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Visibility and image quality of peripheral pulmonary arteries in pulmonary embolism patients using free-breathing combined with a high-threshold bolus-triggering technique in CT pulmonary angiography

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Abstract

Objective: To investigate the visibility of peripheral pulmonary arteries by computed tomography pulmonary angiography (CTPA) and image quality using a free-breathing combined with a high-threshold bolus triggering technique and to explore the feasibility of this technique in pulmonary embolism (PE) patients who cannot hold their breath.

Methods: Patients with suspected PE who underwent CTPA (n=240) were randomly assigned to two groups: free-breathing (n=120) or breath-holding (n=120).

Results: The mean scanning time or visible pulmonary artery distal branches were not different between the groups. Mean CT main pulmonary artery (MPA) values, apical segment (S1), and posterior basal segment (S10) in the free-breathing group were higher compared with the breath-holding group. The subjective image quality score in the free-breathing group was higher compared with the breath-holding group. In the free-breathing group, no respiratory artifact was observed. In the breath-holding group, obvious respiratory artifacts were caused by severe chronic obstructive pulmonary disease (COPD), dyspnea, or other diseases that preclude patients from holding their breath.

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Conclusion: The free-breathing mode CTPA combined with a high-threshold bolus triggering technique can provide high quality images with a lower incidence of respiratory and cardiac motion artifacts, which is especially valuable for patients who cannot hold their breath.

Keywords

Pulmonary embolism, pulmonary angiography, image quality, computed tomography, free-breathing, threshold, x-ray

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Introduction

Computed tomography pulmonary angiography (CTPA) is the recommended method for diagnosing suspected pulmonary embolism (PE) because of its high sensitivity and specificity.[1,2] Acute PE remains a diagnostic challenge for physicians, and it accounts for significant morbidity and mortality in emergency department patients because they often cannot hold their breath, which may lead to misdiagnosis.[3] The aim of this study was to investigate the feasibility of CTPA and image quality using a high-threshold bolus triggering technique and free-breathing.

It is difficult to display the peripheral branches of the pulmonary artery on CTPA images, and it is difficult to diagnose an embolus in the lumen if the patients cannot hold their breath. Peripheral pulmonary embolism can cause lower extremity deep venous thrombosis, and multiple embolisms in the peripheral branches of the pulmonary artery can induce pulmonary hypertension.[4] With the development of CT technology, the scanning speed, time resolution, and spatial resolution of CTPA (combined with maximum intensity projection [MIP], multi-planar reformation [MPR], volume rendering [VR], and other postprocessing technology) have continued to improve, so PE can be diagnosed quickly, reliably, and multidirectionally.

Materials and methods

Ethics approval

The study was approved by the Institutional Ethics Committee at our hospital, and written informed consent was obtained from all participants.

Study population

There were 240 consecutive patients with suspected PE who were undergoing CTPA examination and were referred to our department at Liaocheng, China from November 2016 to May 2017. These patients were enrolled into our study.

CT image acquisition

The patients were randomly divided into the following two groups: free-breathing group (n=120) in which the patients were scanned while freely breathing, and the breath-holding group (n=120) in which the patients were scanned after breathing deeply and holding their breath. The randomized grouping was based on the last digit in the registration number: odd numbers went into the study group that was the free-breathing group and even numbers went into the control group that was the breath holding group. CTPA was performed with a 256-detector CT

