Radiology

Severe Pulmonary Embolism: Pulmonary Artery Clot Load Scores and Cardiovascular Parameters as Predictors of Mortality[1]

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Purpose: To retrospectively evaluate pulmonary artery (PA) clot load scores and computed tomographic (CT) cardiovascular parameters as predictors of mortality in patients with severe pulmonary embolism (PE).

Materials and Methods: Institutional review board approval was obtained with waiver of informed consent. A total of 82 consecutive patients (42 women, 40 men; mean age ± standard deviation, 61 years ± 15) were admitted to the intensive care unit for PE-related conditions and were evaluated by using CT pulmonary angiography. Two independent readers who were blinded to clinical outcome quantified PA clot load by using four scoring systems. Cardiovascular measurements included right ventricular (RV) and left ventricular (LV) short-axis measurements; RV short axis to LV short axis (RV/LV) ratios; main PA, ascending aorta, azygos vein, and superior vena cava diameters; and main PA diameter to aorta diameter ratios. Reflux of contrast medium into the inferior vena cava, leftward bowing of the interventricular septum, pleural or pericardial effusion, pulmonary consolidation, infarct, platelike atelectasis, and mosaic ground-glass opacity were also recorded. Results were correlated with patient outcome during hospital stay by using the Wilcoxon rank sum and χ^2 tests.

Results: Twelve patients died within 1–14 days. RV and LV short axis; RV/LV ratio; azygos vein, superior vena cava, and aorta diameters; and contrast medium reflux into the inferior vena cava were significantly different between survivors and nonsurvivors ($P < .05$). No significant relationship was found between PA clot load and mortality rate. RV/LV ratio and azygos vein diameter allowed correct prediction of survival in 89% of patients ($P < .001$).

Conclusion: RV/LV ratio and azygos vein diameter are predictors of mortality in patients with severe PE.

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If untreated, pulmonary embolism (PE) is fatal in up to 30% of patients, but the death rate can be reduced to 2%–10% if PE is diagnosed and treated promptly (1–3). When PE is fatal, patients usually die after right ventricular (RV) failure and circulatory collapse, which frequently occurs within the first hours after admission (1,2,4). This suggests that RV dysfunction should be diagnosed rapidly to identify patients, even those with normal blood pressure, who could benefit from fibrinolytic therapy (3–10). Nevertheless, because the current forms of fibrinolytic therapy increase costs and can produce dramatic side effects, the diagnostic method for detecting RV dysfunction should be highly specific (3,11).

Computed tomographic (CT) pulmonary angiography can be used to identify clots within distal pulmonary arteries (PAs) with a specificity of 95% and can demonstrate alternative diagnoses and underlying lung diseases. Consequently, CT pulmonary angiography has become the first imaging examination performed in patients suspected of having PE (12–15). Although echocardiography is currently used to detect RV dysfunction, CT pulmonary angiography could replace this technique because it can be used to diagnose PE and assess RV function simultaneously.

Some investigators (16–22) have evaluated the accuracy of CT scoring systems for PA clot load, and others have reported CT findings for RV dysfunction (19,20,22–27). Few, however, have investigated the relationships between clot load score, RV dysfunction, and patient outcome (20–22,26,27). The aim of our study was to retrospectively evaluate PA clot load scores and CT cardiovascular parameters as predictors of mortality in patients with severe PE.

Materials and Methods

Patients and Outcome

The institutional review board of the University Hospital of Liege approved this study with waiver of informed consent. From January 1995 to December 2001, 90 consecutive patients were admitted to the intensive care unit for severe acute PE-related conditions. In 84 patients, PE was diagnosed by using CT pulmonary angiography, which has been the primary imaging technique in our hospital since 1995. In the remaining six patients, PE was diagnosed by means of ventilation-perfusion lung scanning (two patients), digital subtraction pulmonary angiography (two patients), or echocardiography, which showed major dilation of the right cardiac chambers and clinical findings suggestive of PE (two patients). Of the 84 CT pulmonary angiograms, two were not available for review. Therefore, our final study group included 82 patients of which 42 (51%) were women and 40 (49%) were men (63 outpatients [77%] and 19 inpatients [23%] before admission to the intensive care unit). Mean patient age ± standard deviation was 61 years ± 15 (range, 22–84 years). On admission to the intensive care unit, clinical presentation, which was assessed according to the classification system proposed by Stein et al (28), included pulmonary infarction or hemorrhage syndrome in 21 patients (26%), isolated dyspnea in 29 patients (35%), and circulatory failure in 32 patients (39%).

