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Investigation in image quality and immediate patient safety using pre-dual-flow injection for low-contrast dose spectral pulmonary artery CT angiography

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HIGHLIGHTS

- 42.5 % reduction in contrast agent usage by pre flow dual flow method.
- Evaluate the safety of contrast agent examination plans from the perspective of patients' subjective feelings.
- Emphasize the subjective feelings of patients.

ARTICLE INFO

Keywords:
Pulmonary artery CT angiography
Pre-dual-flow injection
Safety
Image quality

ABSTRACT

Purpose: The patient safety of iodine contrast-enhanced pulmonary artery CT angiography (CTPA) is widely concerned. This study aimed to investigate the image quality and immediate patient safety of spectral CTPA using a lower-contrast dose pre-dual-flow injection method.

Methods: This retrospective study included 120 patients with suspected pulmonary embolisms who received spectral CTPA between February and December 2022. Patients were divided into normal contrast injection (Group A, n=60) and pre-dual-flow group (Group B, n=60). CT values of pulmonary arteries (PAs) at different levels, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR), arteriovenous separation performance, and beam hardening artifact (BHA) index of two sets of images were measured or calculated. The subjective image quality and immediate patient safety were also scored using the three-point method.

Results: Group B had a contrast dose reduction by 42.5 % (60 vs. 34.5 mL). Radiation exposure dose was not statistically different between the two groups ($P>0.05$). CT values of different-level PAs on group B images were higher than those on group A images ($P<0.05$). Group B images had higher SNR and CNR, better arteriovenous separation between PA trunk and pulmonary vein, and lower BHA index on soft tissue and PA (all $P<0.05$). For subjective evaluation of image quality, group B had a better score in beam hardening artifact ($P<0.05$). For immediate patient safety, the score in comfortability was statistically higher in group B, with $P<0.05$.

Conclusions: Comparing with the normal injection method, pre-dual-flow spectral CTPA with a lower contrast dose injected results in better image quality and shows potential in patient-safety promotion.

1. Introduction

Acute pulmonary embolism is the third most common acute cardiovascular disease after myocardial infarction and stroke [1]. Computed tomography Pulmonary angiography (CTPA) has become the preferred imaging examination method in the diagnosis and follow-up of pulmonary embolism due to its non-invasiveness, efficiency, and high accuracy [2,3]. CTPA can also determine the presence, degree, location, and distribution of the embolism [4].

To improve the CTPA image quality, high-dose contrast agents are

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often needed,which sometimes cause adverse reactions, such as post-contrast acute kidney injury (PC-AKI) [5,6], allergies, and cardiovascular diseases [7].

The balance between acceptable image quality and patient safety is attractive as a constant hot topic in CTPA scanning. Excellent image quality not only relies on lower noise which is partly determined by higher radiation doses, but also comes from greater contrast of vessel to surrounding tissues derived from iodinated contrast agents-resulted vascular enhancement. According to ICRP 2007[8], patients may only withstand a maximum of 50 mSv X-ray radiation doses in a year, and a cancer incidence rate is increased with an increment of 5.5 %/Sv. As for contrast utility, although relevant data indicate that greater dosages of contrast agents increase the incidence of contrast-associated acute kidney injury (CA-AKI) following intra-arterial delivery [9], there is no comparable data on dose-ranging toxicity with intravenous treatment over the clinical dose range. In addition, according to 2020ACR/NKF Consensus [10], if lowering the contrast dose has been proved to be appropriately diagnostic in specific protocols, clinical practice should consider lowering the dose for all patients imaged using these protocols, not only those with impaired renal function.

Commonly used methods to reduce contrast agent dose include: (1) reducing the tube voltage (kvp); however, the image quality would be impaired for large-sized patients owing to obvious noise [11]; (2) increasing the injection rate, which might result in safety concerns including, local swelling, pain, blister formation, and even skin ulceration caused by contrast agent leakage; and (3) using high-concentration iodine contrast; however, high viscosity solutions hinder transportation, leading to adverse reactions. Pre-dual-flow injection involves replacing a portion of the contrast agent with a proportional mixture of contrast agents and injecting 15 mL of the mixture before the contrast agent energy spectrum computed tomography (CT) imaging could generate various monoenergetic CT images by transient switching between high and low kvp. Iodine contrast displays high CT attenuation at low kvp, thus providing the feasibility of a lower iodine contrast dose while maintaining acceptable enhancement, which has been verified by previous studies [12]. A combination of pre-dual-flow contrast injection and spectral imaging might be a prospective protocol to maintain image quality and decrease contrast dose further; however, few studies have been reported.