(Revolution CT; GE Healthcare, Milwaukee, WI, USA). The scan parameters were as follows: area, 256 × 0.625 mm; tube voltage, 100 kV; automatic tube current technology, 59 to 189 mA; rotation time, 0.28 s; and pitch, 0.992:1. Scanning used high threshold bolus-tracking technology through the cubital vein by injecting iodinated contrast agent (iopamidol, 370 mg iodine/mL; Bracco Sine Pharmaceutical Corp. Ltd., Pudong, China) at a volume of 40 mL and an infusion rate of 5 mL/s. This was followed by administering 20 mL of 0.9% saline to flush the line after injecting the contrast agent to reduce side effects, reduce the contrast medium dose, and eliminate artifacts. The trigger point was located in the pulmonary artery trunk. The threshold value was 250 HU in the free-breathing group, and the scan began as soon as the threshold was reached. The threshold for the breath-holding group was 150 HU, and the scan began 5 s after the threshold was reached. The scanning direction was from foot to head, and the scanning range included the whole lung (apical to the costophrenic angle). A soft tissue algorithm was used to reconstruct the image. The window width was 900 HU, the window position was 300 HU, the matrix was 512 × 512, and the interval between layers and thicknesses was 0.625 mm. The Adaptive Statistic Iterative Reconstruction-V (ASiR-V) algorithm was used.

Image postprocessing and analysis

All data were transferred to an advantage workstation (ADW4.6, GE Healthcare) for image postprocessing and analysis. Images were reconstructed using the MIP, MPR, curvature plane reconstruction, and VR. Axial images at the mediastinal window (window width, 360 HU; window level, 60 HU) and lung window (window width, 1500 HU; window level, −900 HU) were used to determine the anatomical position.

The average scan time of the two groups was recorded and analyzed by two senior radiologists. The farthest branches of the pulmonary artery that were clearly displayed in the two groups were observed at the mediastinal window (window width 360, HU; window level, 60 HU) on the axial images and observed combined with the lung window (window width, 1500 HU; window level, −900 HU) to determine the anatomical position and alternative image reconstruction methods. These included the MIP, MPR, curvature plane reconstruction, and VR.

Visual image quality assessment

The vessels that were evaluated included pulmonary segments, sub-segmental arteries to eighth-grade pulmonary arteries, which were named based on their construction principle by Remy-Jardin.[5] The surrounding branches of the pulmonary arteries that were observed were defined as the entire vessels that could be seen on one image or the continuous images from the proximal to the distal ends; which walls were clear and had no partial volume effect; and which lumen could be analyzed to show if there were filling defects.

Three regions of interest (ROIs) were placed, respectively, on the main pulmonary artery (MPA), apical segment (S1, aortic arch level), and posterior basal segment (S10, left atrial level) to measure the CT value. Image noise was expressed as the standard deviation of the CT value of manubrium air. The signal-to-noise ratio (SNR) was calculated for each ROI as follows: SNR = ROI CT value/image noise.

The image quality and visibility of the peripheral pulmonary arteries were independently rated by two experienced radiologists (D Liu and L Wei). The ROI area was approximately 200 mm^2. Five-point scales were used in a double-blind manner to subjectively evaluate the image quality. Standards for evaluation were as follows: 5 points indicated that the pulmonary artery edge was sharp, there was no respiratory or cardiac motion artifacts, and there was full diagnostic confidence; 4 points indicated that the image quality was between 3 and 5 points; 3 points indicated that there were artifacts, the pulmonary artery edge was slightly rough, the observation of any structure was not affected by artifacts, and diagnosis may be confident; 2 points indicated that the image quality was between 1 and 3 points; and 1 point indicated that there was no diagnostic confidence, showing respiratory and cardiac motion artifacts, fuzzy image, and inability to identify the pulmonary edge, and indicating that the main structure was affected by artifacts.

Statistical analysis

Data were expressed as the mean ± standard deviation (SD). Independent sample *t*-test statistics were used to compare the average scan time of the two groups. Chi-square tests were used to analyze the difference in the detection rate of the pulmonary artery branches. Independent two-sample *t*-tests were used to compare the differences in the CT values, image noise, and SNR. A non-parametric Mann–Whitney U-test was used to compare the subjective scores between the two groups. The kappa test was used to compare the differences between observers. $P<0.05$ was considered to indicate a statistically significant difference. All statistical analyses were performed using the SPSS statistical package (version 14.0 for Windows; SPSS Inc., Chicago, IL, USA).

