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RESEARCH

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Clinical application of third-generation dual-source CT-based dynamic imaging reconstruction for pulmonary embolism imaging

Kai Liao[1†], Biao Ye[2†], Xi Li[3], Wei Liu[3], Tongtong Jia[3], Zongbao Han[3], Ziyi Liang[3], Yongli Duan[3], Xiaoli Sun[3], Jianmei Zhang[3], Rengui Wang[3] and Jiao Gong[4*]

Abstract

Background To evaluate the clinical diagnostic value of third-generation dual-source CT for pulmonary embolism, focusing on the optimization of dual-source CT scanning with dynamic reconstruction in acute pulmonary embolism (PE) and various imaging manifestations.

Methods Eighty-two patients with pulmonary embolism were enrolled and randomly divided into standard CT angiography (SCTA) and dynamic CT angiography (DCTA). DCTA patients were divided into dynamic CT angiography arterial phase (DCTAa), time phase Angiography reconstruction (TMIP-CTA), and 4D noise reduction TMIP-CTA according to the image reconstruction. The region of interest was selected in the region of the pulmonary trunk and its branches, respectively. The vessel CT value and image background noise (IN) of each subgroup were also determined, and the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated. Simultaneously two radiologists performed a subjective evaluation of the quality of the picture images.

Results The DCTA group had a lower contrast dose than the SCAT group, but the vessel CT value, IN, CNR, and SNR were significantly higher in the DCTA group compared with the SCTA group. CT of the vascular lumen was generally higher in all subgroups of DCTA than in SCTA, with the highest in the TMIP-CIA group. IN was significantly higher in both the DCTAa and TMIP-CTA groups than in the SCTA group. SNR and CNR were elevated in TMIP-CTA and 4D noise reduction TMIP-CTA compared to the SCTA group. In addition, the subjective image quality scores of the DCTA group were significantly higher than those of SCTA, and the 4D noise reduction TMIP-CTA had the most. However, the ED of the SCTA group was lower than that of the DCTA group.

Conclusion 4D noise reduction TMIP-CTA based on DCTA reconstruction significantly improves the quality of pulmonary artery CTPA images and increases the clinical diagnostic rate, with potential for clinical dissemination.

Keywords CTPA, PE, TMIP-CTA, SNR, CNR

†Kai Liao and Biao Ye contributed equally to this work.

*Correspondence:
Jiao Gong
gongjiaocq380@163.com

Full list of author information is available at the end of the article

Background

Pulmonary embolism (PE) represents a spectrum of clinical and pathological manifestations arising from the obstruction of the main trunk and branches of the pulmonary arteries by different types of emboli [1, 2]. As is the third most common acute cardiovascular disease, PE has the highest incidence after myocardial infarction and stroke [3]. However, due to complex etiology and hidden symptoms, patients are easy to misdiagnose and underdiagnose. In addition, the acute onset and sudden incidence of PE patients, resulting in a mortality rate of up to 25% [4], poses a serious threat to human health and imposes a huge medical and economic burden on the country. It is estimated that annual expenditure on the treatment of PE in United states reaches up to $10 billion [5]. Rapid and accurate diagnosis of PE can significantly improve patient outcomes and avoid overdiagnosis and unnecessary treatment.

Computed tomography pulmonary angiography (CTPA) remains the preferred option for pulmonary angiography in patients with suspected PE, because of its high sensitivity (83%) specificity (96%), and accessibility [6]. However, it should be noted that despite these advantages, CTPA may have limitations in detecting embolism in distal pulmonary arterioles [7]. Facrtors such as pulmonary artery anatomic variation, respiratory movement artifact and contrast agent enhancement patterns can contribute to missed diagnoses, potentially contributing to the current PE mortality rate o 8–15% [8]. Therefore, there is an urgent need to find an imaging method that can replace or supplement CTPA. Dual-source CT (DSCT) has attracted much attention in the image diagnosis of PE in recent years due to it can obtain the whole-lung thin layer dissection image and functional information in a single scan. Previous studies have found that the use of DSCT can prove to be of added value in PE diagnosis by providing additional spectral information and reducing radiation dose [9].

Standard computed tomography angiography (SCTA) of pulmonary arteries sometimes fails to accurately capture the optimal phase of arterial enhancement. In contrast, temporal maximum intensity projection (TMIP) revascularization with dynamic computed tomography angiography (DCTA) of the pulmonary artery has been more widely used in acute ischemic stroke [10] and cardioembolic stroke [11], and it can more accurately demonstrate intracranial thrombus loading than SCTA. However, the application of TMIP-CTA in CTPA has been less studied.

