

Research Article

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Value of Dual-energy Lung Perfusion Imaging Using a Dual-source CT System for the Pulmonary Embolism

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Abstract: Objective: To investigate the diagnostic value of dual-energy lung perfusion imaging (DEPI) using a dual-source CT system for the pulmonary embolism (PE). Methods: 50 patients in high acute PE prevalence were enrolled to accept the DEPI (lung perfusion image and CTA image of pulmonary artery acquired through the Dual Energy software) and emergent DSA angiography (golden diagnostic criterion). Results: Patients using CT had significantly reduced examination duration and dosage of contrast agent than those using DSA examination, ($P < 0.05$). In total, 260 pulmonary arteries and 1020 pulmonary segments were examined through CTA, in which embolisms were identified in 50 lobes of lung, 108 pulmonary segments and 82 sub-segments. Reduction or lack of perfusion was identified through DEPI in 48 lobes of lung (concordance rate of 96.0%), 103 pulmonary segments (concordance rate of 95.4%) and 78 sub-segments (concordance rate of 95.1%). The comparison of embolism quantity and morphological characteristics of pulmonary artery between CTA images and DEPI images showed no statistically significant difference. Conclusion: Better application value can be achieved in the diagnosis of pulmonary embolism by dual-energy lung perfusion imaging using a dual-source CT system.

Keywords: Dual-energy lung perfusion imaging using a dual-source CT system; pulmonary embolism; diagnostic value

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1 Introduction

Pulmonary embolism (PE) is a disease with acute onset, severe symptoms and high mortality. The prevalence and mortality of PE are 0.5 to 12.6% and 30 to 90% respectively [1]. Pathogenesis of PE includes long-term confinement to bed, tumors, orthopedic surgery, perinatal period, trauma, vein thrombosis in lower limbs, etc. The incidence of erroneous diagnosis and misdiagnosis of PE is as high as 20 to 70% due to its atypical symptoms [2]. Generally, the clinical examination methods for PE include radionuclide ventilation/lung perfusion imaging, MR pulmonary perfusion, CTA and DSA. Radionuclide ventilation/lung perfusion imaging shows a high sensitivity in early stage diagnosis but a poor specificity, requires prolonged examination duration and is incapable of accurately assessing the severity of PE [3]. MR pulmonary perfusion could be used to monitor the anatomic and functional changes of PE but the technology is apt to interference by artifacts of heart and breath activity, as well as the gas inside the lung, and its image quality is in dire need of improvement [4]. CTA, a preferable method for diagnosis of PE with a higher sensitivity and specificity [5], measures anatomic changes but cannot be used to monitor the functional changes of pulmonary perfusion [6]. DSA, the preferred standard in PE diagnostics, is performed through incisions, resulting in the limited application of DSA in the early stages of PE [7]. With dual-energy lung perfusion imaging using a dual-source CT system processed by Dual Energy software, we can simultaneously obtain the image of pulmonary perfusion and the CTA image of the pulmonary artery, which shows better application value for the early diagnosis of PE [8-9]. In this study, we summarized the experience of DEPI application in diagnosis of PE, and obtained satisfactory results.

2 Subjects and methods

2.1 Data of subjects

We consecutively enrolled 50 patients who were hospitalized in the emergency department for the high prevalence of PE between January 2014 and June 2016 with clinical manifestations like severe chest distress, dyspnea, hypoxia or chest pain and various other high-risk factors. Patients with the following conditions were excluded: pulmonary diseases such as pulmonary infection, chronic obstructive pulmonary diseases, bronchial asthma, bronchiectasis, pulmonary interstitial fibrosis, pleural effusion or respiratory failure; extrapulmonary diseases such as heart failure, acute myocardial infarction, aortic dissection or esophageal hiatal hernia. Among these 50 patients, there were 32 males and 18 females, with an average age of 52.6 (\pm 16.7) years and an average onset-time of 1.5 (\pm 0.2) h.

Informed consent: Informed consent has been obtained from all individuals included in this study

Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

2.2 Study methods

DEPI and emergency DSA angiography were performed for examination, in which the DSA was performed regularly. The examination method for DEPI was as follows: we adopted the dual energy 64-slice spiral computed tomography (Siemens, Germany) with the voltages setting as 80 kv and 140 kv, currents as 220 mA and 55 mA, matrix as 512 \times 512, radiation dosage as 2 to 3 mSv, collimator as 32 \times 1.5 mm, pitch as 0.5, slice thickness as 0.6 mm and FOV as 26 cm. The scanning was ranged from the thoracic entrance to the horizontal plane of diaphragm. 50 ml of ultravist was injected using a double-syringe power injector by the intravenous mass injection through the elbow at a rate of 5 ml/s. Activation of the scanning system through artificial intelligence was delayed by 6 s and superior vena cava was set as the region of interest (ROI) with the threshold of 100 HU. The images were transmitted to the workstation, in which the 3 groups of images were reconstructed as

double energy images with the reconstruction value of 30 f and reconstruction slice thickness of 0.75 mm. Dual Energy software was initiated to select the automatic lung perfusion analysis pattern of lung PBV for image formation and color-coding DEPI. Perfusion-failed or sparsely perfused areas were observed through coronal view, sagittal view and axial view. CTPA images were loaded by 3D post-processing software for observing the presence, site and quantity of embolisms and morphologic characteristics of the pulmonary artery through different dimensions. PE was diagnosed using both CTPA and DEPI images interpreted by two professional radiologists simultaneously. A third professional radiologist would interpret if different opinions emerged. With the normally perfused area as reference, the abnormally perfused areas were divided into two degrees, i.e. sparsely perfused area and perfusion-failed area with lighter color or no color; the embolisms were divided into partial and complete embolism according to the morphologic features.

2.3 Observation indexes

The pulmonary artery was analyzed through the lobes, segments and sub-segments and examination time, as well as the dosage of contrast agent of CT and DSA, were compared to evaluate the accuracy, sensitivity, specificity, PPV and NPV of CT diagnosis with the diagnosis of DSA as reference to indicate the differences in the site and quantity of embolisms and the morphologic characteristics of pulmonary artery.

2.4 Statistical methods

SPSS20.0 software was applied for statistical analysis. Measurement data were presented as mean \pm standard deviation and independent t test was performed in intergroup comparison; count data were presented as case or (%) and chi-square test was performed in intergroup comparison. P value of $<$ 0.05 was used to determine statistical significance.

3 Results

3.1 Analysis of the examination duration and the dosage of contrast agent of CT and DSA

The examination duration and the dosage of contrast agent of CT were found to be significantly lower than

those of the DSA, with statistically significant differences ($P < 0.05$). See Table 1.

3.2 Analysis of accuracy, sensitivity, specificity, PPV and NPV of CT diagnosis

There were a total of 46 cases of PE (92.0%) diagnosed by DSA with 2 cases of hysteria, and 2 cases of acute cerebrovascular disorders. 42 cases of PE (84.0%) were diagnosed by CT with an accuracy of 91.3% (42/46). There were 41 true positive cases, 3 true negative cases, 1 false positive case and 5 false negative cases. The sensitivity, specificity, PPV and NPV were respectively 89.1%, 75.0%, 84.0% and 16.0%.

3.3 Analysis of the site and quantity of embolisms and the morphologic features of pulmonary artery

A total of 260 pulmonary arteries and 1020 pulmonary segments were evaluated by CTA examination, in which embolisms were identified in 50 lobes of lung, 108 pulmonary segments and 82 sub-segments. According to the diagnosis of DEPI, reduction or lack of perfusion was found in 48 lobes of lung with the concordance rate of 96.0% (48/50), 103 pulmonary segments with the concordance rate of 95.4% (103/108), and 78 sub-segments with the concordance rate of 95.1% (78/82). There was no statistically significant difference in comparison of the quantity of embolism and morphologic features of

pulmonary artery between the diagnoses of CTA and DEPI ($P > 0.05$). See Table 2.

4 Discussion

Research [10] has indicated that the clinical symptoms of pulmonary embolism are not significantly associated with the size and site of embolism and severe hypoxia might also be caused by small-sized embolism and embolism in peripheral artery. Dual-source CT, with shorter scanning time, less dosage of contrast agent and the ability to manage the radiation dosage in the minimal and safe margin and to acquire the anatomic and perfusion information of pulmonary artery simultaneously, shows a better application value in evaluation of lesions in lung and mediastinum and exclusion of extrapulmonary diseases [11]. As a functional imaging method, dual-energy CT can reflect the redistribution of iodine in the pulmonary parenchyma which is consistent with the distribution of blood perfusion; pulmonary embolism is mainly manifested by the reduction or lack of lung perfusion [12]. DEPI with better temporal and spatial resolution can obtain the anatomic data of slices of whole lung with a single scan, process the image of the pulmonary artery in three dimensions and shows a high sensitivity to small-sized embolisms and has small loss of perfusion [13].

