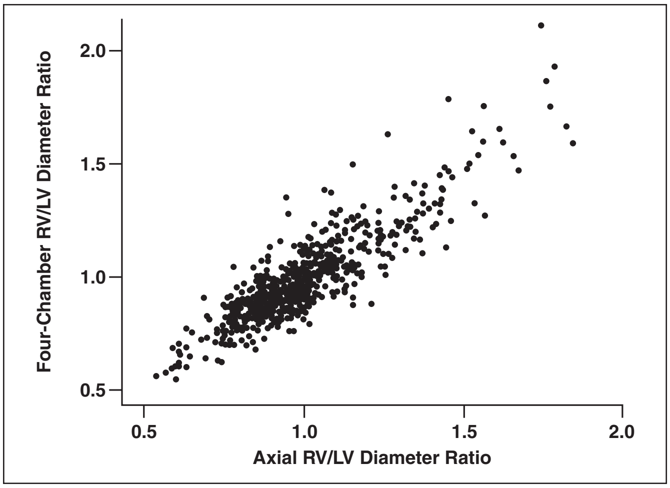


Fig. 3—Scatterplot of axial and four-chamber right ventricular–to–left ventricular (RV/LV) diameter ratios. Correlation coefficient was 0.86.

may be related to differences in CT acquisition (two thirds of the pulmonary CT angiograms in that study used electron beam rather than MDCT), outcomes (PE-related mortality was subjectively assessed by one of 12 nurse study coordinators, rather than both all-cause and PE-related mortality), study population, or measurement technique (ventricular diameter was measured on the axial slice where the atrioventricular valve was widest, rather than where the ventricle was widest) [22]. Stein et al. [21] studied 157 patients and found that an axial RV/LV diameter ratio greater than 1 was not a significant predictor of in-hospital all-cause mortality after PE. However, only four of the 157 patients suffered in-hospital mortality; this low mortality rate and choice of in-hospital rather than 30-day mortality may be the source of the discrepancy between the study by Stein et al. and the present study. Differences in the chosen threshold and study population may also have contributed.

One consequence of the binary decision between a normal versus abnormal RV size in patients with CT images diagnostic for PE is the need for a threshold. We chose 0.9 because it was the threshold in previous studies supporting the four-chamber RV/LV as a predictor of mortality after PE [15, 16]. When measurements are performed on axial images alone, an RV/LV threshold of 1 is commonly used, with the practical advantage that it is qualitatively easier to identify when the RV is larger than the LV [10]. Had we used a cutoff of 1 (instead of 0.9) and performed the same univariate and multivariate HR analyses, there would have been no significant difference between axial and four-chamber HRs. Specifically, by using a cutoff of 1 and assessing all-cause mortality, there was no significant difference (p = 0.69) between the univariate axial (HR, 1.73; 95% CI, 1.16–2.58; p = 0.010) and four-chamber (HR, 1.85; 95% CI, 1.24–2.76; p = 0.004) HRs. There was no significant difference (p = 0.78) between the multivariate HRs for an axial and four-chamber RV/LV greater than 1 (HR, 1.62; 95% CI, 1.07–2.45; p = 0.023 and HR, 1.54; 95% CI, 1.02–2.33; p = 0.039, respectively). Likewise, for PE-related mortality, there was no significant difference (p = 0.88) between univariate axial (HR, 5.80; 95% CI 2.66–12.6; p < 0.001) and four-chamber (HR, 5.34; 95% CI 2.53–11.3; p < 0.001) HRs. There was no significant difference (p = 1.0) between the multivariate HRs for an axial and four-chamber RV/LV greater than 1 (HR, 4.91; 95% CI, 2.21–10.9; p < 0.001 and HR, 4.31; 95% CI: 2.01–9.23; p < 0.001, respectively).

We also considered the scenario where the "best" threshold for the axial RV/LV is 1, whereas that for the four chamber was 0.9. Specifically, we performed additional comparisons that did not involve setting an arbitrary RV/LV threshold. This included finding that axial and four-chamber RV/LV measurements were well correlated (correlation coefficient, 0.86; Fig. 3). Likewise, an ROC analysis found no significant difference at a fixed sensitivity (Table 4) or in overall accuracy (Fig. 4).

Limitations of our study should be considered. First, it was retrospective. Second,

