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Low-dose and low-contrast computed tomography pulmonary angiography in pediatric with pulmonary embolism: a prospective study

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Abstract

Objective We evaluated the feasibility of reducing contrast agent and radiation dose in pediatric computed tomography pulmonary angiography (CTPA) while ensuring image quality.

Materials and methods In this prospective study, two readers assessed the computed tomography (CT) image quality (using a 5-point scale (1: undiagnosable and 5: excellent) and objective evaluation criteria (measuring CT and noise values of the left atrium and pulmonary trunk) of 116 patients who underwent pulmonary artery computed tomography angiography (CTA) from January 2023 to April 2024. independent sample *t*-test and Chi-square test were used to analyze and evaluate group differences.

Result Fifty-eight participants were enrolled in the study group (mean age, 6.86 years ± 2.74, 30 males) and fifty-eight participants were enrolled in the control group (mean age, 6.71 years ± 2.59, 22 males). The radiation dose was significantly decreased in the study group (study group, 3.01 ± 0.24 mGy, control group 3.77 ± 1.06 mGy, $p < 0.001$). Overall quality was higher in control group, but displaying ability of pulmonary artery trunk and branch was higher in study group ($p < 0.001$).

Conclusion This study proved that a low-dose, low-contrast CTPA strategy could reduce radiation dosage by 50% and contrast agent by 20% while maintaining a satisfying image quality.

Keywords Children, Computed tomography pulmonary angiography, Low-dose, Low-contrast, Pulmonary embolism

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Introduction

Pulmonary embolism (PE) is a severe clinical condition with high mortality. Clinical doctors used to underestimate the incidence rate of PE among the children population, however, the recent United States database has shown a frequency high up to 106 per 10,000 hospital admissions in tertiary care institutions [1]. Moreover, researchers are finding that the causes of pediatric PE are different from those in adults, which means in the pediatric population, PE is mainly aroused by diseases that cause coagulation dysfunction. For instance, mycoplasma pneumonia can cause coagulation abnormalities, which can then lead to PE [2, 3]. Timely and accurate diagnosis is essential in emergency cases [4].

Computed tomography angiography (CTA) is recommended as the first-line test for several pediatric vascular diseases such as arteritis, cardiovascular disease, and coronary abnormalities [5, 6, 7]. In the diagnosis of pediatric PE, computed tomography pulmonary angiography (CTPA) is a reliable tool with relatively high accuracy [8]. Since pediatric PE may not be a rare case and several researchers have clarified that CTPA should be used early once the suspicious patient is stable enough for such a test [9], an increasing number of pediatric patients with high risk of PE might take CTPA in the future. Though reliable, the potential damage caused by radiation always remains a problem with caution [10], especially in pediatric patients. For example, childhood radiation exposure is correlated to future tumorigenesis to some extent [11, 12, 13]. Contrast alone may cause allergic-like reactions, thyroid dysfunction, contrast-induced nephropathy, and nephrogenic systemic fibrosis [14]. Thus, the Diagnostic reference levels (DRLs) and achievable doses (ADs) reports for pediatric computed tomography (CT) examinations released in 2022 have both called for a low-dose CT protocol [15, 16]. Several researchers have already attempted to apply various strategies to reduce the dosage of radiation, while maintaining the image quality, in different diseases such as pediatric heart disease, adult coronary diseases, and cranial vascular issues [17, 18, 19, 20]. However, even though the efforts to put potential PE patients under a low-dose CT have been around for decades [21, 22], the research results are still limited, especially in pediatric background.

We hypothetically assumed that low-dose and low-contrast CTPA protocol, which reduced the radiation dose and contrast agent, could also have satisfying image quality and reliable diagnostic accuracy of pediatric PE. Therefore, we conducted this prospective cohort study to test the feasibility of achieving low-dose and low-contrast CTPA in children based on a short-term high-speed contrast agent injection protocol [17, 19] and meanwhile maintaining the image quality.