Results

Two hundred forty consecutive patients with suspected PE who were undergoing CTPA examination and who were referred to our department at Liaocheng, China from November 2016 to May 2017 were enrolled into this study. Among the 240 patients, 109 patients were male and 131 were female (age range, 25–89 years; mean age, 56.5±5.3 years). They had dyspnea, chest tightness, shortness of breath, chest pain, cough, and expectoration, which included 92 patients with chronic obstructive pulmonary disease (COPD), 63 patients with coronary heart disease, 43 patients with deep venous thrombosis, 26 postpartum patients, and 16 patients with lung cancer.

All CTPA images were successful and the average scanning time was 0.67 s. The observed distal branches of the pulmonary artery and the results of the analysis between the two groups that used different scanning methods and that were assessed by two radiologists during image postprocessing and grading are shown in Table 1. The farthest branches of the pulmonary artery all reached at least to level 6. The number of farthest displayed branches from levels 6/7/8 were 29.2%/55%/15.8% compared with 56.7%/17.5%/25.8%, respectively. There was no significant difference between the two groups (χ^2=0.372) or for the pairwise comparison.

The objective evaluation results for image quality are shown in Table 2. The average CT value of MPA, S1, and S10 in the free-breathing group was higher compared with the breath-holding group (516±146 HU, 482±139 HU, and 473±153 HU vs. 483±128 HU, 467±129 HU, and 436±165 HU, $P < 0.05$). There was no significant difference between the two groups for SNR-MPA, SNR-S1, and SNR-S10 (14.1±10.4, 14.8±10.8, and 13.7±10.8 vs. 13.9±10.3, 14.1±10.6, and 12.9±10.7).

Subjective evaluation of image quality is shown in Table 3. There were no artifacts caused by respiration in any of the patients, and all the cases met the diagnostic

Table 1. Comparison of the maximum displayed distal branches of the pulmonary arteries between two different scanning CTPA methods.

Order of free-breathing group (number)	Free-breathing group (%)	Breath-holding group (%)	
6	35 (29.2)	31 (25.8)	
7	66 (55)	68 (56.7)	
8	19 (15.8)	21 (17.5)	
Total number	120	120	P=0.830, $\chi^2 = 0.372$

CTPA, computed tomography pulmonary angiography.

Table 2. Comparison of objective evaluation of image quality.

	Free-breathing group	Breath-holding group	T value	P value
CT value (HU)				
MPA	516 ± 146	463 ± 128	2.4	0.021
S1	482 ± 139	437 ± 129	2.75	0.019
S10	473 ± 153	416 ± 165	3.57	0.014
SNR (HU)				
MPA	14.1 ± 10.4	13.9 ± 10.3	0.921	N.S.
S1	14.8 ± 10.8	14.1 ± 10.6	0.897	N.S.
S10	13.7 ± 10.8	12.9 ± 10.7	0.786	N.S.

N.S., not significant; CT, computed tomography; MPA, main pulmonary artery; SNR, signal-to-noise ratio.

Table 3. Subjective evaluation of the image quality.

	Free-breathing group	Breath-holding group
Reader 1	4.3 ± 0.67	3.1 ± 1.4
Reader 2	4.2 ± 0.72	3.2 ± 1.45

Kappa value, 0.649; P value <0.001.

requirements (more than 3 points) in the free-breathing group. The number of patients with 5, 4, and 3 points were 84 (70%), 25 (20.8%), and 11 (9.2%) in the free-breathing group compared with 16 (16.3%), 20 (16.7%), and 53 (44.2%) in the breath-holding group, respectively. The subjective image quality scores in the free-breathing group were higher compared with the breath-holding group (P=0.015). Respiratory artifacts occurred in patients with serious COPD, shortness of breath, and other conditions precluding patients from hold their breath in the breath-holding group. There were 14 (11.7%) patients with 1 point and 17 (14.1%) patients with 2 points in the breath-holding group.