Based on the third-generation DSCT technology, this study further studied the application of different reconstruction methods in PE by comparing the CTA image effect and diagnosable ratio.

Methods

The study was conducted following the guidelines of the Declaration of Helsinki and approved by the Beijing Shijitan Hospital Ethics Committee (Approval number: 2020-18). Subjects signed an informed consent form.

Participants in this research

Patients with suspected PE were admitted to the Beijing Shijitan Hospital from March 2020 to December 2021. The inclusion criteria were: (1) having suspected manifestations of PE, such as chest pain, chest tightness, dyspnea, and cerebral hypoxia; (2) signing informed consent and undergoing DSCT examination. Exclusion criteria: (1) allergy to contrast media; (2) presence of medically and technically interfering conditions such as critical illness, pacemakers, cardiovascular disease, or joint prostheses; (3) chronic obstructive pulmonary disease, massive pleural effusion, pulmonary interstitial fibrosis; (4) recent (within one month) history of trauma, major surgery, and intracranial hemorrhage. SPSS random generator (SPSS, version 23.0) was utilized to randomized 84 subjects into two examination groups: SCTA and DCTA. Among them, DCTA was subdivided into a total of 3 groups according to different reconstruction methods, such as dynamic CT angiography arterial phase (DCTAa), TMIP-CTA, and 4D noise reduction TMIP-CTA. Clinical baseline characteristics of patients in each group were recorded.

CT scanning protocol

All examinations were conducted with Siemens's third-generation dual-source CT. Before examination, all patients were removed from the metal foreign body and placed in a supine position for examination with the headfirst and the patient's arms parallel over the head. Patients were also asked to hold their breath for 5–10 s after injection of the contrast agent to capture the image when the concentration of the contrast agent in the pulmonary artery reaches its peak, to ensure image quality and diagnostic accuracy.

For SCTA, the cluster injection tracking technique was mainly used to place the pulmonary trunk bifurcation and the area of interest to measure the peak time. At the same time, 50 mL of nonionic contrast agent iopromamide injection (350 mg/mL) at a rate of 4 mL/s, followed by 30 mL of NaCl; helical scanning mode with collimation of 192 mm×0.6 mm, pitch of 0.55, tube voltage 90 kV, tube current CAREDose 4D, rotation time of 0.25 s; layer thickness of 1.0 mm, and layer spacing of 0.7 mm were used to reconstruction.

For DCTA, the dynamic CTA consisted of 6 thin-layer sequences (6 successive thin layer collections), and a single injection of 20 mL of non-ionic contrast ioprotramine injection was injected at a rate of 5 mL/s, followed by 20 mL NaCl, and 6 times were collected in a cranio-caudal dirrection in an adaptive 4D spiral mode, with an interval of 8–12 s between scans at the end of the scan and the next scan. The tube voltage is 80 kVm and the tube current is 50 mA. The rotation time is 0.32s. Scans were triggered using tracking at a trigger threshold of 100 HU, and in order to obtain adequate pulmonary vascular filling, scans were performed immediately 7 s after the peak of pulmonary artery enhancement. The layer thickness was 1.0 mm and the layer interval was 0.7 mm for reconstruction. Acquisition and reconstruction parameters in the two groups are recorded in Table 1.

Image reconstruction of the DCTA data set

At the end of the examination, 3 sets of data were automatically generated, respectively sn140kV, 80 kV, the average weighted 120 kV image with a fusion coefficient of 0.6, the raw data were reconstructed to a layer thickness of 1.0 mm and a layer spacing of 0.7 mm, and the reconstructed image data were transferred to the Syngo. via post-processing workstation for DCTA data processing. Data processing for DCTA using Syngo.via post-processing workstation. For the DCTAa reconstruction: 120 thin layer sequences from DCTA were analyzed with a dynamic angiography card, and lumen-enhanced CT values were measured at the mian pulmonary artery bifurcation, with the highest peak period phase was obtained on the time-density curve, defined as DCTAa. In contrast, TMIP-CTA images were reconstructed by extracting from the DCTA dataset and using the the DCTAa phase as the centroid, the two phases before and after the DCTAa phase were selected from the plotted time-density curves for image fusion, and the centroid phase was used as the electro-mechanical for the voxel motion correction. Next, the node of the maximum CT value generated by each voxel at the enhancement overweight was evaluated and fused to generate the TMIP data, and fincally, the reconstructed 3D vascular image become TMIP-CTA. As for the 4D noise reduction TMIP-CTA, we used the 4D-CTA commercial software package and the intrinsic data-driven HYPR4D noise reduction technique to reconstruct the 3D images of blood vessels by dynamically processing the TMIP-CTA data and applying automated voxel motion correction and dedicated noise reduction techniques (Fig. 1). For fair comparison, an iterative reconstruction algorithm with similar noise reduction effect was selected for image reconstruction in SCTA.

