INTRODUCTION

Acute pulmonary embolism (APE) is a common disease in clinic and can lead to acute right ventricular failure and even sudden death. APE is associated with a high rate of misdiagnosis due to the lack of specific manifestations. Right ventricular dysfunction is a reliable prognostic predictor, and right ventricular failure is a major cause of death related to APE within 30 days. Therefore, a timely, accurate assessment of severity of APE is of high importance. Pulmonary artery CT angiography (CTA) is the preferred choice for the diagnosis of suspected cases. We performed a retrospective analysis on 86 cases with different severity of APE and detected the parameters of right ventricular function.

PATIENTS AND METHODS

From January 2015 to April 2016, 86 APE cases diagnosed by pulmonary artery CTA at our hospital (47 males and 39 females, aged 21–75 years old, with an average of 52.41±16.57 years) were reviewed. Underlying ventricular and lung diseases were excluded. All cases received conventional pulmonary artery CTA and electrocardiogram (ECG)-gated pulmonary artery CTA, based on which APE was classified into two types. The first was the central type, with pulmonary artery of at least one pulmonary lobe affected; the second was the peripheral type, with only

ECG-gated pulmonary artery CTA for evaluation of right ventricular function in patients with acute pulmonary embolism

Hong-Wei Liang MM1,* | De-Li Zhao MM1,* | Xin-Ding Liu Bachelor BM1 | Peng Chen Bachelor BM2 | Hai-Ting Zhou MM1 | Cheng-Lei Zhao Bachelor MB1 | Guo-Kun Wang MM1 | Mei-Ling Xu MM1 | Jin-Ling Zhang MD1

1Department of CT, The Second Affiliated Hospital of Harbin Medical University, Harbin, China
2Radiology Department of the Fourth Hospital of Harbin, Harbin, China

Correspondence
Jin-Ling Zhang, Department of CT, The Second Affiliated Hospital of Harbin Medical University, Harbin, China.
Email: jinlingzi@163.com

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Objective: To evaluate right ventricular function in patients with acute pulmonary embolism (APE) using electrocardiogram-gated CTA and to discuss the clinical value of pulmonary artery CTA

Patients and methods: Based on death risk evaluation, 86 APE patients were divided into high-risk group (n=46) and non–high-risk group (n=40). The CT pulmonary embolism (PE) index and parameters of right ventricular function were analyzed from the CTPA images and compared between the two groups. Potential correlation between the two was also discussed.

Result: CT PE index (median 24.69%) of the high-risk group was obviously higher than that of the non–high-risk group (median 8.58%) (P<.05). Except the diameter of superior vena cava, all other parameters of right ventricular function were significantly different between the two groups (P<.05). CT PE index was correlated with the parameters of right ventricular function.

Conclusion: ECG-gated pulmonary artery CTA is suitable for assessing the severity of APE and right ventricular function.

Keywords: angiography, pulmonary embolism, right ventricular function, x-ray computed
segmental or subsegmental pulmonary arteries affected. According to the 2008 Guidelines for Diagnosis and Treatment of APE by European Society of Cardiology, high-risk APE was diagnosed if any of the following clinical manifestations was present: (1) arterial systolic blood pressure below 90 mm Hg or a drop of blood pressure by over 40 mm Hg from the baseline; (2) tachycardia, with ventricular rate above 100 beats/min; (3) tachypnea, with respiratory rate above 25 times/min; (4) partial pressure of oxygen below 60 mmHg. According to the above criteria, 46 cases were diagnosed as high-risk APE.

2.1 | Scan equipment and method

All CTA operations were performed on Philips Brilliance iCT 256-slice scanner, using Philips EWB 4.01 workstation and SCT-211 double-barreled syringe. Cardiac CT with standard retrospective ECG gating was adopted for all cases, with probe width of 80 mm. First conventional CTPA was performed, under 120 kV voltage, 200mAs current, 0.5 s/r tube rotation rate, and 0.625 pitch. Ultravist was injected (350 mgI/mL) via the antecubital vein at the rate of 4–5 mL/s for a total dose of 60–80 mL. Then, 30 mL of normal saline was injected at the same rate. The time delay was determined by artificial intelligence, with the trigger threshold set at 100HU. Then, monitoring sequence was started in the main pulmonary artery. Each scan was performed within breath-hold for about 5–8 seconds. ECG-gated CTPA images were collected 2–3 minutes after conventional CTPA, with 280–380 mAs. Other scanning parameters were the same as in conventional CTPA. Ultravist, the contrast medium (130–180 mL), was injected at the rate of 4–5 mL/s for both conventional CTPA and ECG-gated CTPA. The temporal resolution of 85–180 ms (depending on the ventricular rate). The rotation time was 350 ms, and the total distance covered in each rotation was 4 cm. Thus, cardiac CTA scan was completed within five ventricular beats.