However, current studies related to contrast reduction often focus on image quality and neglect patient status, which is not only associated with patient safety but also influences the scan completion and imaging effects. Therefore, this study aimed to compare the performances of the pre-dual-flow injection method and the traditional normal injection scheme on image quality and patient safety in CTPA spectral imaging.

2. Methods

2.1. Study participants

This study retrospectively collected clinical and radiological data from 130 patients with suspected pulmonary embolism who received spectral CTPA from a tertiary referral teaching hospital between February and December 2022. The inclusion criteria were as follows: (1) underwent spectral CTPA; and (2) suspected pulmonary embolism patients with clinical symptoms, such as difficulty breathing, chest pain, chest tightness, suffocation, and cough. The exclusion criteria were as follows: (1) patients in the intensive care unit (ICU) or patients with multiple comorbidity; and (2) severe metal artifacts in the image. (3) could not cooperate in breath administration and resulted in severe respiratory artifacts. Patients with left-sided heart disease (1 case), ICU inpatients (3 cases), patients with multiple diseases (3 cases), severe metal artifacts (2 cases), and severe respiratory artifacts (1 case); 120 patients were ultimately included for analysis. Finally, there were 60 patients in the normal injection group (Group A) and 60 in pre-dual-flow group (Group B). This study was reviewed and approved by the Ethics Committee of Fujian Medical University Affiliated Union Hospital (IRB number:2023KY054). All patients provided informed consent for CT-enhanced scanning.

2.2. Equipment and materials

CT examinations were performed using a GE HealthCare Revolution CT scanner with patients in the supine position, hands raised, and holding their breath. The scanning range was from the clavicle to the diaphragmatic surface of the lung floor. The tube voltage was fast switched between 80 and 140 keV (0.25 ms per switch), tube current 445 mA, pitch 0.992:1, rotation speed 0.5 s, reconstruction layer thickness 0.625 mm, reconstruction interval 0.625 mm. Images were reconstructed by the standard kernel and adaptive statistical iterative reconstruction Veo algorithm with a blending ratio of 40 %. Utilized automatic bolus tracking, CTPA began after the CT attenuation on the pulmonary artery trunk achieved 70 HU with a delay of 3.1 s. Using a double-syringe power injector with a 20 G needle (Hengrui, Jiangsu, China), iodine contrast agent (350 mgI/mL, Loversol Ingection, Jiangsu, China), and saline were injected through the median cubital vein. The details for the contrast injection scheme were shown in Table 1.

All images were transmitted to Advanced Workstation 4.6 (GE HealthCare, Milwaukee, US) for post-processing and evaluation. Monoenergetic images at 140 keV were created. Volume rendering (VR), multi-planar reconstruction (MPR), and maximum intensity projection (MIP) images were generated. One of the senior radiologists delineated and measured the region of interest (ROI, area $\geq$ 50 mm^2) on the MPR axial image with a double-blind method. The round ROI was selected at the center of the blood vessel, avoiding the embolic and artifact areas as much as possible, and taking the average of two measurements. The main measurements included: CT and SD values of the pulmonary artery trunk (f), primary branch (left and right pulmonary artery trunk), secondary branch (interlobar artery), tertiary branch (intersegmental artery: right lower lobar basilar artery), right pulmonary vein, and thoracic aorta. CT and SD values of anterior wall soft tissue (a) with sclerotic beam artifacts, pulmonary artery blood vessels (b) and fat tissue (o) without sclerotic beam artifacts on the same layer, and of the latissimus dorsi muscle (d) at the pulmonary artery level were measured. The beam hardening artifact (BHA) for soft tissue hardening in the blood vessel: $BHA_a = (SD_a^2 - SD_o^2)^{½}$;$BHA_b = (SD_b^2 - SD_o^2)^{½}$, signal-to-noise Ratio ($SNR = CT_f/SD_d$), and contrast-to-noise Ratio ($CNR = [CT_f - CT_d]/SD_d$) were calculated. The CT value difference between the pulmonary artery trunk and the aorta or right pulmonary vein was then calculated to evaluate the arterivenous separation. In detail, according to Kilic K's report [13] , a CT value difference larger than 150 HU was considered a as good separation.