In this study, we found that the examination duration and the dosage of contrast agent of CT were significantly lower than those of the DSA, indicating that the CT shows a better application value in the emergency examination

Table 1. Analysis of the examination duration and the dosage of contrast agent of CT and DSA

Group	Cases	Examination duration (min)	Dosage of contrast agent (ml)
CT examination	50	25.6±4.7	48.7±5.3
DSA examination	50	48.7±8.2	82.9±9.1
T		15.632	21.524
P		0.000	0.000

Table 2. Comparison of the quantity of embolism and morphologic features of pulmonary artery

	Quantity of embolism	Lobes of lung (cases)		Pulmonary segments (cases)		Sub-segments (cases)	
		Partial embolism	Complete embolism	Partial embolism	Complete embolism	Partial embolism	Complete embolism
CTA	2.5±1.3	38	12	78	30	42	40
DEPI	2.3±1.5	36	12	74	29	39	39
t/χ ²	0.152	0.013		0.004		0.024	
P	0.896	0.908		0.951		0.877	

and diagnosis of PE. CT exhibited a high accuracy, sensitivity, specificity and PPV in the diagnosis of PE, and the concordance rates were higher using CTA and DEPI to detect the embolism quantity in lung lobes, pulmonary segments and sub-segments. There was no statistically significant difference in comparison of the quantity of embolism and morphologic features of pulmonary artery between the diagnoses of CTA and DEPI, indicating the better application value of dual-energy lung perfusion imaging using a dual-source CT system in the diagnosis of pulmonary embolism.

However, the lung perfusion examination is affected by the body position, scanning sequence and blood flow of extrapulmonary organs. Clough et al. [14] found that under regular conditions, the volume of blood perfusion in the lower positions is larger than that in the higher positions, the volume in two lower lung fields is larger than that in two higher lung fields in upright posture and the volume in the dorsal part is higher than that in the ventral part in the supine posture; pulmonary lesions also affect the local volume of blood perfusion, leading to the abnormal blood perfusion. The inconformity in the condition of embolisms between CTA and DEPI can also be caused by the small-sized branches of the pulmonary artery, scanning in the early stage, insufficiently enhanced tiny pulmonary arteries, volume effect and cardiac motion; signs of clogged arteries are usually less obvious in CTA with decreased lung perfusion [15-16]. No linearity was identified between the severity of clinical symptoms of PE and the range of embolism. Complementary advantages between CTA and DEPI could be applied to clinical practices: with CTA easily identifying larger embolisms in the pulmonary artery, and DEPI showing a high detection rate in the small-sized PE in peripheral arteries [17-18]. Additionally, DEPI could also be used to assess the revascularization in the site where the embolism is dissolved and predict the clinical outcomes [19-20].

Conflict of interest: Authors state no conflict of interest.