Discussion

Currently, multidetector CTPA can be completed in 1 s, and difficulties with respiratory and heart motion artifacts are almost resolved. Thus, the diagnostic sensitivity for PE is highly increased. Breath-holding after inhalation reduces the intrathoracic pressure and affects blood (contrast agent) reflux, leading to insufficient contrast agent in the peripulmonary artery branch lumen and possibly to the phenomenon of contrast agent discontinuation.[6,7]

In addition, breath-holding after deep inhalation can induce Valsalva breathing, which greatly increases the pressure in the thoracic cavity and blood vessels. This prevents blood reflux into the right atrium and reduces heart rate and cardiac output per stroke, thereby affecting contrast media filling in the pulmonary artery branches during CTPA examination. This affects the diagnosis of PE. The mechanism of physiological changes has been studied for a long time.[8–10] The results of this study showed that the use of free-breathing combined with high threshold triggering technology when the scan time is short (approximately 0.65 s) reduced contrast agent interruption and Valsalva breathing to the greatest extent. This significantly reduces or even eliminates breathing artifacts, while increasing the contrast-enhancement effect.

PE was reported to be diagnosed reliably only when the vessels were enhanced to a certain level, and PE could be accurately excluded only if the CT value was over 250 HU.[11–14] Therefore, 250 HU was chosen as the excitation threshold. Because the threshold was increased, scanning was triggered immediately because the CT value of the ROI reached the threshold, and thereby achieved “what you see is what you get”. This method could increase contrast agent filling in the peripheral branches and increase the displayed series of peripheral pulmonary artery branches. This study showed that using a high-threshold bolus-triggering technique under free-breathing conditions, 29.2% of grade 6 and 55% of grade 7 pulmonary arteries were observed, along with a few patients (15.8%) in whom grade 8 pulmonary arteries could be observed (Figure 1a–i). Grade 7 and grade 8 pulmonary arteries could not be displayed because of the partial volume effect in the slim vascular branches.

Additionally, because of the high threshold technology, CT values in the free-breathing group were higher compared with the breath-holding group ($P<0.05$), while the SNR in the lumen did not differ significantly between the two groups. Thus, all the patients in the free-breathing group obtained the highest degree of enhancement, and the CTPA image quality was improved (Figure 1a–i). This result is consistent with other research.[15–17] Because false or missed diagnosis can easily occur,[10,18] this technology is used more frequently to evaluate low-dose chest pulmonary nodules and the heart.[19–23]

Studies have used the method of high scanning pitch to reduce the scanning time, which also reduces the influence of the respiratory motion on CTPA. However, simply increasing the scanning pitch will inevitably lead to decreases in the tube current and X-ray photons in certain body voxels as well as increases in image noise, which can seriously and negatively affect image quality by increasing the image noise and decreasing the imaging quality (especially in patients who are overweight or obese).

The limitations of our research were that the study did not set standard examination methods for comparison and did not analyze the sensitivity and specificity. Second, to avoid the partial volume effect on the measurement, CT and SNR values were only measured in the central pulmonary artery and did not involve attenuation of peripheral branches. Although a relatively small amount of contrast medium was used (40 mL), contrast agent still remained in the superior vena cava, which may affect observation of the pulmonary artery branches in the right upper lobe. This indicated that further research to optimize the contrast agent injection schemes is needed to reduce the amount of contrast agent.