Once PE was diagnosed, treatment was initiated according to the established guidelines (29) and included intravenous heparin in 61 patients (74%) and systemic thrombolysis in 21 patients (26%). In addition, the Trendelenburg surgical procedure was performed in six patients (7%), and an inferior vena cava filter was inserted in five patients (6%). No patient underwent mechanical thrombolysis. Fifteen patients (18%) required mechanical ventilation.

Patient outcome during hospital stay was retrospectively analyzed on the basis of medical charts by one author (A.G.). As a first step, the outcome was evaluated in terms of overall in-hospital mortality. As a second step, the outcome was restricted to early mortality (ie, within 48 hours after the onset of symptoms).

CT Pulmonary Angiography

CT pulmonary angiographic acquisition.—CT pulmonary angiograms were obtained with a commercially available CT scanner (PQ 5000; Philips, Eindhoven, the Netherlands). Before scanning, patients were trained to hold their breath in full inspiration for 10–40 seconds while in the supine position. For patients who underwent mechanical ventilation, ventilation was manually suspended in deep inspiration. Scanning was performed during shallow breathing in patients who were short of breath. A caudocranial helical acquisition was obtained with a collimation of 5 mm (11 patients), 3 mm (14 patients), or 2 mm (57 patients) and a pitch of 1.5–2.0, which was varied according to breath-hold capabilities.

Acquisition time was 1 second per rotation, tube current was 125 mA, and peak voltage was 130 kVp. Images were reconstructed by using a soft-tissue kernel, with an increment of 1–3 mm and a matrix of 512 × 512. The z-axis coverage started 2 cm below the diaphragm and extended up to the aorta, thereby enabling visualization of the heart and PAs, which included the subsegmental arteries. Twenty seconds before acquisition began, a 140-mL peripheral intravenous injection of 30% iodinated contrast medium (Xenetix; Guerbet, Aulnay-sous-Bois, France) was administered at a flow rate of 3 mL/sec. The results of CT pulmonary angiography

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Abbreviations:
A_z = area under the receiver operating characteristic curve
LV = left ventricular
PA = pulmonary artery
PE = pulmonary embolism
RV = right ventricular

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were transmitted immediately to the physician for patient care but were not included in the present study. Images were stored on CD-ROMs.

CT pulmonary angiographic reading.—Images were reviewed on a workstation (Voxel Q; Philips) by two independent readers. Reader 1 (B.G.) was a chest radiologist with 12 years of experience reading thoracic CT scans, and reader 2 (V.W.) was a 5th-year radiology resident with 3 years of experience reading CT pulmonary angiograms. The diagnosis of PE was based on criteria recommended by Ghaye et al (12). Readers scored PA clot load, evaluated cardiovascular measurements, and assessed qualitative findings as detailed below. Readers were blinded to clinical data (with the exception of patient admission to the intensive care unit), to the results of other imaging techniques, and to patient outcome.

The presence and location of arterial clots and the degree of arterial obstruction were scored by using the systems proposed by Miller et al (30), Walsh et al (31), Qanadli et al (17), and Mastora et al (18). For comparison, each score was expressed as the percentage of the PA that was obstructed. Percentages were calculated by dividing the value obtained with each system by the maximum possible value for that particular system and then multiplying by 100. Details on each scoring system are presented in the Appendix.

Cardiac measurements for the RV and left ventricular (LV) short axes were obtained. Axes were measured in diastole on a single transverse scan perpendicular to the long axis of the heart and were defined as the largest distance between the inner aspect of the interventricular septum and the free wall of the ventricle (20,22,26,27). The RV/LV ratio was then calculated from these measurements.

