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# Added value of lung perfused blood volume images using dual-energy CT for assessment of acute pulmonary embolism

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ABSTRACT

*Purpose:* To investigate the added value of lung perfused blood volume (LPBV) using dual-energy CT for the evaluation of intrapulmonary clot (IPC) in patients suspected of having acute pulmonary embolism (PE).
*Materials and methods:* Institutional review board approval was obtained for this retrospective study. Eighty-three patients suspected of having PE who underwent CT pulmonary angiography (CTPA) using a dual-energy technique were enrolled in this study. Two radiologists who were blinded retrospectively and independently reviewed CTPA images alone and the combined images with color-coded LPBV over a 4-week interval, and two separate sessions were performed with a one-month interval. Inter- and intraobserver variability and diagnostic accuracy were evaluated for each reviewer with receiver operating characteristic (ROC) curve analysis.
*Results:* Values for inter- and intraobserver agreement, respectively, were better for CTPA combined with LPBV (ICC = 0.847 and 0.937) than CTPA alone (ICC = 0.748 and 0.861). For both readers, diagnostic accuracy (area under the ROC curve [$A_z$]) were also superior, when CTPA alone ($A_z$ = 0.888 [reader 1] and 0.912 [reader 2]) was compared with that after the combination with LPBV images ($A_z$ = 0.966 [reader 1] and 0.959 [reader 2]) ($p < 0.001$). However, $A_z$ values of both images might not have significant difference in statistics, because $A_z$ value of CTPA alone was high and 95% confidence intervals overlapped in both images.
*Conclusion:* Addition of dual-energy perfusion CT to CTPA improves detection of peripheral IPCs with better interobserver agreement.



## 1. Introduction

Pulmonary embolism (PE) is a potentially fatal disorder, and is the third most common acute cardiovascular disease, after myocardial infarction and stroke [1]. CT pulmonary angiography (CTPA) has been established as a first-line diagnostic technique for the patients suspected of having pulmonary emboli [2,3]. Lung perfused blood volume (LPBV) images can directly extract the iodine component by application of the material decomposition theory [4] and using dual-energy technique, the degree of iodine enhancement representing lung perfusion can be seen on an image without having to compare it with an unenhanced CT image and the potential of perfusion images obtained by LPBV is shown as a perfusion impairment due to PE [5]. LPBV based vascular iodine analysis also proves the sensitivity of acute peripheral PE detection compared with conventional CTPA alone in a canine model [6].

Our hypothesis is that additional features gathered from first- and second-look CTPA combined with LPBV should improve diagnostic performance in the analysis of intrapulmonary clots (IPCs) in patients with acute PE. Thus, our purpose was to determine the value of adding dual-energy technique to CTPA for predicting IPCs.

## 2. Materials and methods

Institutional review board approval was obtained for this retrospective study, and informed consent requirement was waived.

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### 2.1. Subjects

We retrospectively queried our database and retrieved all initial weighted average CTPA using the dual-energy technique performed between April 1, 2012 and March 31, 2013 at our institution ($n = 104$). Twenty-one patients were excluded from this study, because of the presence of motion artifact caused by insufficient breath-holding ($n = 6$) or previous history of PE ($n = 15$). LPBV was performed using 64-slice dual-source CT (DSCT) within 48 h of symptom onset, such as dyspnea, chest discomfort or pain. Echocardiography and the D-dimer assay were also performed within 24 h before or after scan of LPBV. A total of 83 patients (31 males and 50 females, mean age: 64.5 ± 15.1 years) was included in this study, and their initial LPBV images were divided into two groups based on the presence of intrapulmonary clots (IPCs). Acute PE was diagnosed in 30 (14 males and 16 females, mean age: 64.9 ± 15.4 years) of these patients using a laboratory data, echocardiography and thin slice CTPA.

### 2.2. Reference standard

The final diagnosis of PE was made by CTPA or LPBV referring to clinical and physical findings. When CTPA showed a complete filling defect with a lack of enhancement of the entire lumen of pulmonary arteries, a partial filling defect surrounded by areas of contrast enhancement or a peripheral filling defect that formed an acute angle with the pulmonary arterial wall. After the treatment, the improvement of clinical symptoms such as dyspnea or chest pain, a decrease in the high D-dimer (normal value: 0–1 mg/L) or estimated systemic PA pressure (eSPAP: 15–30 mmHg) on echocardiography and the disappearance of perfusion defects on LPBV were also considered to be positive indicators of the presence of acute PE.

### 2.3. Acquisition of dual-energy CT

All CT examinations were performed using 64-slice DSCT scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany). The detector collimation was set to 64 mm × 0.6 mm, the gantry rotation time was 0.33 s, and the pitch value was 0.5. Low-osmolar nonionic iodinated contrast material (body weight less than 60 kg: 300 mgI/ml and body weight over 60 kg: 350 mgI/ml, Omnipaque; Daiich-Sankyo, Tokyo) followed by 30 mL of saline was injected at a flow rate of 4 mL/s through an 20-gauge antecubital intravenous line, CTPA using dual-energy technique was started with bolus-tracking measurement in the pulmonary artery at a threshold of 100 HU. A caudocranial scan direction was chosen to minimize the streak artifacts from dense contrast material in the superior vena cava or innominate vein.