Table 1 Acquisition and reconstruction parameters

Parameters	SCTA	DCTA
Scan mode	Spiral scan	Adaptive 4D spiral model
Collimation	192 × 0.6 mm	Whole pulmonic tree
Rotation time, s	0.25	0.32
Tube Voltage, kV	90	80
Tube current time product, mAs	CARE Dose 4D	50
Amount of contrast medium, mL	50	20
Amount of saline chaser medium, mL	30	20
Flow rate, mL/s	4	5
Slice Thickness, mm	1.0	1.0
Reconstruction Interval, mm	0.7	0.7

Annotation: DCTA, dynamic computed tomography angiography; SCTA, Standard computed tomography angiography

Evaluation of objective image quality

Objective evaluation of results by image quality and radiation dose. Two senior doctors selected regions of interest (ROIs) were selected at the beginning of the main pulmonary artery, right pulmonary trunk artery, left pulmonary trunk artery, right upper lobe pulmonary artery, right middle lobe pulmonary artery, right lower lobe pulmonary artery, left upper lobe pulmonary artery, left middle lobe pulmonary artery, left lower lobe pulmonary artery in each group of images, respectively, and the CT values were measured separately. According to the previous studies [1], the image background noise (IN) was determined by the standard deviation (SD) of the CT value by placing an ROI in the pericardial fat zone. Signal to noise ratio (SNR) = CT_{vessel} / IN; contrast to noise ratio (CNR) = (CT_{vessel}-CT_{muscle})/ IN. The CT dose index ($CTDI_{vol}$ [mGy]) and dose length product (DLR [mGy·cm]) were extracted from the examination reports transmitted from the CT scanner to PACS. Effective dosage (ED [mSv]) = DLR (mgy·cm) × *k*, in which, *k* is the weight or conversion factor of the chest CT scan and is approximately 0.014 $mSv \cdot mGy^{-1} \cdot cm^{-1}$.

Subjective analysis of image quality

In the syngo.via post-processing workstation, image quality was evaluated by two attending radiologists with many years of experience using a 5-point rating method [12]. Scoring criteria: image quality, border sharpness, noise, and artifacts of grade 5 and 6 pulmonary artery branches are related from 5 to 1 in order of good to poor.

Score 5: Clear image with fully visible grade 5 and 6 pulmonary artery branches, rich in detail, sharp vessel borders, little noise, and minimal artifacts not affecting observation.

Score 4: Mostly clear image with most pulmonary artery branches visible, slight blurring of some details, sharp vessel borders, minimal noise and artefacts not affecting observation.

Score 3: Average image quality with grade 5 branches visible but grade 6 blurred, slightly blurred vessel borders, some noise, and artefacts, not hindering overall observation.