Vascular measurements for the diameters of the main PA lumen, ascending aorta, azygos vein, and superior vena cava were also obtained. The ratio of the main PA diameter to the aorta diameter was calculated from these figures. Vascular measurements were obtained on adjusted multiplanar reformatted images in the plane that was perpendicular to the long axis of the vessel being considered and were acquired by using electronic calipers. The diameter of the main PA lumen was measured proximal to its branching division. Measurements were taken of the aorta at the level of the middle third of its ascending portion, of the portion of the azygos vein facing the right tracheal wall, and of the superior vena cava at the level of the azygos arch. The following observations were also recorded: reflux of contrast medium into the inferior vena cava, convex leftward bowing of the interventricular septum, pleural and/or pericardial effusion, and pulmonary findings, including pulmonary consolidation, infarct, platelike atelectasis, and mosaic ground-glass opacity.

Statistical Analysis

Statistical analyses were performed with a personal computer by using a commercially available software program (Statistica, version 6.1; StatSoft, Tulsa, Okla). Following the Kolmogorov-Smirnov test, data with a normal distribution were expressed as means ± standard deviations, and data with a skewed distribution were expressed as medians, with first and third quartiles.

Interobserver variations were evaluated by means of the Spearman rank correlation coefficient (r_s) for continuous variables and by using Cohen κ statistics for qualitative variables. If the interobserver agreement was either good (κ = 0.61–0.80) or excellent (κ = 0.81–1.00), further calculations for qualitative variables were based on the results of the more experienced reader (reader 1) (32).

To investigate the relationship between CT findings and patient outcome, we used the Wilcoxon rank sum test to evaluate differences in the distributions of CT measurements between survivors and nonsurvivors; the χ^2 test was used to evaluate differences in qualitative findings. Correlations between continuous variables were determined by using the Pearson coefficient (r).

The relationship between the sensitivity and specificity of CT measurements was investigated by means of receiver operating characteristic curves. The areas under the receiver operating characteristic curves (A_z values) were calculated and compared. The threshold value for which sensitivity equaled specificity was calculated for measurements with an A_z value that was significantly different from 0.5 (33).

All CT parameters were submitted to univariate logistic regression analysis in order to identify cutoff values associated with a probability of death of 5%, 10%, 20%, 30%, 40%, and 50%. Finally, discriminating parameters were subjected to multivariate regression analysis in order to detect parameters that most reflected the probability of death. From these results, odds ratios were calculated. For all tests, a P value of .05 was considered to indicate a statistically significant difference.

Results

Parameters Evaluated and Patient Outcome

All CT parameters except reflux into the inferior vena cava were assessable in all patients. Reflux was not assessable in 32 patients (39%) because the inferior vena cava was not included in the CT pulmonary angiographic range. Hospital stay ranged from 1 to 68 days (mean, 15 days ± 10). Twelve patients (15%) eventually died, with a median survival of 2 days (first and third quartiles, 1 and 8 days).

CT Quantitative Measurements

PA clot load score.—The Spearman correlation coefficient for comparisons between PA clot load scores of each scoring system ranged from 0.770 to 0.967 ($P <$ .001), which indicated highly significant correlations. No significant difference was found between survivors and nonsurvivors (P = .092–.215) (Table 1).

CT cardiovascular measurements.—Comparison of cardiovascular measurements between survivors and nonsurvivors (Table 1) showed significant differences in aorta diameter (P = .040), RV short axis (P = .022), RV/LV ratio (P = .011), superior vena cava diameter ($P <$ .001), and azygos vein diameter ($P <$ .001). When only early mortality was considered, the RV/LV ratio ($P = .006$), RV short axis ($P = .018$), LV short axis ($P = .035$), superior vena cava diameter ($P = .045$) and azygos vein diameter ($P = .004$) were also significantly different between survivors and nonsurvivors.

For the correlation between PA clot load scores and cardiovascular measurements (Table 2), Pearson correlation coefficients were highest between LV short axis, RV short axis, and RV/LV ratio and PA clot load and lower (but still significant) between azygos vein diameter and PA clot load, as scored according to Qanadli et al (17) and Mastora et al (18).

For CT measurements that were tested for their ability to predict survival, A_z was significantly higher than 0.5 for aorta diameter ($P = .039$), superior vena cava diameter ($P = .004$), azygos vein diameter ($P = .003$), and RV/LV ratio ($P = .009$) (Table 3, Figure). These A_z values, however, were not significantly different ($P = .389$–$.865$). For CT measurements for which A_z was significantly higher than 0.5, Table 3 lists the threshold values for which sensitivity equaled specificity.