For all patients, the weighted average CTPA images were approximate to a 120 kVp image, which was automatically generated from a combination of the 140 kVp and 80 kVp CT data using a weighting factor of 6:4 (140 kVp:80 kVp). Transverse CTPA images (Fig. 1A) were reconstructed in 2 mm-slice thickness using a soft tissue kernel (D30f), and native iodine perfusion CT scans were generated using LPBV application mode of a dedicated dual-energy post-processing software program (Syngo Dual Energy software, Siemens Healthcare, Forchheim, Germany).

Using these 120 kVp CTPA images, the presence of IPCs was evaluated, and CTPA was combined with color-coded LPBV using a multi-data fusion software program (ziostation 2, Ziosoft Inc., Tokyo, Japan) and CTPA combined with color-coded LPBV was reconstructed in 2 mm slice thickness (Fig. 1B).

### 2.4. Image analysis

Two readers (Y.K. and Y.N. with 13 and 12 years of experience in cardiovascular radiology, respectively) who were blinded

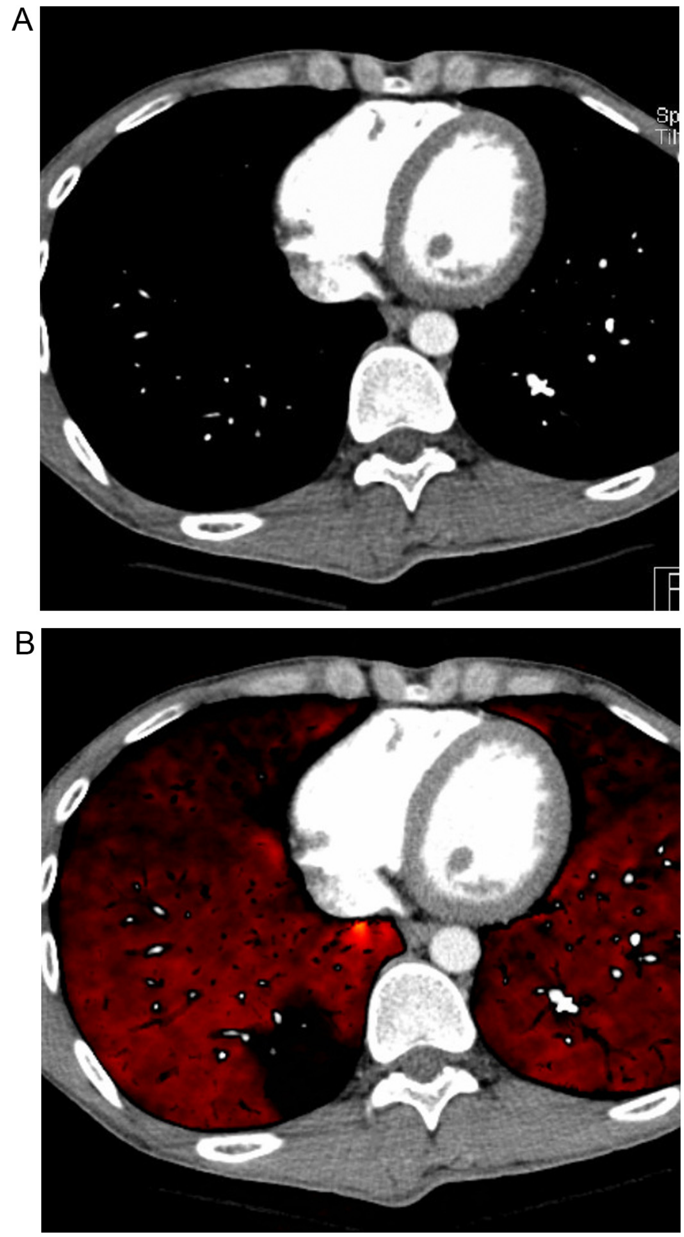


**Fig. 1.** CT pulmonary angiography (CTPA) and CTPA combined with color-coded lung perfused blood volume (LPBV) images in a patient suspected of having acute pulmonary embolism. In the peripheral pulmonary segments, the intrapulmonary clot is difficult to distinguish from the neighboring segmental or subsegmental branches using a CTPA (A). A trapezoidal-shaped iodine perfusion defect attaching with dorsal pleura suggests the presence of intrapulmonary clot in a peripheral pulmonary segment (B).

to the specific diagnoses and clinical information independently reviewed 2-mm slice CTPA and CTPA with color-coded LPBV images at a picture archiving system workstation (ShadeQuest/ViewR, Yokogawa Medical Solution Co., Tokyo, Japan). CTPA images with and without color-coded LPBV images were evaluated in separate session 4-week apart to minimize recall bias. Two interpretation sessions were held for each radiologist to review the CTPA only and CTPA with color-coded LPBV images over a 4-week interval. For each review session, the 2 readers were asked to record the following findings: the locations of IPCs (central, segmental or subsegmental) in each segment on CTPA and the regional iodine perfusion defects with IPCs on LPBV. On CTPA with color-coded LPBV, there were some artifacts correlated with the dense contrast material or cardiac motion artifact and the patients with