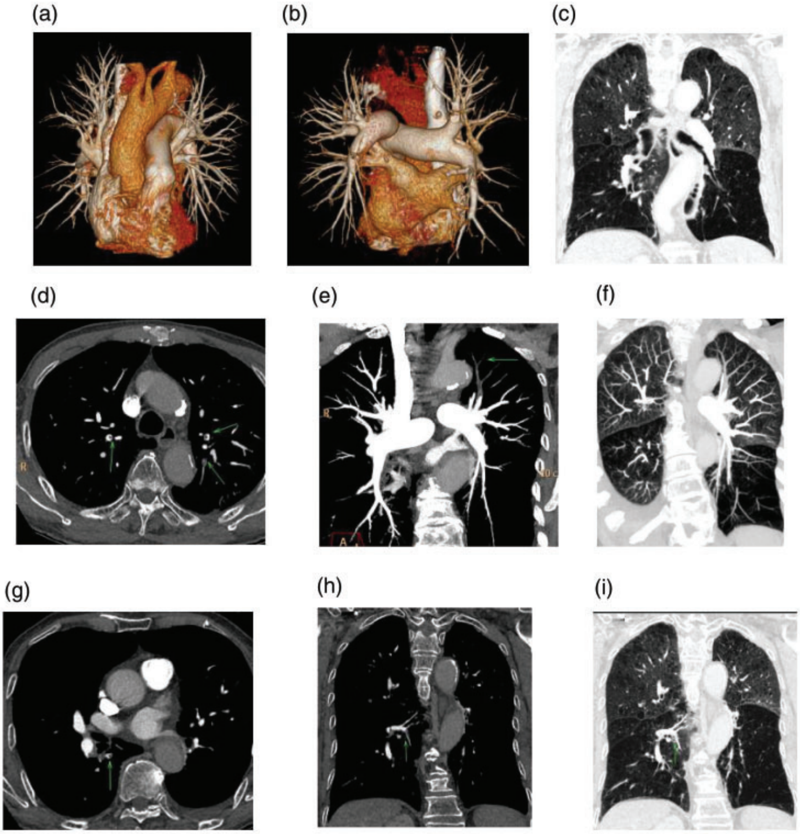

Figure 1. (a–i) The patient was an 89-year-old man who was deaf and had repeated chest pain, cough, and expectoration that increased over the past 30 years. Examination results were as follows: PCO_2, 41 mmHg; PO_2 ,73 mmHg; D-dimer, 2.8 mg/L (normal value <2 mg/L); and thrombin time, 19.1 s (normal value <10.3–16.6 s). Emboli were shown in the branches of the right lower lung dorsal segment and bilateral apical segment on CTPA images (arrows). Severe emphysema was found in lung window images with right pleural effusion. a and b are VR images, and c was a coronal lung window image. d and g are axial images of the mediastinum window. e and h are MPR images. f and i are lung windows of e and h. Scan time was 0.65 s, DLP was 77.1 mGy-cm, and ED was 1 mSv. After intravenous anticoagulation for 3 days, D-dimer was 1.4 mg/L and thrombin time was 14.8 s.
PCO_2, partial pressure of carbon dioxide; PO_2, partial pressure of oxygen; CTPA, computed tomography pulmonary angiography; VR, volume rendering; MPR, multi-planar reformation; DLP, dose-length product; ED, effective dose.

Conclusions

The free-breathing mode of CTPA combined with the high-threshold bolus-triggering technique can produce good quality images with a lower incidence of respiratory and cardiac motion artifacts, which is especially valuable for the patients who cannot hold their breath.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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References