Materials and methods

Study design and participants

This article was a prospective cohort study approval by the Ethical Committee of Children's Hospital Affiliated of Zhengzhou University. The research protocols were according to the approved guidelines and regulations of our hospital. Informed consents were signed by all the parents of the involved children.

The image data of the study group were collected from January 2024 to April 2024. (1) clinically diagnosed mycoplasma pneumonia or other primary diseases that have a high risk of PE; (2) clinically suffering from sudden chest pain or other related symptoms; (3) with increasing D-dimer; (4) less than 18 years old. The exclusion criteria were (1) allergic to iodine contrast agents; and (2) with parents rejecting undergoing CTPA. The control group participants ($n = 58$) were selected through age-stratified matching from our hospital database, adhering to the following protocol: (1) four age strata corresponding to key developmental stages (0–5, 6–10, 11–14, 15–18 years); (2) followed other collection criteria; (3) temporal restriction to scans performed between January 2023 and December 2023. This matching strategy ensured comparable demographic characteristics between groups while maintaining clinical relevance to current practice patterns.

CT acquisition

All examinations were performed on a 256-row spiral CT scanner (Brilliance iCT, Philips). We used 80kV low voltage scanning in the study group, with a speed of 0.33 s, PITCH of 0.76, detector width of 8 centimeters, matrix size of 512×512 pixels, and voxel of 1.0 millimeters. The display field of view (DFOV) for image reconstruction is 250 mm, with an image thickness and interval of 1.0 mm. Referring to the relevant studies [15, 16], different fixed tube current scans were used in children of different ages to ensure that the radiation dose CT dose index of volume (CTDIvol) meets the following standards; (1) 2.3 mGy for children less than one-year-old; (2) 3.0 mGy for children of 1-to 5-year-old; (3) 3.5 mGy for children of 5-to 10-year-old; (4) 3.9 mGy for children of 10-to 15-year-old. The control group was examined using the 100 kV voltage with a radiation dose of 2.9 mGy for patients less than 1 year old, 4.1 mGy for patients of 1-to 5-year-old, 6.1 mGy for patients of 5-to 10-year-old, and 6.9 mGy for patients of 10-to 15-year-old. The other parameters were set as the study group. The obtained images were all reconstructed into idose4 images with a thickness of 1 mm layers, not using any kernel. Some children were too young to cooperate and thus were given dexmedetomidine nasal drops as standards for sedation before scanning.

Contrast agent administration

In study group, the contrast agent was Iohexol (350mgI/ml, GE Healthcare) and the dosage was calculated to be 0.8 ml/kg. The **injecting** was conducted within 8 s using a dual barrel injector (Stellant D–CE dual barrel dual flow high-pressure injector, Bayer), followed by an additional injection of saline at the same injection rate for 16 s. During the process, the senior operator performed an ROI area in the right atrium, observing the changes in CT values in the areas of interest and when the CT value increased by 50HU or more, the scan would be triggered manually. After triggering the scan, the device would automatically expose it in the shortest possible time allowed (6–8 s). In the control group, the total amount of contrast agent was calculated at 2.0 ml/kg. The injection was completed at 17 s and the scanning began 4 s later.

Subjective image quality evaluation

Two doctors who were skilled in diagnosing cardiovascular illnesses and had 19 and 8 years of expertise with CT scans for children respectively, utilized a 5-point rating system (1: undiagnosable and 5: excellent) to independently assess image quality. The patient's data and results from image scanning were concealed from the review process, and the case order was determined at random.