2.3. Subjective image quality evaluation

Two senior physicians performed a double-blind subjective evaluation on axial and coronal MPR images of the two groups. Overall, the image quality was scored on five aspects, including arteriovenous separation, respiratory artifacts, superior vena cava hard bundle artifacts, pulmonary artery enhancement, and whether they meet diagnostic

Table 1
Contrast injection administration of two groups.

Group	Contrast/Saline	Dosage (mL)	Rate (mL/s)
A (n=60)	Contrast Agent	60	3.5
	0.9 % NaCl	30	3.5
B (n=60)	Contrast agent mixture[1]	15	3.5
	Contrast Agent	30	3.5
	0.9 % NaCl	30	3.5

Abbreviation: Group A. Normal injection; Group B. Pre dual-flow;1 The volume ratio of contrast agent and normal saline is 3:7

requirements. The scoring criteria are shown in Table 2.

2.4. Safety scoring

After scanning, the patients were observed and surveyed. The safety scoring was conducted on five aspects: radiation dose [14,15], comfortability, drug allergic reactions, injection site status, and scanning completion. The scoring criteria are shown in Table 2.

2.5. Radiation dose

The CT dose index (CTDI) and dose-length product (DLP) were automatically obtained from computer dose reports.

Table 2
Subjective image quality and safety scoring criteria.

Subjective Image Quality			
	1	2	3
Arteriovenous separation	Ideal separation of pulmonary artery and vein, strong connection between pulmonary artery and right pulmonary vein	Balanced brightness, separation of pulmonary artery and right pulmonary vein	Right vein concentration brighter than pulmonary artery
Motion artifact	Artifacts, clear pulmonary artery ducts, sharp edges	Mild artifacts, blurry pulmonary artery edges, not affecting judgment	Obvious artifacts and inability to determine pulmonary arteries
Beam hardening artefact	No artifacts, veins have significantly lower brightness than arteries	Mild artifacts, but limited to upper chamber artifacts	Obvious artifacts, inability to determine hard bundle artifacts in pulmonary arteries, affecting pulmonary artery observation
Vascular filling	Filling exceeding sub level	Mild artifact filling value sub segment	Excellent filling
Diagnosis requirement	Poor image quality and could not meet diagnosis requirement	Good image quality and meet diagnosis requirement	Excellent image quality and provide outstanding diagnosis confidence
Subjective Safety			
	1	2	3
Radiation Dose	Greater than 75 % of the international lung dose reference standard	in the international lung dose reference standard of 50 −75 %	Under 50 % of the international lung dose reference standard line
Comfortability	Irritation, vomiting, and unbearable injection pain	Fever, mild nausea, and slight pain during injection	No abnormal feelings
Allergic reaction	Suffering from nausea, vomiting, sneezing, and rash	Suffering from high fever, dizziness, palpitations	No abnormal feelings
Injection site status	Ectopic indwelling needle tube with obvious subcutaneous leakage and swelling	The indwelling needle tube is basically intact, with slight leakage and swelling	The indwelling needle tube is intact, and there is no subcutaneous leakage or swelling
Scan completion	Scan not completed, final scan	Scan completed with interruption	Scan completed without interruption

2.6. Statistical analysis

SPSS 25.0 software was used for all statistical analysis. Normally distributed continuous data were represented by means ± SD, and the comparison was conducted using an independent sample t-test. Continuous data not normally distributed were represented as median and interquartile range and were compared using Mann Whitney U test. The category data were represented as numbers (%), and compared using χ^2 method. The consistency between the two radiologists' scores were evaluated using the Kappa consistency test (0.40–0.60: moderate consistency, 0.61–0.80: strong consistency, 0.81–1.00 u: strong consistency). Two-tailed P <0.05 was considered statistically significant.

3. Results

3.1. Clinical characteristics, radiation and contrast dose

This study included 120 patients (60 patients per group). There were 33 males and 27 females in the normal double flow group, aged 49–80 years (average age 65 ± 11 years). There were 33 males and 27 females in the preposition flow double flow group, aged 22–78 years (average age of 57 ± 10 years). There was no statistically significant difference in gender, height, weight, age between the two groups (P >0.05, Table 3). The contrast agent dosage of 60 mL in group A was significantly higher than the 34.5 mL in group B (P <0.001). The CTDI and DLP were not statistically significant between the two groups (P both < 0.05). There was no statistically significant difference in TT or PT, between the two groups (P > 0.05, Table 3). The D-Dimer in group A was significantly lower than group B (0.44±0.73 vs. 1.36±2.65, P < 0.05), as well as FIB was statistically significant difference between the two groups (P < 0.05, Table 3).