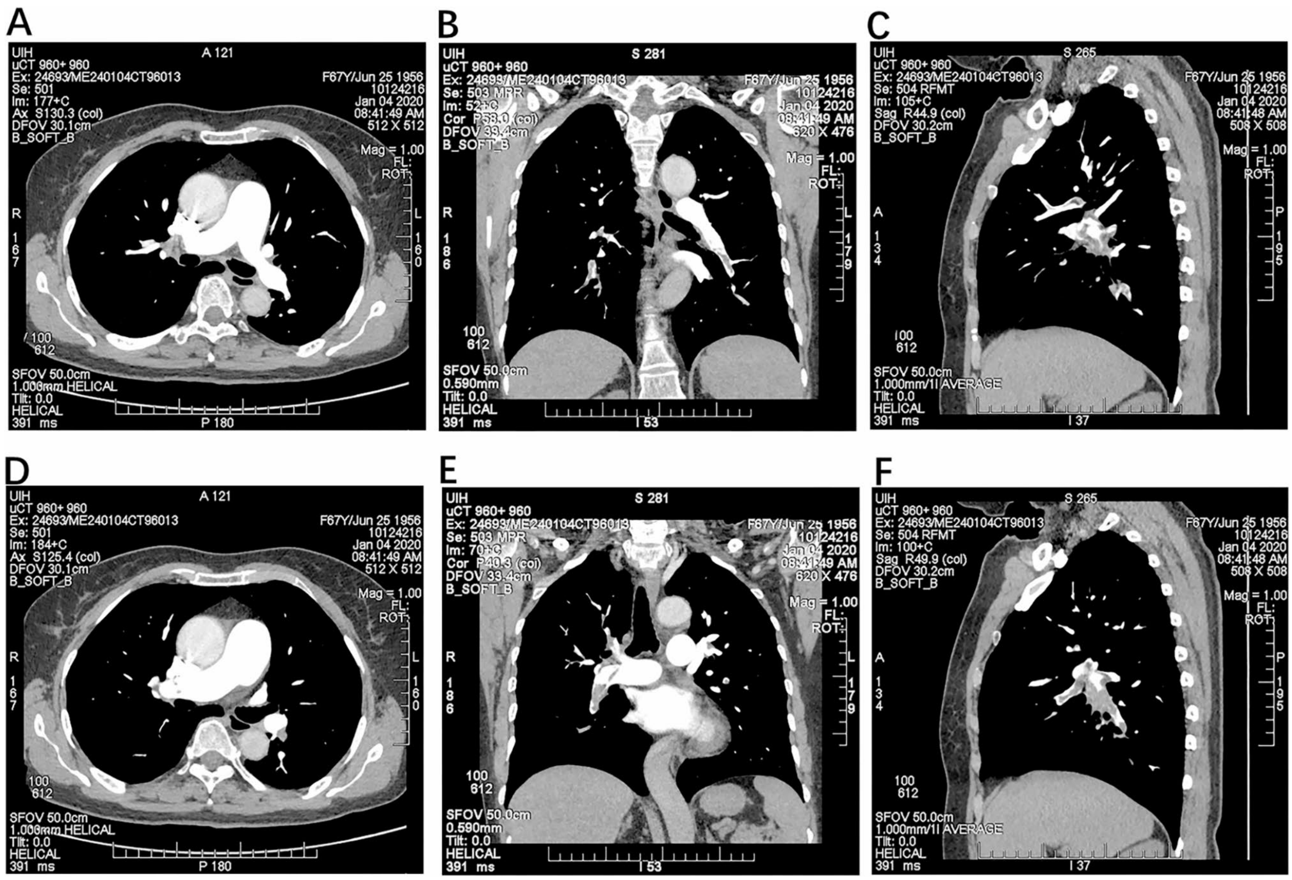

Fig. 1 Pulmonary attery 4D noise reduction TMIP-CTA (**A**-**C**) and SCTA examination (**D**-**F**). **A**/**D** is the horizontal axis; **B**/**E** is coronal; **C**/**F** is sagittal

Score 2: Poor image quality with partially visible grade 5 branches and difficult-to-recognize grade 6 branches, blurred vessel boundaries, more noise and artefacts impacting observation.

Score 1: Very poor image quality with barely visible grade 5 and 6 branches, vessels indistinguishable from surrounding tissue, severe noise, and artefacts greatly affecting observation.

In this study, image quality with a subjective score of 4 to 5 was defined as diagnosable PE, and image quality with a subjective score of 1–3 was defined as non-diagnosable PE.

Statistical analysis

Statistical software SPSS 23.0 and GraphPad Prism 9.0 were used for statistical analysis and chart drawing. Continuous variables are expressed as mean ± SD when normally distributed and were compared with ANOVA analysis. Whereas, when data did not conform to normal distribution they were expressed as median (interquartile spacing) and analyzed using the Mann-Whitney U test. The count data were expressed as n (%) and analyzed by chi-square test. The results were considered significant if the P value was ≤ 0.05.