Table 1 Subjective image quality evaluation criteria

Score	Definition
Overall image quality	
5	None perceivable image noise
4	Little image noise
3	Moderate image noise and acceptable to diagnosis or exclude PE
2	High image noise and unacceptable to diagnosis or exclude PE
1	severe image noise and totally unacceptable image quality
Display ability of pulmonary artery trunk	
5	Displayed very good and without hesitation to diagnosis or exclude PE
4	Displayed good and enough to diagnosis or exclude PE
3	Displayed acceptable and able to accurately measure
2	Displayed insufficient for diagnosis or unable to accurately measure
1	Displayed totally unacceptable
Display ability of pulmonary artery branch	
5	>75 % of segmental/subsegmental arteries are opacified and distinguishing pulmonary veins without hesitation
4	>50 % of segmental/subsegmental arteries are opacified and distinguishing pulmonary veins without hesitation
3	>50 % of segmental/subsegmental arteries are opacified and distinguishing pulmonary veins acceptable
2	<50 % of segmental/subsegmental arteries are opacified or hard to distinguishing pulmonary veins
1	<50 % of segmental/subsegmental arteries are opacified and hard to distinguishing pulmonary veins

PE: pulmonary embolism

The observers' habits could be taken into consideration when adjusting the window width and bed position, and the clinical doctors could also modify the window width and level based on their personal preferences throughout the evaluation procedure. Viewing options included multiplanar reconstruction (MPR) and volume rendering (VR). Based on the relevant research [23, 24], the evaluation content included overall image quality and display ability of the pulmonary artery trunk and pulmonary artery branch. The specific scoring criteria are listed in Table 1.

Objective image quality evaluation

Objective image quality evaluation was performed by two observers together on an image workstation (IntelliSpace Portal, Philips) for every CTPA examination. The CT value and noise (SD) in Hounsfield units (HU) of the pulmonary artery truck were examined at the level of the large area section slice, and the CT value and SD of the left atrium were measured as well. The contrast-to-noise ratio (CNR) for the pulmonary artery truck to muscle (P–M-CNR) and CNR for the pulmonary artery truck to left atrium (P–A-CNR) were calculated using the following equation:

$$\begin{aligned}\text{P - M - CNR} = {} & (\text{CT}\ (_{\text{pulmonary}})\ \text{- CT}\ (_{\text{muscle}})) \\ & /\ ((\text{SD}\ (_{\text{pulmonary}})\ + \text{SD}\ (_{\text{muscle}}))/2)\end{aligned}$$

$$\begin{aligned}\text{P - A - CNR} = {} & (\text{CT}\ (_{\text{pulmonary}})\ \text{- CT}\ (_{\text{left atrium}})) \\ & /\ ((\text{SD}\ (_{\text{pulmonary}})\ + \text{SD}\ (_{\text{left atrium}}))/2)\end{aligned}$$

Radiation dose and contrast agent dose

The radiation dose and contrast agent dose were documented. The radiation dose included volumetric CT dose index (CTDIvol) as well as dose-length product (DLP), and the contrast dose included the total volume of contrast agent used.

Statistical analysis

Statistical analysis was performed using SPSS 22.0 software. All the data were expressed using the form of mean ± standard deviation (SD). For the two scanning groups, the continuous data was compared using the independent sample *t*-test, and the nominal data was compared using the Chi-square test. The ordinal scales or variables that failed to follow the normal distribution were analyzed by the Kruskal–Wallis test. The kappa test was used to determine the consistency of the subjective scores of the two radiologists. *P* value less than 0.05 was considered statistically significant.