3.2. Objective parameters

The results of the objective image parameters are summarized in Table 4. For enhancement, the CT values of left PA and right PA were higher in group B images than in group A images (P < 0.05). For secondary-ordered PA, group B images had higher CT values in arteries for the left (upper, interior, and lower arteries), with a statistical difference from group A images (P<0.05). However, for secondary ordered arteries in the right (upper, interior, and lower arteries), the difference in CT values between the two groups was not statistically different (P>0.05). The SNR and CNR values of the MPA trunk were significantly

Table 3
Characteristics of participant.

Characteristics	Group A (N=60)	Group B (N=60)	P value
Age, years	65±11	57±10	0.164
Gender [n (%)]			1.000
Female	27 (45)	27 (45)	
Male	33 (55)	33 (55)	
Height, cm	162±7	164±8	0.183
Wight, kg	59±8	62±8	0.091
BMI, kg/m^2	22.78±2.76	23.10±2.01	0.466
CTDI, mGy	5.80 (4.73, 5.81)	5.80 (4.73, 6.87)	0.510
DLP, mGy·cm	213.42 (182.63,255.31)	234.83 (199.61,286.99)	0.052
Contrast Agent, mL	60 (60, 60)	34.5 (34.50, 34.50)	<0.001
Embolism [n (%)]	6(10.00)	8(13.33)	
D-Dimer	0.44±0.73	1.36±2.65	0.046
FIB, g/L	3.40±1.03	4.14±1.46	0.012
TT, s	16.97±1.01	16.90±0.78	0.703
PT, s	12.61±0.78	12.61±0.66	0.985
SCR, mg/dL	63.63±14.03	69.53±17.02	0.104

Abbreviation: SD, Standard Deviation; BMI, Body Mass Index; CTDI, Computed Tomography Dose Index; DLP: Dose Length Product; FIB, Fibrinogen; TT, Thrombin Time; PT, Prothrombin Time; SCR, Serum Creatinine;

Table 4
Objective image quality comparison between two groups.

Variables	Group A (N=60)	Group B (N=60)	P value
CT values, HU			
PA trunk	346.15 ±89.66	380.981 ±103.69	0.135
Left PA	336.58 ±94.93	386.23 ±108.77	0.038
Left upper artery	316.77 ±90.68	360.70 ±101.19	0.048
Left interior artery	324.00 ±90.59	376.43 ±121.76	0.039
Left lower artery	324.68 ±87.66	373.38 ±109.42	0.046
Right PA	336.85 ±84.81	392.85 ±118.74	0.022
Right upper artery	315.08 ±89.73	359.38 ±112.53	0.057
Right interior artery	323.35 ±88.90	356.03 ±94.217	0.171
Right lower lobe segmental branches	320.25 ±87.29	363.58 ±104.89.	0.075
Aorta	157.75 ±50.41	136.40±52.68	0.121
Right pulmonary vein	209.25 ±49.53	180.43±58.37	0.016
MPA SNR	18.02±6.04	22.74±7.38	<0.001
MPA CNR	20.01±7.59	24.44±8.81	0.004
Arteriovenous Separation [n, (%)]			
Good separation between PA trunk and vein	25 (41.6)	41 (68.3)	0.003
Good separation between PA trunk and aortic	50 (83.3)	58 (96.6)	0.014
BHA			
Soft tissue	27.27 ±10.54	13.86±6.19	<0.001
PA trunk	24.08±7.52	15.67±4.25	<0.001

Abbreviation: PA, Pulmonary artery; SD, Standard deviation; SNR, signal noise ratio; CNR, contrast noise ratio; Good separation indicates CT value of PA>300HU and higher than right inferior pulmonary vein or aortic with difference>150 HU; BHA, beam hardening artefact

higher in group B compared to group A images ($P < 0.05$).