For all quantitative CT measurements for which significant differences between survivors and nonsurvivors were observed, we calculated the cutoff values associated with probability of death (Table 4). For all measurements, a higher value indicated a higher probability of death.

CT Qualitative Findings

Reflux into the inferior vena cava was the only finding that differed significantly between survivors and nonsurvivors ($P = .026$) (Table 5). When only early mortality was considered, reflux ($P = .016$) and pericardial effusion ($P = .030$) were significantly different between survivors and nonsurvivors.

Among all CT pulmonary angiography measurements, RV/LV ratio and azygos vein diameter were the best discriminators of mortality and enabled correct prediction of survival in 89% of patients ($P < .001$). The odds ratio for predicting death was 8.6 (95% confidence interval: 1.5, 48.3; $P < .001$) for RV/LV ratio and 1.5 (95% confidence interval: 1.05, 2.03; $P = .025$) for azygos vein diameter.

Interreader Agreement

For quantitative measurements, the Spearman correlation coefficient ranged from 0.726 to 0.973 ($P < .001$), indicating high agreement between readers. For qualitative parameters, the κ coefficient ranged from 0.755 to more than 0.99, indicating good to excellent agreement.

Table 1

Comparisons of Quantitative Measurements between Survivors and Nonsurvivors

Measurement	Survivors ($n = 70$)	Nonsurvivors ($n = 12$)	P Value
PA obstruction (%)*			
Miller et al (30)	97 (58, 100)	100 (91, 100)	.158
Walsh et al (31)	64 (41, 67)	66.6 (61, 67)	.215
Qanadli et al (17)	51 (31, 58)	56.9 (51, 58)	.092
Mastora et al (18)	40 (20, 55)	49 (42, 60)	.102
PA diameter (mm)	30.4 ± 4.2	32.2 ± 3.8	.195
Aorta diameter (mm)	32.7 ± 4.8	36.1 ± 4.5	.040
PA/aorta ratio	0.9 ± 0.1	0.9 ± 0.1	.298
RV short axis (mm)	47.2 ± 10.0	54.5 ± 7.8	.022
LV short axis (mm)	38.3 ± 6.6	33.5 ± 8.1	.102
RV/LV ratio	1.3 ± 0.4	1.8 ± 0.6	.011
Superior vena cava diameter (mm)	18.9 ± 4.1	23.2 ± 4.6	<.001
Azygos vein diameter (mm)	9.3 ± 2.1	13.1 ± 5.3	<.001

Note.—Unless otherwise indicated, data are the mean ± standard deviation.

* Data are the median, with first and third quartiles in parentheses.

Table 2

Correlation between PA Clot Load and Cardiovascular Measurements

	Miller et al (30)		Walsh et al (31)		Qanadli et al (17)		Mastora et al (18)	
Measurement	Correlation Coefficient	P Value	Correlation Coefficient	P Value	Correlation Coefficient	P Value	Correlation Coefficient	P Value
PA diameter	0.077	.505	0.012	.920	0.068	.553	−0.028	.807
Aorta diameter	0.183	.112	0.156	.174	0.173	.131	0.144	.214
PA/aorta ratio	−0.113	.330	−0.149	.196	−0.114	.322	−0.193	.094
RV short axis	0.339	.003	0.300	.008	0.420	<.001	0.360	.001
LV short axis	−0.386	.001	−0.401	<.001	−0.411	<.001	−0.509	<.001
RV/LV ratio	0.416	<.001	0.393	<.001	0.494	<.001	0.515	<.001
Superior vena cava diameter	0.114	.324	0.049	.686	0.154	.181	0.147	.206
Azygos vein diameter	0.187	.105	0.159	.176	0.232	.043	0.242	.037

Note.—Correlation coefficients were calculated by using the Pearson correlation coefficient.

Discussion

The findings of this study show that, in patients admitted for severe PE-related conditions, RV/LV ratio and azygos vein diameter, as measured at CT pulmonary angiography, are the best predictors of survival, enabling correct prediction of survival in 89% of patients. Despite their differences, the various systems for scoring PA clot load provided highly correlated scores, but no system appropriately discriminated between survivors and nonsurvivors. In two previous CT pulmonary angiographic studies, Wu et al (21) and van der Meer et al (22) reported that the score obtained with the system proposed by Qanadli et al (17) is an adequate predictor of survival. The median scores obtained by Wu et al and van der Meer et al (10% and 32%, respectively) were lower than those obtained in our study (52%), which reflects differences in the populations studied. On the other hand, we found a correlation between PA clot load (as estimated with all four systems) and RV short axis, LV short axis, and RV/LV ratio and confirmed the relationship between RV/LV ratio (as measured at echocardiography or CT pulmonary angiography) and the score obtained with the system proposed by Qanadli et al (17,22).