Table 2 The baseline data of subject in the two group

Parameters	SCTA ($n = 42$)	DCTA ($n = 42$)	P value
Age (year)	53 ± 11	54 ± 10	0.738
Weight (kg)	72.88 ± 16.67	73.47 ± 19.71	0.883
Height (m)	1.72 ± 0.10	1.69 ± 0.06	0.080
BMI (kg/m^2)	24.86 ± 6.05	25.56 ± 6.77	0.621
Males, n (%)	27 (64.29)	25 (59.52)	0.822

Annotation: DCTA, dynamic computed tomography angiography; SCTA, Standard computed tomography angiography; BMI, body mass index

Results

Baseline characteristics of patients

CTA was completed in both groups without any contrast allergic reaction. The clinical baseline characteristics of patients in the two groups are shown in Table 2. In the DCTA groups, the mean age was 54 ± 10 years old, BMI was 25.56 ± 6.77 kg/m^2 and 25 (59.52%) were males. In the SCTA group, the mean age was 53 ± 11 years old, BMI was 24.86 ± 6.05 kg/m^2 and 27 (64.29%) were males. There was no statistical difference between the two groups in terms of age, height, weight, BMI, and gender.

Objective image quality

The objective evaluation of image quality in each group is shown in Table 3. The mean vessel CT values in the DCTA group were significantly higher than in the SCTA ($P < 0.05$). The CT values of the individual pulmonary artery trunks and branches were also generally higher in the different reconstruction modalities of DCTA than in the SCTA group ($P < 0.05$). In addition, IN and SNR were significantly higher in the DCTA than in the SCTA group ($P < 0.05$). In addition, IN and SNR were significantly higher in the DCTA than in the SCTA ($P < 0.05$). Among the four groups, SCTA had the lowest IN ($P < 0.05$). Furthermore, compared with the SCTA group, SNR and CNR were significantly increased in the 4D-noise reduction TMIP-CTA and TMIP-CTA ($P < 0.05$), among which the increase was most significant in the 4D-noise reduction TMIP-CTA ($P < 0.05$).

Subjective image quality assessment

There was a significant difference in the subjective scores between the two groups of patients (Table 4), where the subjective scores of DCTA were all significantly higher than those of SCTA in the 2,3, and 5 point compartments ($P < 0.05$), and the subjective scores of 4D noise reduction TMIP-CTA were mostly in the range of 5 (92.86%), whereas most of the subjective scores of SCTA were in the 3-point (40.48%).

Radiation dose measurement

The mean DLR in the SCT group was 104.75 ± 31.85 mGy·cm, while 131.79 ± 29.19 mGy·cm in the DCTA group. ED in the SCTA group was 1.47 ± 0.45 mSv was lower than the DCTA 1.84 ± 0.41 mSV ($P < 0.001$, Table 4).

Diagnosis of PE patients by DCTA and SCTA

As shown in the results of Table 4, the difference between DCTA and SCTA in the diagnosable rate of PE patients was statistically significant ($P = 0.023$). The diagnosable rate of SCTA was 50%, whereas the diagnosable rate of DCTAa was 76.19%, whereas the diagnosable rates of both TMIP-CAT and 4D noise reduction TMIP-CTA were 100% and significantly higher than those of SCTA and DCTAa ($P < 0.001$, Table 4). Good consistency in observer ratings (Kappa = 0.805).

Discussion

CTPA has become the reference standard for PE. CTPA can be performed within minutes in patients with suspected PE and has high sensitivity and specificity [13]. An estimated 2.4 million CTPA scans are performed annually in emergency departments in the USA to look for PE, and the number of CTPAs is expected to increase globally due to the increasing availability of computed