From the perspective of arteriovenous separation, group B images displayed lower CT values on the right pulmonary vein and aorta than group A images. Moreover, group B images exhibited better arteriovenous separation between the MPA trunk and the pulmonary vein (25 [41.6 %] vs. 41 [68.3 %], $P<0.05$), as well as between PA trunk and aorta, with a statistical difference (50 [83.3 %]) vs. 58 [96.6 %], $P<0.05$). The BHA value of the soft tissue on group A images was 27.27 ±10.54, which was significantly higher than that on group B (13.86 ±6.19, $P <0.001$). The BHA value of the main pulmonary artery in group A was 24.08 ±7.52, also significantly higher than that in group B (15.67 ±4.25, $P <0.001$, Table 4).

3.3. Subjective image quality analysis

A summary of these subjective image quality results is displayed in Table 5. The motion artifact showed no difference between the normal dual-flow and pre-dual-flow groups (1 [0 %],2[18.3 %],3[81.7 %]) vs. 1 [0 %],2 [13.3 %],3[86.7 %] P=0.453 Table 5, Fig. 1).The scores for vascular filling (1 [0 %],2[13.3 %],3[86.7 %]) vs. 1 [0 %],2 [6.7 %],3 [93.3 %]), and scan completion (1 [0.0 %],2[0.0 %],3[100.0 %]) vs. 1 [0.0 %],2 [0.0 %],3[100.0 %]) also showed no significant difference between the normal dual-flow and preposition dual-flow group (all $P > 0.05$, Table 5,). However, the BHA score (1 [0 %],2[36.7 %],3[63.3 %]) vs. 1 [0 %],2 [18.3 %],3[81.7 %]), and degree of arteriovenous separation(1 [3.3 %],2[33.3 %],3[63.3 %]) vs. 1 [0 %],2 [16.7 %],3 [83.3 %]), in the pre-dual-flow group were both significantly higher than those in the normal dual-flow group (all $P < 0.05$, Table 5). The kappa value was 0.80, indicating high consistency.(Fig. 2)

3.4. Subjective safety analysis

The results of this analysis are displayed in Table 5. The perception score of patient's comfortability using the normal dual-flow method was significantly lower than that using the pre-dual-flow method (1 [0.0 %],2[18.3 %],3[91.7 %]) vs. 1 [0 %],2 [5.0 %],3[95.0 %], respectively; $P<0.05$, Table5, Fig. 1). Although not statistically significant, the allergic reaction score of the normal dual-flow method was lower than that of the pre-dual-flow method, with two cases of allergic reaction and contrast agent exudation occurring in group A. The radiation dose, scan completion, and subcutaneous integrity scores of the two groups were similar, with no statistically significant difference. The Kappa value was 0.81, indicating high consistency.

4. Discussion

This retrospective study indicated that the pre-dual-flow method with a contrast dose reduction of 42.5 % improved image quality and provided better safety for patients in spectral CTPA. Previous literature has suggested a relationship between PC-AKI and the dose of contrast agent used. Therefore, this study could contribute to the optimization of the contrast injection plan for CTPA and offer more effective choices for imaging in other areas. In the pre-dual-flow group, spectral CTPA was successfully completed using 34.5 mL of contrast agent, resulting in significant improvements in SNR and CNR of PA, pulmonary artery filling, arteriovenous separation, and BHA performance compared to the normal dual-flow group. Firstly, the lower contrast dose resulted in good image enhancement quality. Secondly, there was a significant decrease in subjective upper lumen artifacts and objective soft tissue and pulmonary artery sclerosis beam values. Additionally, there was a significant difference in the enhancement effect between the pulmonary artery and pulmonary static contrast, leading to enhanced dynamic static

Table 5
Subjective image quality and safety rating comparison between two groups.

	Group A			Group B			*P* value
Score	1	2	3	1	2	3	
Image Quality							
Arteriovenous separation	2(3.3)	20(33.3)	38(63.3)	0(0.0)	10(16.7)	50(83.3)	0.030
Motion artifact	0(0.0)	11(18.3)	49(81.7)	0(0.0)	8(13.3)	52(86.7)	0.453
Beam hardening artefact	0(0.0)	22(36.7)	32(63.3)	0(0.0)	11(18.3)	49(81.7)	0.008
Vascular filling	0(0.0)	8(13.3)	52(86.7)	0(0.0)	4(6.7)	56(93.3)	0.371
Diagnosis requirements	0(0.0)	0(0.0)	60(100.0)	0(0.0)	0(0.0)	60(100.0)	1.000
Safety							
Radiation Dose	0(0.0)	60(100.0)	0(0.0)	0(0.0)	60(100.0)	0(0.0)	1.000
Comfortability	0(0.0)	11(18.3)	49(91.7)	0(0.0)	3(5.0)	57(95.0)	0.022
Drug Allergic Reaction	0(0.0)	2(3.3)	58(96.7)	0(0.0)	0(0.0)	60(100.0)	0.153
Injection site status	0(0.0)	1(1.7)	59(98.3)	0(0.0)	0(0.0)	60(100.0)	0.315
Scan completion	0(0.0)	0(0.0)	60(100.0)	0(0.0)	0(0.0)	60(100.0)	1.000