In accordance with the report by Collomb et al (19), findings from our study show that, for patients admitted to the intensive care unit, PA clot load indicates the extent of the clot but does not predict RV failure or death. In PE, the pulmonary vascular resistance is indeed increased not only by mechanical arterial obstruction but also by vasoactive agents, vasoconstriction reflex, and/or systemic arterial hypoxemia (4,34). Furthermore, in the systems proposed by Miller et al (30), Walsh et al (31), and Mastora et al (18), the segmental PAs are the most distal arteries that can be assessed; the system proposed Qanadli et al (17) includes subsegmental PAs. In other words, none of these systems address clots located distal to subsegmental arteries. In addition, none consider sequelae of previous episodes or associated disorders, such as chronic obstructive pulmonary disease, which can contribute to pulmonary hypertension (4).

In previous studies based on angiography or scintigraphy results (35–38), researchers found that RV failure resulting from both arterial obstruction and underlying cardiopulmonary conditions is a better determinant of mortality than PA clot load alone. In acute PE with severe arterial pulmonary hypertension, RV dilation results in an increased RV/LV ratio. In our study, this ratio was significantly different between nonsurvivors (mean, 1.8) and survivors (mean, 1.3). In terms of probability, an RV/LV ratio of 1 or less is associated with a 5% likelihood of death, which is close to the mortality rate in all patients with treated PE (2,37,39). Results from

Table 3

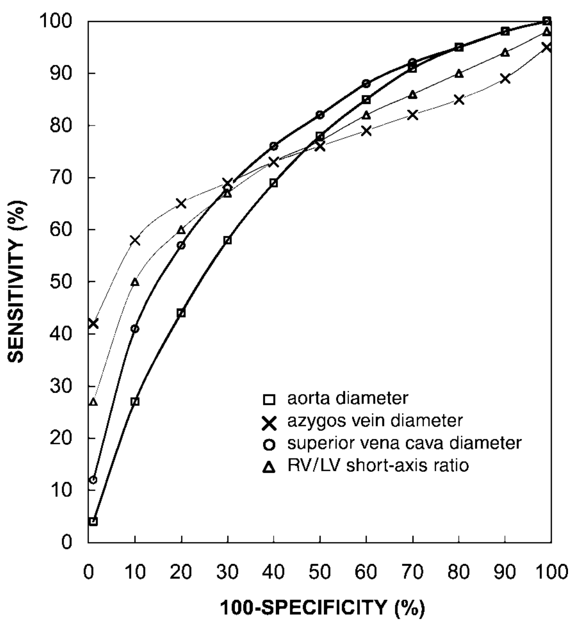
Performance of CT Measurements for Discrimination of Survivors from Nonsurvivors, as Indicated by Receiver Operating Characteristic Curves

Measurement	A_z Value: Value*	A_z Value: *P* Value	Threshold Value[†]	Sensitivity Equals Specificity (%)[†]
PA clot load score				
Miller et al (30)	0.624 (0.436, 0.813)	.193	NA	NA
Walsh et al (31)	0.617 (0.428, 0.806)	.218	NA	NA
Qanadli et al (17)	0.659 (0.473, 0.846)	.094	NA	NA
Mastora et al (18)	0.655 (0.468, 0.842)	.102	NA	NA
Aorta diameter	0.694 (0.511, 0.877)	.039	34.5 mm	64
RV/LV ratio	0.742 (0.565, 0.918)	.009	1.5	69
Superior vena cava diameter	0.762 (0.589, 0.934)	.004	20.9 mm	69
Azygos vein diameter	0.775 (0.605, 0.945)	.003	10.4 mm	70

Note.—A_z values were calculated and tested for difference from 0.5. For A_z values that demonstrated difference from 0.5, threshold values were calculated for which sensitivity equaled specificity.

* Data in parentheses are 95% confidence intervals.