1. Stein PD, Woodard PK, Weg JG, et al. Diagnostic pathways in acute pulmonary embolism: recommendations of the PIOPED II investigators. *Radiology* 2007; 242: 15–21.
2. Huisman MV and Klok FA. Diagnostic management of acute deep vein thrombosis and pulmonary embolism. *J Thromb Haemost* 2013; 11: 412–422.
3. Den Exter PL, Van Es J, Klok FA, et al. Risk profile and clinical outcome of symptomatic subsegmental acute pulmonary embolism. *Blood* 2013; 122: 1144–1149.
4. Liu LR, Fan Y, Zhao XQ, et al. The diagnostic value of multi-slice spiral CT pulmonary angiography in pulmonary arterial embolization. *J Clin Med* 2012; 17: 441–443.
5. Remy-Jardin M, Remy J, Artaud D, et al. Peripheral pulmonary arteries: optimization of the spiral CT acquisition protocol. *Radiology* 1997; 204: 157.
6. Vardhanabhuti V, Loader R and Roobottom CA. Assessment of image quality on effects of varying tube voltage and automatic tube current modulation with hybrid and pure iterative reconstruction techniques in abdominal/pelvic CT: a phantom study. *Invest Radiol* 2013; 48: 167–174.
7. Buls N, Van Gompel G, Van Cauteren T, et al. Contrast agent and radiation dose reduction in abdominal CT by a combination of low tube voltage and advanced image reconstruction algorithms. *Eur Radiol* 2015; 25: 1023–1031.
8. Vardhanabhuti V, Ilyas S, Gutteridge C, et al. Comparison of image quality between filtered back-projection and the adaptive statistical and novel model-based iterative reconstruction techniques in abdominal CT for renal calculi. *Insights Imaging* 2013; 4: 661–669.
9. Lim K, Kwon H, Cho J, et al. Initial phantom study comparing image quality in computed tomography using adaptive statistical iterative reconstruction and new adaptive statistical iterative reconstruction V. *J Comput Assist Tomogr* 2015; 39: 443–448.
10. Jones SE and Wittram C. The indeterminate CT pulmonary angiogram: imaging characteristics and patient clinical outcome. *Radiology* 2005; 237: 329–337.
11. Ramadan SU, Kosar P, Sonmez I, et al. Optimisation of contrast medium volume and injection-related factors in CT pulmonary angiography: 64-slice CT study. *Eur Radiol* 2010; 20: 2100–2107.
12. Bae KT, Tao C, Gurel S, et al. Effect of patient weight and scanning duration on contrast enhancement during pulmonary multi-detector CT angiography. *Radiology* 2007; 242: 582–589.
13. Goble EW and Abdulkarim JA. CT pulmonary angiography using a reduced volume of high-concentration iodinated contrast medium and multiphasic injection to achieve dose reduction. *Clin Radiol* 2014; 69: 36–40.
14. Bae KT and Heiken JP. Scan and contrast administration principles of MDCT. *Eur Radiol* 2005; 15: E46–E59.
15. Henzler T, Meyer M, Reichert M, et al. Dual-energy CT angiography of the lungs: comparison of test bolus and bolus tracking techniques for the determination of scan delay. *Eur J Radiol* 2012; 81: 132–138.
16. Kilic K, Erbas G, Ucar M et al. Determination of lowest possible contrast volume in computed tomography pulmonary angiography by using pulmonary transit time. *Jpn J Radiol* 2014; 32: 90–97.
17. Renne J, Falck CV, Ringe KI, et al. CT angiography for pulmonary embolism detection: the effect of breathing on pulmonary artery enhancement using a 64-row detector system. *Acta Radiol* 2014; 55: 932–937.
18. Heyer CM, Mohr PS, Lemburg SP, et al. Image quality and radiation exposure at pulmonary CT angiography with 100- or 120-kVp protocol: prospective randomized study. *Radiology* 2007; 245: 577–583.

19. Parikh N, Morris E, Babb J, et al. MDCT diagnosis of acute pulmonary embolism in the emergent setting. *Emerg Radiol* 2015; 22: 379–384.
20. Kröpil P, Rojas CA, Ghoshhajra B, et al. Prospectively ECG-triggered high-pitch spiral acquisition for cardiac CT angiography in clinical routine: initial results. *J Thorac Imaging* 2012; 27: 194–201.
21. Sandfort V, Ahlman MA, Jones EC, et al. High pitch third generation dual-source CT: coronary and cardiac visualization on routine chest CT. *J Cardiovasc Comput Tomogr* 2016; 10: 282–288.
22. Boos J, Kröpil P, Lanzman RS, et al. CT pulmonary angiography: simultaneous low-pitch dual-source acquisition mode with 70 kVp and 40 ml of contrast medium and comparison with high-pitch spiral dual-source acquisition with automated tube potential selection. *Br J Radiol* 2016; 89: 20151059.
23. Sabel BO, Buric K, Karara N, et al. High-pitch CT pulmonary angiography in third generation dual-source CT: image quality in an unselected patient population. *PLoS One* 2016; 11: e0146949.