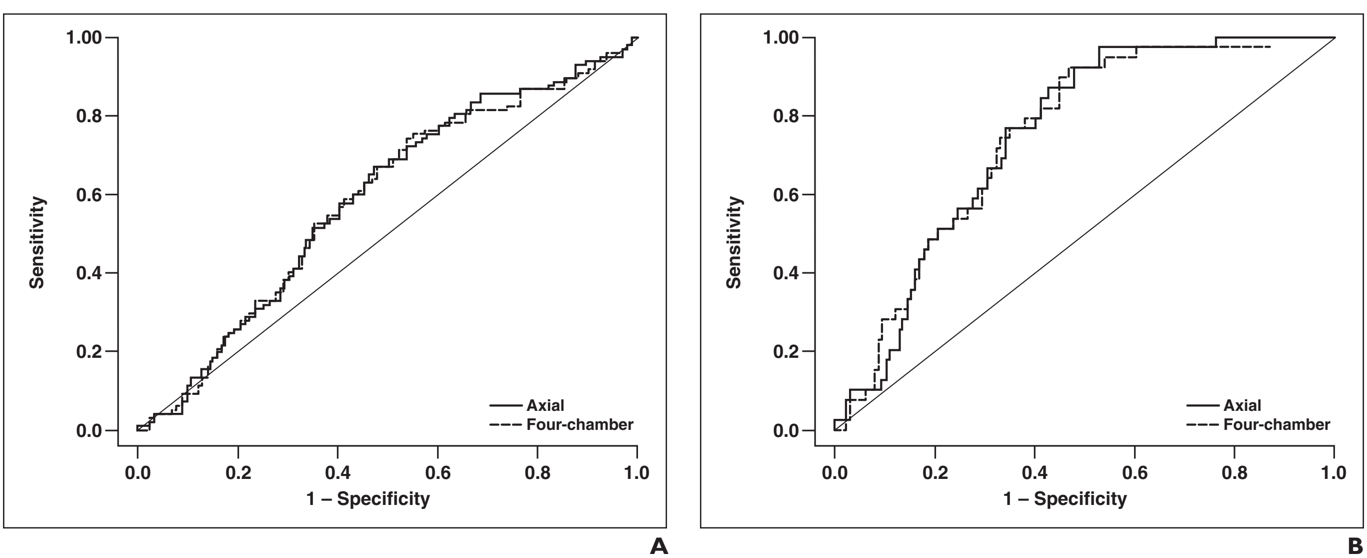


Fig. 4—Receiver operating characteristic (ROC) curves of axial and four-chamber right ventricular–to–left ventricular diameter ratios.
A, ROC curve for 30-day all-cause mortality. There was no significant difference in area under curve (AUC) of axial and four-chamber diameter ratios (0.582 vs 0.577; p = 0.75).
B, ROC curve for pulmonary embolism–related mortality. There was no significant difference in AUC of axial and four-chamber diameter ratios (0.743 vs 0.744; p = 1.0).

TABLE 4: Comparison of Diameter Ratios at Fixed Sensitivity of 0.80

Outcome, Measure	Axial RV/LV	Four-Chamber RV/LV	*p*
All-cause mortality			
Specificity	0.36 (0.24–0.48)	0.33 (0.16–0.50)	0.70
NPV	0.92 (0.87–0.96)	0.91 (0.85–0.97)	0.79
PPV	0.17 (0.13–0.21)	0.17 (0.12–0.22)	0.69
Pulmonary embolism–related mortality			
Specificity	0.59 (0.48–0.70)	0.59 (0.49–0.69)	0.97
NPV	0.98 (0.97–0.99)	0.98 (0.97–0.99)	0.98
PPV	0.12 (0.072–0.16)	0.12 (0.073–0.16)	0.98

Note—Data are proportions (95% CI). There was no significant difference between axial and four-chamber right ventricular–to–left ventricular ratios (RV/LV) in terms of specificity, negative predictive value (NPV), and positive predictive value (PPV) for both mortality parameters.

pulmonary CTA was performed without ECG gating. Because ECG gating does not improve diagnostic accuracy for the detection of PE and involves significantly higher radiation dose, nongated pulmonary CTA is the standard of clinical practice [23]. ECG-gated pulmonary CTA would largely eliminate motion artifact, though more work is necessary to determine whether this would translate into improved prognostic accuracy for mortality [24–27]. In any case, nongated pulmonary CTA remains the standard for the diagnosis of PE. Third, we did not assess interobserver variability, though a number of published reports have described a high degree of interobserver agreement with both axial and four-chamber RV/LV diameter ratios [12, 14, 15, 17]. Most recently, Kang et al. [28] assessed several CT signs of RV dysfunction after PE in 50 patients and found that the RV/LV diameter ratio was among the most reproducible, with a Spearman correlation coefficient of 0.88 for the axial and 0.85 for the four-chamber RV/LV diameter ratios.

Our study's mortality rate was similar to reported mortality rates after acute PE. The all-cause 30-day mortality rate (14%) was concordant with the rate (13%) in a similarly designed study of 431 patients by Schoepf et al. [16]. Likewise our PE-related mortality rate (5.8%) was similar to that found in a registry of 6512 patients with acute PE (4%) [29]. In contrast, another study of 1880 patients found a PE-related mortality rate of only 1.1% [30]. The relatively low mortality rate in this study may be explained by its inclusion criterion; only outpatients were considered, whereas the 6512 patient registry and our study included all patients with PE.

An axial RV/LV diameter ratio greater than 0.9 had high sensitivity and NPV for short-term PE-related mortality. However, specificity and PPV were low, which underscores the need to consider the RV/LV diameter ratio in the context of other determinants of prognosis, including clinical presentation, cardiac biomarkers [31], echocardiography [32], comparison with prior imaging [33], and other pulmonary CTA findings [11]. Algorithms that integrate these parameters may allow a more accurate assessment of prognosis [34, 35].

In conclusion, RV/LV diameter ratios measured on the standard axial view are no less accurate than diameter ratios measured on the reformatted four-chamber view for predicting 30-day mortality after acute PE. We recommend that the RV/LV diameter ratio be computed from the simpler more widely available axial pulmonary CTA images.

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