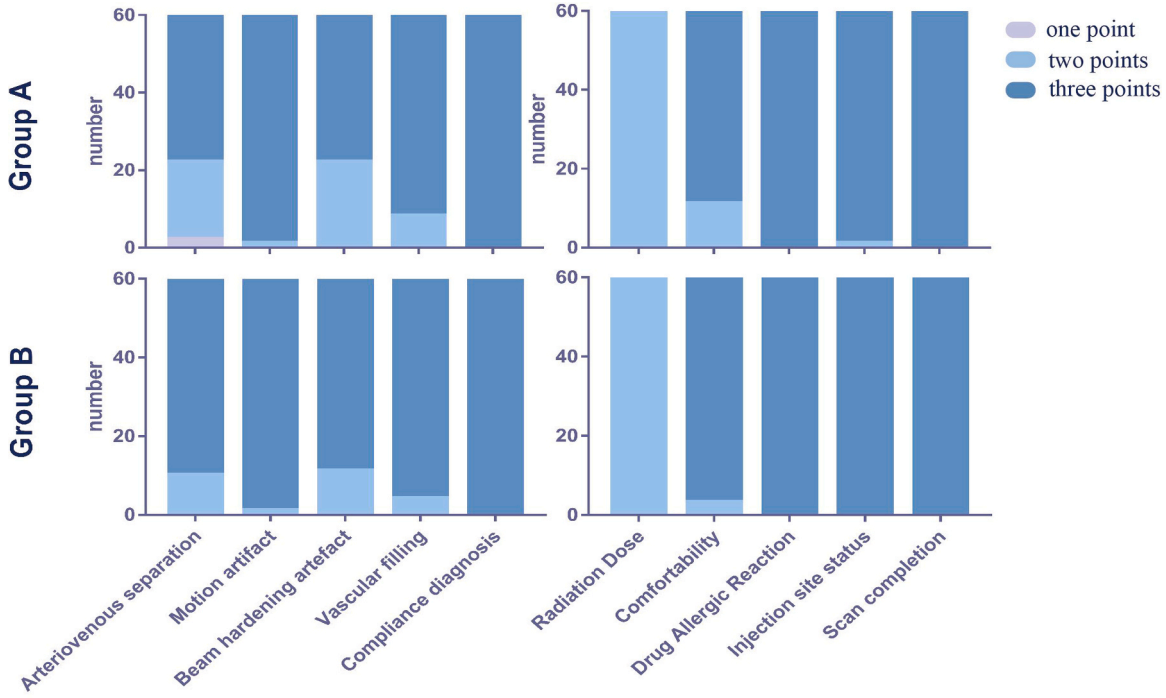

Fig. 1. Subjective image quality and safety rating comparison between two groups.