Table 3 Data of objective image quality for both protocols

Parameters	SCTA	DCTA				P value$_{\text{DCTA vs. SCTA}}$	P value $_{\text{DCTAa vs. SCTA}}$	P value $_{\text{vs. SCTA}}$	P value$_{\text{4D}}$
		DCTAa	TMIP-CTA	4D noise reduction TMIP-CTA	Total				noise reduction TIMP–CTA vs. SCTA
CT $_{\text{vessel}}$, HU									
Global	326.09 ± 60.20	583.28 ± 92.59	613.14 ± 96.25	606.67 ± 86.74	600.05 ± 30.33*	0.000	0.000	0.000	0.000
MPA	346.30 ± 47.32	517.37 ± 90.55	550.18 ± 94.83	640.80 ± 85.99	569.78 ± 104.21*	0.000	0.000	0.000	0.000
RPA	338.74 ± 58.60	537.24 ± 96.60	567.33 ± 75.67	553.44 ± 69.08	552.67 ± 81.59*	0.000	0.000	0.000	0.000
LPA	311.25 ± 77.11	586.30 ± 84.49	620.16 ± 67.98	621.22 ± 76.82	609.22 ± 77.84*	0.000	0.000	0.000	0.000
RULPA	334.84 ± 52.77	580.74 ± 95.09	561.79 ± 81.98	547.98 ± 86.41	563.50 ± 88.32*	0.000	0.000	< 0.000	0.000
RMLPA	327.91 ± 63.17	619.22 ± 87.36	660.22 ± 73.23	588.23 ± 98.46	622.56 ± 91.21*	0.000	0.000	0.000	0.000
RLLPA	315.87 ± 81.47	602.52 ± 86.07	654.97 ± 90.33	626.38 ± 79.64	627.96 ± 87.46*	0.000	0.000	0.000	0.000
LULPA	331.63 ± 58.41	577.67 ± 72.34	643.30 ± 77.16	624.97 ± 86.58	615.31 ± 77.44	0.000	0.000	0.000	0.000
LMLPA	316.82 ± 58.86	618.38 ± 83.83	606.26 ± 89.09	623.96 ± 93.65	616.20 ± 86.15	0.000	0.000	0.000	0.000
LLLPA	332.87 ± 53.32	610.05 ± 87.48	654.1 ± 79.46	632.03 ± 75.28	630.48 ± 80.49	0.000	0.006	0.000	0.000
IN, HU	24.46 ± 3.81	33.96 ± 3.23	32.04 ± 4.76	28.31 ± 7.66	31.77 ± 5.12	0.000	0.000	0.000	0.073
SNR	13.33 ± 3.76	16.94 ± 3.02	18.15 ± 2.56	19.57 ± 4.27	18.54 ± 3.39	0.013	0.086	0.027	0.000
CNR	12.87 ± 2.49	14.98 ± 2.08	17.90 ± 2.52	18.85 ± 4.26	17.57 ± 3.68	0.002	0.055	0.018	0.000

Annotation: DCTA, dynamic computed tomography angiography; SCTA, Standard computed tomography angiography; BMI, body mass index. MPA, Main pulmonary artery; RPA, Right pulmonary trunk artery; LPA. Left pulmonary trunk artery; RULPA, Right upper lobe pulmonary artery; RMLP,. Right middle lobe pulmonary artery; RLLPA, Right lower lobe pulmonary artery; LULPA, Left upper lobe pulmonary artery; LMLPA, Left middle lobe pulmonary artery; LLPA, Left lower lobe pulmonary artery; IN, image background noise; SNR, Signal to noise ratio; CNR, contrast to noise ratio

Table 4 Subjective image quality

Parameters	SCTA (n = 42)	DCTA (n = 42)			P value	P value	P value	P value
		DCTAa	TMIP-CTA	4D noise reduction TMIP-CTA	DCTA vs. SCTA	DCTAa vs. SCTA	TMIP–CTA vs. SCTA	4D noise reduction TMIP–CTA vs. SCTA
Subjective scoring, n (%)								
2	4 (9.52)	0 (0)	0 (0)	0 (0)	0.006	0.116	0.116	0.116
3	17 (40.48)	10 (23.81)	0 (0)	0 (0)	0.000	0.160	0.000	0.000
4	19 (38.78)	22 (52.38)	7 (16.67)	3 (7.14)	0.196	0.663	0.009	0.000
5	2 (4.76)	10 (23.81)	35 (83.33)	39 (92.86)	0.000	0.026	0.000	0.000
Mean scoring	3.44 ± 0.73	3.96 ± 0.68	4.74 ± 0.45	4.90 ± 0.28	0.000	0.000	0.000	0.000
Available for diagnosis, n (%)	21 (50)	32 (76.19)	42 (100)	42 (100)	0.038	0.023	0.000	0.000
DLR, mGy·cm	104.75 ± 31.85	131.79 ± 29.19			0.006			
ED, mSv	1.47 ± 0.45	1.84 ± 0.41			0.000			