[†] NA = not applicable.



Receiver operating characteristic curves of four CT measurements tested for their ability to predict survival for which A_z was significantly higher than 0.5. These values were not significantly different (*P* = .389–.865).

the receiver operating characteristic analysis indicate that when the RV/LV ratio is 1.5, the sensitivity equals specificity (ie, 69%) for discriminating between survivors and nonsurvivors.

These results do not confirm those of Araoz et al (20), who reported an absence of correlation between cardiac CT measurements and mortality rate. The 173 patients included in their study had PE of low to moderate severity, a mean RV/LV ratio of 1.1, and a subsequent mortality rate of 5%. On the other hand, our results confirm those of van der Meer et al (22), who reported a significantly higher RV/LV ratio in nonsurvivors (mean, 1.5) than in survivors (mean, 1.1).

The cardiac measurements and ratios obtained with CT pulmonary angiography could be different from those obtained with a four-chamber view, as obtained at echocardiography. Quiroz et al (26) reported that an RV/LV ratio of more than 0.9 is a significant predictor of adverse clinical events when measured on reconstructed CT four-chamber views but not on transverse CT sections. More recently, investigators (27) also reported a higher mortality rate in patients who had an RV/LV ratio of more than 0.9 on four-chamber views compared with those who had an RV/LV ratio of 0.9 or less.

Among vascular measurements, the mean diameters of the azygos vein, superior vena cava, and aorta were higher in nonsurvivors than in survivors. Collomb et al (19) also found differences in the diameter of the superior vena cava between patients with severe PE, nonsevere PE, or no PE. After investigating chest radiographs, Pistolesi et al (40) reported upstream manifestations of right-sided heart insufficiency in systemic veins and showed significant correlations between right atrial pressure and superior vena cava and azygos vein diameters. Conversely, other investigators have shown significant correlations between right-sided heart hemodynamics and the diameter of the inferior vena cava, as measured with ultrasonography (41,42).

Among the qualitative findings considered in our study, reflux of contrast medium into the inferior vena cava is the only finding that can be used to discriminate between nonsurvivors and survivors. The leftward bowing of the interventricular septum does not seem to do so, which confirms the results of studies by Araoz et al (20) and van der Meer et al (22). Some investigators (19,20) have nevertheless reported that leftward bowing of the interventricular septum may be an indicator of the clinical severity of PE. This could be explained by the fact that *(a)* these investigators considered flattening of the interventricular septum as an indicator of leftward bowing and *(b)* such a finding could be dependant on the x-ray tube rotation time and therefore may not be detectable with a 1-second rotation time, as was used in our study.

Concerning early mortality, the best parameters for discriminating between survivors and nonsurvivors are the same as those for determining overall in-hospital mortality. In addition, decreased LV short axis and pericardial effusion are supplementary findings that were more frequent in patients who died within the first 48 hours than in those who survived beyond 48 hours. However, because of the small number of patients with pericardial effusion, we cannot draw definite conclusions about this association.

Several limitations in our study warrant consideration. First, its retrospective design prevented us from producing correlations with findings of other diagnostic tests, especially echocardiography. Second, our study group consisted of patients admitted to the intensive care unit for severe PE-related conditions. Consequently, we were unable to evaluate patients with nonsevere PE-related conditions whose mortality is lower (2). Third, we did not classify patients into subgroups according to their history of associated cardiopulmonary

Table 4

Threshold Values of Quantitative Measurements as Predictive Indices of Death

Measurement	Probability of Death 5%	10%	20%	30%	40%	50%
PA obstruction (%)						
Qanadli et al (17)	27	43	60	72	81	90
Mastora et al (18)	5	30	57	75	90	100
RV/LV ratio	1.0	1.3	1.7	1.9	2.1	2.3
RV short axis (mm)	40	48	57	61	65	69
Superior vena cava diameter (mm)	16	19	23	25	27	29
Azygos vein diameter (mm)	7	9	12	13	14	15