2.2 | Image reconstruction and postprocessing

All original images were uploaded to the EBW workstation. The reconstruction thickness was 0.625 mm, and the reconstruction interval was 0.625. With 5% of RR cycle as the reconstruction interval, the entire cardiac cycle was divided into 20 phases. Short-axis images of the left ventricle were reviewed to define the end-systole and end-diastole. Conventional CTPA images were imported to the 3D software, and the end-systole and end-diastole frames of ECG-gated CTPA images were imported to the Circulation software package. The images were analyzed and computed as follows for each case: proper window width and window level were selected to observe the ventricular chambers and ventricular valves. Left ventricular analysis (LVA) software was used to delineate the right ventricular endocardium and right ventricular chamber automatically. The delineation was adjusted manually to include trabecular muscles and papillary muscles. Thus, the ventricular outflow tract was included, and the parameters of right ventricular function were calculated. The maximum minor axis of the right ventricle (RVMMA) and the maximum minor axis of the left ventricle (LVMMA) were calculated from the cross-sectional view and four-chamber view, respectively, using end-diastole images. For conventional CTPA, RVMMA and LVMMA were similarly computed from the cross-sectional view and four-chamber view, respectively, using the 3D software.

2.3 | CTPA image analysis

The images were evaluated independently by two radiologists who had 3–5 years of working experience using the double-blind method. Any divergence of opinions was settled by discussion.

2.4 | CT-based diagnostic criteria for APE

APE was shown as central or eccentric low-density filling defect in the pulmonary artery. Severe cases presented truncated vessels, with widening of the main pulmonary artery and its branches.

2.5 | Computation of CT PE index

Mastora score was computed as a measure of APE severity, with the highest score being 155. CT PE index was defined as the percentage of obstruction of all segments of bilateral pulmonary arteries, that is, CT PE index=[Σ(n×d)/155]×100%.

2.6 | Measurements of parameters of right ventricular function

Normal morphology of interventricular septum is a convex toward the right ventricle. Abnormal morphology includes flattening of interventricular septum and convex toward the left ventricle. Left ventricular maximal short axis (LVMSA) and right ventricular maximal short axis (RVMSA) were measured from the transverse CT images, and the ratio of the two was calculated. Diameters of main pulmonary artery, superior vena cava, and azygos vein were measured.

2.7 | Statistical analysis

All data were statistically analyzed using SPSS 18.0 software. Measurements were presented as $x \pm s$ and counts as percentages (%). CT PE index was expressed as a median. Parameters of right ventricular function were compared using a t test. Measurements were analyzed by Mann-Whitney U-test, and counts by chi-square test. Correlations between CT PE index and right ventricular function were analyzed using Spearman’s rank correlation analysis.

3 | RESULTS

3.1 | Comparison of CT PE index and parameters of right ventricular function between the two groups

CT PE index of the high-risk group was 14.69%-28.13% (median 24.69%), which was significantly higher than 5.06%-12.02% (median 8.58%) in the non–high-risk group ($P<.05$). Table 1 shows the RVMSA,
LVMSA, RV:LV ratio, diameter of main pulmonary artery, diameter of azygos vein, diameter of superior vena cava and morphology of interventricular septum in the two groups. Except the diameter of superior vena cava, the remaining parameters were significantly different between the two groups (P<.05). Figures 1, 2, and 3 are the typical CTPA images of normal people, high-risk group, and non–high-risk group, respectively.

3.2 Correlation between CT PE Index and Parameters of Right Ventricular Function

RVMSA, RV:LV ratio, diameter of main pulmonary artery, diameter of superior vena cava, and diameter of azygos vein were positively correlated with the CT PE index, with correlation coefficient being 0.693–0.946. LVMSA was negatively correlated with the CT PE index, and the correlation coefficient was −0.724, indicating significant difference (P<.05) (Table 2).