The table presents the subjective evaluation of one CT physician's image, while the mean scoring comes from the average of two experts. DLP, dose-length product; ED, effective dose, calculated as DLP × conversion factor of thorax (k = 0.014)

tomography scanners in many parts of the world [5]. However, concerns persist regarding CTPA due to its associated radiation dose, anatomical variability of the pulmonary arteries, inhomogeneity of the contrast agent, and artifacts of the patient's respiratory movements that often to unsatisfactory diagnosis or missed diagnosis [14]. Thus far, several studies have investigated CTPA scanning protocols in the search for solutions to improve image quality and diagnostic feasibility [15]. Compared with ordinary CT, DSCT has the advantages of fast imaging speed, excellent image quality, larger scanning range, low radiation dose, and a wide range of applicable people, which can display the information of the disease in a more subtle way, which is conducive to the early discovery of the disease, early diagnosis, and early and effective treatment [16]. For patients with PE, DSCT can precisely delineate the location and size of the embolism, facilitating improve lesion location [17]. Therefore, in this study, we combined CTPA with third-generation DSCT and analyzed the image quality and diagnostic value of different SCTA and DCTA in diagnosing PE. SNR and CNR are important measures of image quality, and they are affected by a variety of factors, of which the reconstruction parameters are one of the key factors. To ensure the accuracy of SNR and CNR comparisons, we compared the differences in SNR and CNR after ensuring that the reconstruction parameters (layer thickness, layer spacing) were consistent. In DCTA, the 4D noise reduction on the TMIP-CTA reconstruction technique accurately obtains the phase of the period in which the contrast reaches the peak, thus constructing the maximum intensity of the complete pulmonary vascular tree with enhanced consistency and improving the detection rate of pulmonary emboli. In the present study, we have found that 4D noise reduction on TMIP-CTA is higher than other CTA techniques in terms of CT value of vessel lumen, SNR, CNR and quality of pulmonary artery vascular images.

The low density and poor contrast of the sub-segments of the pulmonary arteries and their distal branches usually lead to failure to diagnose. In contrast, the improvement of contrast-enhanced CT in the lumen of pulmonary arterial vessels strongly increases the tissue contrast with PE emboli and may improve the detection of small lesions. Although there are potential complications following contrast administration, such as contrast nephropathy [18], this risk is relatively low in individuals with normal renal function. In this study, multiple thin-layer sequential acquisitions based on DCTA required a more homogeneous and rapid distribution of the contrast agent, and we used a smaller contrast agent and a faster injection rate. SCTA employs a doughnut injection tracking technique to determine the optimal timing of acquisitions by measuring the time to peak in the region of interest at the level of the bifurcation of the pulmonary arteries trunk, which requires a larger amount of contrast agent to ensure adequate visualization of the pulmonary arteries and accurate This requires more contrast to ensure adequate visualization of the pulmonary arteries and accurate time-to-peak measurements, so we chose to use a larger amount of contrast and a slower speed. In the present study, although the amount of contrast agent used was higher in SCTA (50 ml) than in DCTA (20 ml), according to the available literature, a contrast agent dose of 50 ml is usually considered safe in patients with normal renal function and no significant renal impairment was observed. However, to minimize potential risks, it is still recommended that the amount of contrast agent used is minimized as much as possible while ensuring diagnostic quality. It is worth noting that despite the fact that SCTA uses more contrast agent, the TMIP-CTA technology achieves a significant improvement in image quality through increased lumen CT values and 4D noise reduction, making DCTA superior to SCTA in terms of subjective imaging, with sharper image detail and more pronounced vascular filling. Motion artifacts are another cause of poor diagnostic treatment on CTPA images. For example, patients who are unable to hold their breath and who cannot control their breathing in everyday life (e.g. comatose patients, deaf patients, the elderly, infants, etc.) will have motion artifacts on CT scans [6]. Due to the faster scanning speed of DCTA, the physiological movement of these patients is relatively slower, and the scanning can be completed in the shortest possible time and clear images can be obtained without holding their breath, and the phenomenon of affecting the misalignment and discontinuity of the imaging effect rarely occurs, which greatly improves the success rate of pulmonary arteriography and the detection rate of pulmonary embolism. This broadens the scope of the CTPA's applicability to the population.

Noise and radiation dose are also key factors affecting CTPA. Reducing the tube voltage is considered to be one of the more direct and effective ways to reduce the CT radiation dose since the X-ray radiation dose is proportional to the square of the tube voltage. Lowering the tube voltage reduces the radiation dose to the patient while at the same time increasing the CT value of the pulmonary artery enhancement, as the X-ray spectral energy decreases with decreasing tube voltage. However, the reduction in tube voltage leads to a reduction in the radiation dose and inevitably to a reduction in the penetration of the X-rays, leading to a reduction in the number of photons reaching the detector and an increase in the image noise, thus affecting the diagnostic accuracy. In this study, the tube voltage in the SCTA group was higher than the tube voltage in the DCTA group, so IN was slightly lower in the SCTA group. However, there was no significant difference between 4D noise reduction on TMIP-CTA and SCTA, suggesting that 4D noise reduction on TMIP-CTA can ensure image quality and increase diagnostic results while reducing radiation.