Table 5

Comparison of Qualitative Findings between Survivors and Nonsurvivors

Qualitative Finding	Survivors (*n* = 70)	Nonsurvivors (*n* = 12)	*P* Value
Pleural effusion	26/70 (37)	6/12 (50)	.405
Pericardial effusion	4/70 (6)	2/12 (17)	.183
Pulmonary infarct	33/70 (47)	6/12 (50)	.891
Platelike atelectasis	51/70 (73)	10/12 (83)	.449
Pulmonary consolidation	8/70 (11)	2/12 (17)	.614
Mosaic ground-glass opacity	38/70 (54)	6/12 (50)	.748
Reflux into inferior vena cava	8/41 (20)	5/9 (56)	.026
Interventricular septum bowing	16/70 (23)	3/12 (25)	.873

Note.—Numbers in parentheses are percentages.

disease. Because of the patients' poor condition, it was very difficult to establish such an assessment at admission to the intensive care unit. Fourth, our results are limited to the in-hospital stay. Investigators have reported, however, that 90% of nonsurvivors die within the first hours or days after the onset of symptoms and that very few die after discharge (1,2,4). Fifth, our study was based on single–detector row helical CT scans, but a collimation of 2 mm is adequate to evaluate the PA at the segmental level and allows accurate cardiac measurements (12,19,23,24,43).

In conclusion, the findings of CT pulmonary angiography are adequate for predicting the prognosis of patients with severe PE-related conditions, and RV/LV ratio and azygos vein diameter are the most accurate predictors of mortality.

Appendix

The following parameters were used for the scoring system proposed by Miller et al (30): The right PA has nine major segmental branches (three to the upper lobe, two to the middle lobe, and four to the lower lobe). The left PA has seven major branches (two to the upper lobe, two to the lingula, and three to the lower lobe). One point is scored for the presence of a filling defect or obstruction in any one of these branches. A filling defect that is proximal to the segmental branches is given a value equal to the number of segmental branches that arise distally. The maximum score is 9 for the right lung and 7 for the left lung. The maximum possible CT obstruction score is 16 for both lungs. In addition, the score was originally used to evaluate the effect of embolism on PA flow, which currently cannot be assessed with CT pulmonary angiography.

In the scoring system by Walsh et al (31), different scores are assigned for filling defects and obstructions, depending on their anatomic locations. The following guidelines are used: *(a)* filling defects or occlusions in a single segmental PA may receive a total score that does not exceed 1, regardless of their number; *(b)* abnormalities may receive a total maximum score of 3 for a single upper lobar region, 2 for the middle lobe or lingula, and 4 for the lower lobes (occlusion is given a score of 3 for the upper lobe, 2 for the middle lobe or lingula, and 4 for the lower lobe, whereas any lobar filling defect is given a score of 2); *(c)* obstructions in central anatomic regions receive scores according to the vessel involved (9 for the main PA and 6 for the interlobar PAs); *(d)* if the total score for one lung is greater than 4 without the inclusion of filling defects in central regions, the central filling defects are ignored; all filling defects in a single central region, whether single or multiple, receive a score of 3; *(e)* if a single vessel contains both a filling defect and an obstruction, only the obstruction is scored; and *(f)* the sum of scores for all abnormalities in one lung may not exceed 9. The maximum CT obstruction score is 18.

In the scoring system by Qanadli et al (17), the arterial tree of each lung is regarded as having 10 segmental PAs (three to the upper lobes, two to the middle lobe or the lingula, and five to the lower lobes). An embolus in a segmental PA is given a score of 1, and emboli at the most proximal arterial level are given a value that is equal to the number of segmental PAs that arise distally. To provide additional information on the residual perfusion distal to the embolus, a weighting factor is used for each value (0 indicates no defect; 1, partial occlusion; and 2, complete occlusion). An isolated subsegmental embolus is considered a partially occluded segmental PA and assigned a value of 1. The maximum CT obstruction index is 40.

In the scoring system by Mastora et al (18), scoring is applied to five mediastinal PAs (PA trunk, right and left PAs, and right and left interlobar PAs), six lobar PAs, and 20 segmental PAs (three in the upper lobes, two in the middle lobe or lingula, and five in the lower lobes). The CT severity score is based on the percentage of obstruction on the surface of each central and peripheral PA section and is scored by using a five-point scale (1, <25% obstruction; 2, 25%–49%; 3, 50%–74%; 4, 75%–99%; and 5, 100%). A central score (mediastinal and lobar PAs), a peripheral score (segmental PAs), and a global score (central and peripheral pulmonary PA) can then be calculated. The maximum CT obstruction score is 155.

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