References

- [1] Zhang LJ, Lu GM, Meinel FG, McQuiston AD, Ravenel JG, Schoepf UJ. Computed tomography of acute pulmonary embolism: state-of-the-art. *Eur Radiol* 2015;25(4):2547–2557.
- [2] Zhang LJ, Zhang Z, Li SJ, Meinel FG, Nance JW Jr, Zhou CS, Zhao YE, Schoepf UJ, Lu GM. Pulmonary embolism and renal vein thrombosis in patients with nephrotic syndrome: prospective evaluation of prevalence and risk factors with CT. *Radiology* 2014;273(10):897–906.
- [3] Leuschner G, Wenter V, Milger K, Zimmermann GS, Matthes S, Meinel FG, Lehner S, Neurohr C, Behr J, Kneidinger N. Suspected pulmonary embolism in patients with pulmonary fibrosis: Discordance between ventilation/perfusion SPECT and CT pulmonary angiography. *Respirology* 2016;Aug;21(6):1081-1087.
- [4] Hansch A, Kohlmann P, Hinneburg U, Boettcher J, Malich A, Wolf G, Laue H, Pfeil A. Quantitative evaluation of MR perfusion imaging using blood pool contrast agent in subjects without pulmonary diseases and in patients with pulmonary embolism. *Eur Radiol* 2012 Aug;22(8):1748-1756.
- [5] Geeting GK, Beck M, Bruno MA, Mahraj RP, Caputo G, DeFlicht C, Hollenbeak CS. Mandatory Assignment of Modified Wells Score Before CT Angiography for Pulmonary Embolism Fails to Improve Utilization or Percentage of Positive Cases. *AJR Am J Roentgenol* 2016;Aug 207(2):442-449.
- [6] Raczeck P, Minko P, Graeber S, Fries P, Seidel R, Buecker A, Stroeder J. Influence of Respiratory Position on Contrast Attenuation in Pulmonary CT Angiography: A Prospective Randomized Clinical Trial. *AJR Am J Roentgenol* 2016;Mar 206(3):481-486.
- [7] Leung AN, Bull TM, Jaeschke R, Lockwood CJ, Boiselle PM, Hurwitz LM, James AH, McCullough LB, Menda Y, Paidas MJ, Royal HD, Tapson VF, Winer-Muram HT, Chervenak FA, Cody DD, McNitt-Gray MF, Stave CD, Tuttle BD; ATS/STR Committee on Pulmonary Embolism in Pregnancy. American Thoracic Society documents: an official American Thoracic Society/ Society of Thoracic Radiology Clinical Practice Guideline-- Evaluation of Suspected Pulmonary Embolism in Pregnancy. *Radiology* 2012;Feb;262(2):635-646.
- [8] Tang CX, Zhou CS, Zhao YE, Schoepf UJ, Mangold S, Ball BD, Han ZH, Qi L, Zhang LJ, Lu GM. Detection of pulmonary fat embolism with dual-energy CT: an experimental study in rabbits. *Eur Radiol* 2016;Aug 10(8):156-157.
- [9] Tang CX, Zhang LJ, Han ZH, Zhou CS, Krazinski AW, Silverman JR, Schoepf UJ, Lu GM. Dual-energy CT based vascular iodine analysis improves sensitivity for peripheral pulmonary artery thrombus detection: an experimental study in canines. *Eur J Radiol* 2013; 82(5):2270–2278.
- [10] Vongchaiudomchoke T, Boonyasirinant T. Positive Pulmonary Computed Tomography Angiography in Patients with Suspected Acute Pulmonary Embolism: Clinical Prediction Rules, Thromboembolic Risk Factors, and Implications for Appropriate Use. *J Med Assoc Thai* 2016;Jan 99(1):25-33.
- [11] Sakamoto A, Sakamoto I, Nagayama H, Koike H, Sueyoshi E, Uetani M. Quantification of lung perfusion blood volume with dual-energy CT: assessment of the severity of acute pulmonary thromboembolism. *AJR Am J Roentgenol* 2014;203(15):287–291.
- [12] Nagayama H, Sueyoshi E, Hayashida T, Ashizawa K, Sakamoto I, Uetani M. Quantification of lung perfusion blood volume (lung PBV) by dual-energy CT in pulmonary embolism before and after treatment: preliminary results. *Clin Imaging* 2013;37(13):493–497.
- [13] Meinel FG, Graef A, Thieme SF, Bamberg F, Schwarz F, Sommer WH, Helck AD, Neurohr C, Reiser MF, Johnson TR. Assessing pulmonary perfusion in emphysema: automated quantification of perfused blood volume in dual-energy CTPA. *Invest Radiol* 2013;48(6):79–85.
- [14] Clough AV, Haworth ST, Roerig DL, Hoffman EA, Dawson CA. Influence of gravity on radiographic contrast material-based

- measurements of regional blood flow distribution. *Acad Radiol* 2003;10(2):128-138.
- [15] Chai X, Zhang LJ, Yeh BM, Zhao YE, Hu XB, Lu GM .Acute and subacute dual energy CT findings of pulmonary embolism in rabbits: correlation with histopathology. *Br J Radiol* 2012;85(6):613–622.
- [16] Bauer RW, Frellesen C, Renker M, Schell B, Lehnert T, Ackermann H, Schoepf UJ, Jacobi V, Vogl TJ, Kerl JM. Dual energy CT pulmonary blood volume assessment in acute pulmonary embolism – correlation with D-dimer level, right heart strain and clinical outcome. *Eur Radiol* 2011;21(10):1914–1921.
- [17] Zhang LJ, Lu L, Bi J, Jin LX, Chai X, Zhao YE, Chen B, Lu GM. Detection of pulmonary embolism comparison between dual energy CT and MR angiography in a rabbit model. *Acad Radiol* 2010;17(6):1550–1559.
- [18] Bauer RW, Kerl JM, Weber E, Weisser P, Korkusuz H, Lehnert T, Jacobi V, Vogl TJ. Lung perfusion analysis with dual energy CT in patients with suspected pulmonary embolism – influence of window settings on the diagnosis of underlying pathologies of perfusion defects. *Eur J Radiol* 2011;80(9):e476–e482.
- [19] Krissak R, Henzler T, Reichert M, Krauss B, Schoenberg SO, Fink C. Enhanced visualization of lung vessels for diagnosis of pulmonary embolism using dual energy CT angiography. *Invest Radiol* 2010;45(5):341–346.
- [20] Ferda J, Ferdová E, Mírka H, Baxa J, Bednářová A, Flohr T, Schmidt B, Matějovič M, Kreuzberg B. Pulmonary imaging using dual-energy CT, a role of the assessment of iodine and air distribution. *Eur J Radiol* 2011;77(8):287–293.