The complexity of the pulmonary arteries, their many branches, the existence of a dual blood supply, and changes in cardiac output all make the contrast agent reach each vessel at different times, thus affecting the diagnostic effect. And it is difficult for SCTA to capture the maximum temporal direction of its enhancement. In contrast, when DCTA is performed for rapid doughnut injection, the entire pulmonary artery can be swept back and forth to obtain the value of the full temporal phase dynamics of contrast enhancement. Moreover, since DCTA includes the entire process of contrast agent reflux into the pulmonary artery, its raw data can be restructured for dynamic multi-phase angiographic 3D mapping, thus resolving the temporal interference of SCTA images. The changes in the small branches of each pulmonary artery can also be significantly observed by film playback. In addition, TMIP, as an image fusion technique for four-dimensional data, includes conventional post-processing functions to achieve lumen enhancement in the largest temporal region of the pulmonary artery vasculature, thus avoiding the problem of the arrival time of the contrast agent.

The results of this study showed that all 42 patients were PE patients and the diagnostic rate of DCTA for PE patients was generally higher than that of SCTA, in addition, the diagnostic rate of TMIP-CTA and 4D noise reduction TMIP-CTA in DCTA for PE patients was 100%. However, the latter had a higher subjective image score and clearer images.

Considering the present study, the following limitations must be attended to. Firstly, as heavier patients contain more fat and muscle tissue, and the reduced radiation of X-rays under 80 V and low mA conditions has an effect on the image noise of dual-source CT scanning. This issue was ignored in this study, which is a potential limitation of this study, and in a follow-up study, we will scan the patients at different parameters according to their body size and weight to further improve the diagnosticity of the patients. In addition, the greatest difficulty with DCTA remains the radiation dose, and although the DCTA in this study was within reasonable limits, more reasonable radiation doses and improvements in image quality still need to be investigated. Furthermore, issues such as voxel localisation at different stages, motion blur and temporal resolution also need to be investigated in future studies to incorporate more complex techniques or receive more attention to improve image quality and diagnostic accuracy in a timely manner. In order to obtain more accurate experimental data, we implemented strict exclusion criteria, which may have a certain inclusiveness bias, which is another limitation of this study. We will relax the criteria and expand the sample size for a more in-depth study in the follow-up study.

Conclusions

In conclusion, 4D noise reduction on TMIP-CTA based on DCTA reconstruction significantly improves the quality of pulmonary artery CTPA images and may enhance-clinical diagnostic accuracy. However, it is worth noting that despite the low contrast requirement and high image quality in the DCTA group, which resulted in a high diagnostic PE accuracy, the radiation dose was also significantly higher, which is a potential drawback of this technique and requires further investigation of noise reduction strategies.

Abbreviations

CNR	Contrast-to-noise ratio
CTDI	CT dose index

CTPA	Computed tomography pulmonary angiography
DCTA	Dynamic CT angiography
DCTAa	Dynamic CT angiography arterial phase
ED	Effective dosage
IN	Image background noise
PE	Pulmonary embolism
ROIs	Regions of interest
SCTA	Standard CT angiography
SD	Standard deviation
SNR	Signal-to-noise ratio
TMIP	Temporal maximum intensity projection
TMIP-CTA	Time phase Angiography reconstruction

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Author contributions
K L and B Y designed the research study. W L, TT J, ZB H, ZY L, YL D, XL S and JM Z performed the research. X L, RG W, and J G analyzed the data. K L and B Y wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study was conducted following the guidelines of the Declaration of Helsinki and approved by the Beijing Shijitan Hospital Ethics Committee. Subjects signed an informed consent form.

Consent for publication
N/A.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Radiology, West China Hospital, Sichuan University, Chengdu 610000, China
[2]Department of Radiology, Chongqing Hospital of Jiangsu Province Hospital (The People's Hospital of Qijiang District), Chongqing 401420, China
[3]Department of Radiology, Beijing Shijitan Hospital, Beijing 100038, China
[4]Department of Thyroid Breast Cardiothoracic & Vascular Surgery, Beibei District Hospital of Traditional Chinese Medicine, No. 380 Jiangjun Road, Beibei District, Chongqing 400700, China

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