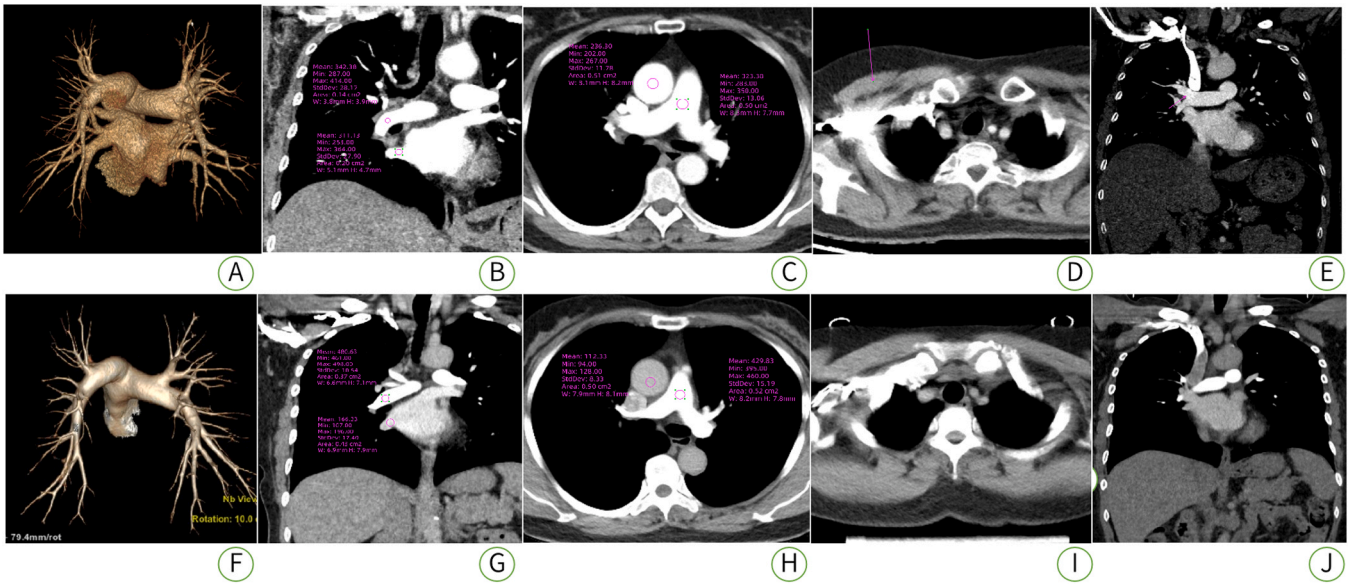

Fig. 2. Comparison of image quality between two groups. Comparison of CTPA images obtained by normal dual flow method (A-E) and preposition dual flow method (F-G), where A and F are VR images; B, E, G, and J are MPR coronal maps; C, D, H, and I are MPR axis bitmaps. A-E is female, 60 years old, F-J is female, 54 years old. The VR image shows that the pulmonary artery, left atrium, and pulmonary vein in Fig. A are all enhanced, while Fig. F shows the pulmonary artery development. The arrow in Figure B shows that there is more residual contrast agent in the superior vena cava, with a difference of 104HU (score: 2 point) in contrast agent between the pulmonary artery and pulmonary vein enhancement. Figure G shows less residual contrast agent in the superior vena cava, and a difference of 314 HU (score: 3 points) in contrast agent between the pulmonary artery and pulmonary vein enhancement; The difference in enhancement between the pulmonary artery and aorta in Figure C is 47 HU (score: 1 points), and the difference in enhancement between the pulmonary artery and aorta in Figure H is 317HU (score: 3 points); The arrow on the D-E image shows a total of 2 hardened beam artifacts, while there is no obvious hardened beam artifact on the I-J image.

contrast effects and improved image quality and diagnostic accuracy.

Previous studies have shown that CT values of the PA trunk and its branches reaching 250 HU or above can meet diagnostic requirements. The pre-dual-flow group achieved this diagnostic threshold while using 42.5 % less contrast agent compared to the normal dual-flow method group. Moreover, the vascular filling performance of different-level PA was better in the pre-dual-flow group compared to the normal group. This is because the pre-injected mixed solution of about 15 mL opened the vascular pathway, reduced the viscosity gradient of the contrast agent, and facilitated its delivery. It also reduces the probability of contrast agent turbulence in the blood vessels, resulting in better vascular imaging filling. Moreover, less contrast injection and flushing with 30 mL of saline in the pre-dual-flow group reduced the residual contrast in the superior vena cava, thereby reducing beam hardening

artifacts (BHA values and BHA subjective scoring) caused by the contrast agent.

The pulmonary arteries and veins are also closely associated, and the circulation time from the pulmonary artery to the pulmonary artery is only 2–3 s. During the process of contrast passing from the pulmonary artery to the vein, there is no additional venous blood, and the dilution effect of the contrast agent is limited. As a result, the enhancement differences between the arteries and veins can be small due to factors such as scanning delay time. In the first phase of the pre-dual-flow method, a 15 mL mixture was injected into the blood vessel with a diluted contrast agent. When the higher-concentrated contrast agent enters the pulmonary artery, the lower-concentrated contrast mixture enters the pulmonary vein, resulting in low-concentrated contrast imaging for veins that does not compromise the visualization of the arteries. This effectively helps to distinguish the differences between the arteries and veins, showing lower CT values in the pulmonary vein and good arteriovenous separation.