4 DISCUSSION

China has witnessed a rise of APE incidence in the past few years given the context of population aging and dramatic changes in lifestyle. It is reported that over 50% of the APE cases may develop secondary right ventricular failure. Those combined with right ventricular failure are faced of a mortality higher by 2-3 times than that of the patients with normal right ventricular function. Therefore, right ventricular failure is a potent predictor of severity and prognosis of APE.6,7 CTPA is now widely used to evaluate APE, based on parameters of right ventricular function and morphology of interventricular septum.8,9

4.1 Assessment Based on CT PE Index

Increase of pulmonary circulation resistance and mean pulmonary artery pressure is the major secondary lesion following APE. Pulmonary artery pressure reflects the hemodynamics and the level of circulatory decompensation. The higher the pulmonary artery pressure, the worse the prognosis might be.10–12 We found that the CT PE index (median 24.69%) was significantly higher in the high-risk group as compared with the non–high-risk group (median 8.58%). CT PE index is a qualified indicator of the severity and scope of APE, and the higher the index, the higher the severity is. CT PE index can be also used to predict the prognosis.

4.2 Assessment based on right ventricular function parameters

Normal morphology of the interventricular septum is a convex toward the right ventricle. But in those with severe APE, increased right ventricular pressure can lead to flattening of the interventricular septum or even convex toward the left ventricle, as was observed in some high-risk APE patients. In our study, the incidence of abnormal morphology of the interventricular septum was 73.17% in the high-risk group vs 31.43% in the non–high-risk group. This means the high-risk APE patients were more prone to right ventricular failure.
According to some reports, the prevalence of mean diameter of main pulmonary artery above 30 cm and the azygos vein diameter were significantly different between severe and nonsevere APE patients. We found that the mean diameters of both main pulmonary artery and azygos vein were higher in the high-risk group than in the non-high-risk group. As APE intensified, the pulmonary artery pressure increased and the main pulmonary artery was dilated. The increase of right ventricular pressure can lead to the increase of right atrial pressure. Consequently, the central vein pressure increased and the azygos vein was dilated. The more severe the widening of the central vein and the azygos vein, the more severe the APE and the higher risk of secondary right ventricular failure will be.

APE combined with anomalous pulmonary venous return may cause poor left ventricular filling and an increase of RV:LV ratio. RV:LV>1 is considered a reliable indicator of right ventricular dysfunction based on pulmonary artery CTA and correlates with severity of APE. This ratio, as an indicator of changes in hemodynamics and right ventricular function, increased considerably in the high-risk group. The higher the ratio, the more severe the right ventricular dysfunction of the APE patient would be.

FIGURE 1  CTA images of normal pulmonary artery. A. Normal main pulmonary artery; B. Coronal view of normal pulmonary artery; C. Sagittal view of normal pulmonary artery; D. Convex toward the right ventricle
Correlation between CT PE index and right ventricular function parameters

CT PE index and right ventricular function parameters could well reflect the severity of APE, and the two were connected as well. RVMSA, LVMSA, RV:LV ratio, diameter of main pulmonary artery, diameter of azygos diameter and diameter of superior vena cava were correlated with the CT PE index, and the RV:LV ratio was most correlated with the CT PE index. It is apparent that mechanical obstruction of the pulmonary artery is the main working mechanism and the most direct influence factor for pulmonary hypertension. Severe APE patients are usually combined with a significant decline of right ventricular function, which further affects the prognosis.

Advantages and shortcomings of the present study

Multislice spiral CT scan has the advantages of minimal examination time, low radiation dose and high image resolution. The contrast-enhanced CTA images can be collected, from which the right ventricular function parameters are calculated without additional scans. However, the present study was limited in the following aspects: firstly, the sample size was small, leading to bias. Secondly, we only
compared the CT images of the two groups without combining clinical manifestations, prognosis, and follow-up. Thirdly, ECG-gated CTA involves complex procedures and requires two scans, which increase the radiation exposure of the patients.

## 5 | CONCLUSION

ECG-gated CTA is more valuable for assessing right ventricular function for APE patients than conventional pulmonary artery CTA. It is a practical and accurate imaging technique for predicting the prognosis of APE.
REFERENCES


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