Furthermore, this study shows that there was a significant improvement in patients' subjective perception and immediate safety in the prep-dual-flow group compared to the normal dual-flow group. Previous studies on the optimization of PA contrast agent injection plans focused more on image quality while neglecting the patients' safety and subjective feelings. In this study, the pre-dual-flow method can reduce the dosage of contrast agents by 42.5 %, which may reduce the burden of contrast-induced nephropathy compared with the conventional method. Regarding the subjective feelings of patients, pre-dual-flow injection has greatly improved the comfort of patients. The 15 mL injection had a transitional effect, reducing the viscosity difference between the contrast agent and the blood and facilitating the delivery of the contrast agent, to alleviate the discomfort and tension during the examination. Research experience shows that patients' nervous moods will affect the scanning effect, especially in the need for respiratory management and chest scanning. In addition, with regard to the status of injection sites, one patient in the conventional injection method had slim leakage and swelling, while all patients in the pre-dual flow method had no adverse reactions at the injection sites, probably because the pre-injection of saline contrast agent mixed solution with low contrast agent concentration and less total iodine contrast agent can reduce the vascular pressure, prevent the possibility of swelling when the indwelling needle is blocked, and improve the safety. As for allergic reactions, one case in Group A was mild; while Group B did not experience any allergies. Although there is no literature to explain the relationship between the contrast agent injection scheme and the contrast agent allergic reaction, this paper provides a possibility that still needs to be further explored.

In this study, the fast kVp switching energy spectrum scanning mode is used to generate a series of single-energy images. At low energy, the attenuation coefficient of iodine is high, so it can meet the enhancement requirements at a low contrast agent flow rate and contrast agent dosage [15] , which may also reduce the risk of subcutaneous leakage during the high-pressure injection process. Therefore, the contrast dose and flow rate used in this paper are lower than those of other conventional scans, and the pre-dual flow method can further reduce the amount of contrast agent used. In addition, energy spectrum scanning CTPA did not increase the scanning radiation dose, which was equivalent to the conventional scanning radiation dose of the center, in line with the requirements of the guidelines, and similar to other literature. In addition to the improvement of image quality, energy spectrum scanning can also provide an energy spectrum curve, iodine base map, energy spectrum pulmonary perfusion image, effective atomic number, etc., which has clinical application potential for the diagnosis, curative effect, and prognosis evaluation of pulmonary embolism.

This study had several limitations. Firstly, being a retrospective and small-sample study, there may be potential biases in the data collection and analysis. Additionally, since only two allergic reactions were found in our study, a larger-sample study should be further conducted to confirm the safety improvement. Future prospective clinical studies should be conducted. Secondly, a BMI or body surface area-specific contrast injection plan may be more reasonable for patients with different body sizes. Thirdly, the purpose of this study was to evaluate whether the pre-dual-flow method can reduce the dosage of contrast agents and improve the safety of CTPA while meeting diagnostic requirements. However, objective safety data evaluation for renal function was lacking. Subsequent research should include indicators such as blood creatinine, glomerular filtration rate, or urine volume to assess renal function [16,17]. Fourthly, this study focused solely on evaluating the pulmonary arteries and did not analyze the left ventricular system [18]. Fifthly, spectral CT provides additional valuable quantitative imaging tools, the influence of the pre-dual-flow method on iodine images and Eff-Z mapping was not investigated. Lastly, the value of the pre-dual-flow method in diagnosing pulmonary embolism needs to be explored. Future studies should address these concerns.

5. Conclusions

In spectral CTPA, the pre-dual-flow contrast injection method not only improves image quality by reducing BHA and enhancing arteriovenous separation, but it also has the potential to promote patients' safety and subjective comfortability, while reducing contrast dose by 42.5 %.

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CRediT authorship contribution statement

Yanping Zheng: Validation, Supervision. **Nianjie Xu:** Project administration, Methodology. **Qing Zhong:** Resources, Investigation, Funding acquisition. **Liwei Xue:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Yuanfen Liu:** Writing – review & editing, Resources, Funding acquisition.

Declaration of Competing Interest

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication. I would like to declare on behalf of my co-authors that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ejro.2024.100571.

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