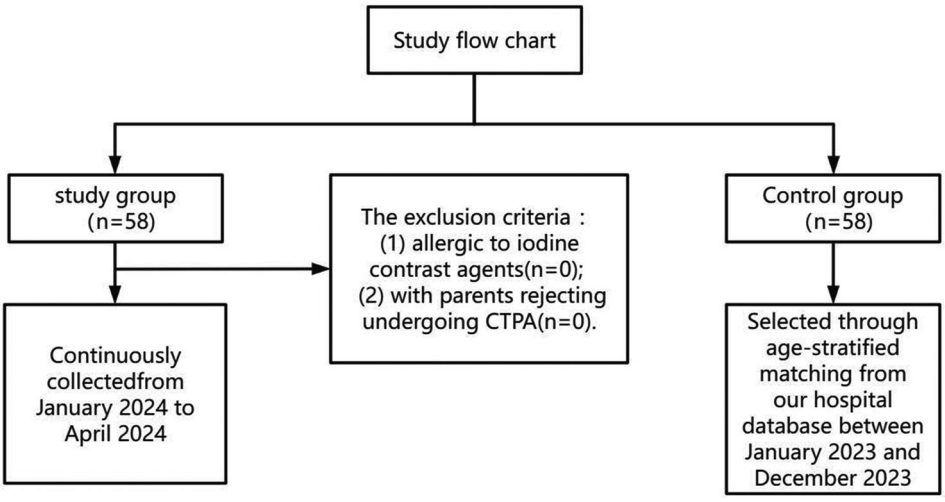

Fig. 1 Trial flow for pediatric participants

Table 2 The patient information and scanning parameters between two groups

	Study group	Control group	Statistical value	*p* value
Cases (N)	58	58	–	–
Sex M:F (N)	30:28	22:26	0.14	0.85
Age (median ± SD)	6.86 ± 2.74	6.71 ± 2.59	0.29	0.77
Weight (kg)	25.35 ± 9.86	25.29 ± 10.44	0.03	0.98
CTDIvol (mGy)	3.01 ± 0.24	3.77 ± 1.06	5.52	<0.001*
DLP (mGy.cm)	80.18 ± 11.62	108.06 ± 37.48	5.89	<0.001*
Contrast agent (ml)	20.69 ± 7.73	44.31 ± 15.11	11.68	<0.001*

CTDIvol CT dose index of volume, DLP dose length product, F female, M male, SD standard deviation

*Significant for $P < 0.05$

Result

Participants and radiation and contrast agent dose

Pediatric participant flow through the trial is presented in Fig. 1. A total of 116 pediatric patients suspected of pulmonary embolism were enrolled in our study. The study group included 58 patients (mean age, 6.86 years ± 2.74, 30 males) and the control group included 58 patients (mean age, 6.71 years ± 2.59, 22 males). The mean weight of the study group was 25.35 ± 9.86 kilograms, and the mean weight of the control group was 25.29 ± 10.44 kilograms. All demographic characteristics were not statistically significant between groups. In the study group, all patients were diagnosed with pneumonia, and 32 were diagnosed with PE, whereas in the control group, all cases were likewise diagnosed with pneumonia, and 28 were diagnosed with PE.

The amount of contrast agent used in the study group was 20.69 ± 7.73 ml, and the amount of contrast agent used in the control group was 44.31 ± 15.11 ml ($p < 0.001$), the dosage of contrast agent was reduced by 53.31%. The CTDIvol and DLP of the study group were 3.01 ± 0.24 mGy and 80.18 ± 11.62 mGy.cm, respectively, which were 20.16% and 25.80% lower than 3.77 ± 1.06 mGy and 108.06 ± 37.48 mGy.cm of the control group. There were statistically significant differences in the reduction of CTDIvol and DLP (both $p < 0.001$). Detailed data were exhibited on Table 2.

Subjective image quality evaluation

The subjective evaluation results showed that the overall image quality was mainly based on the image noise, and thus was most related to the scanning radiation dose. The image quality of both groups was high (4.47 ± 0.5 and 4.66 ± 0.48, respectively), but the quality was higher in the control group with statistical significance ($p < 0.001$). Although the radiation dose in the study group decreased by more than 20%, the subjective score was still high, indicating that the overall image quality of the study group was also satisfying but there was still room for optimization and further investigation of the topic. However, the subjective scores of the pulmonary artery trunk and pulmonary branch in the study group were 4.6 ± 0.61 and 4.25 ± 0.85, both higher than those in the control group (3.04 ± 0.24, 3.01 ± 0.09, respectively) with statistical significance ($p < 0.001$). Even though the objective evaluation results showed that the CT values of the pulmonary artery trunk in the control group were slightly higher than those in the study group, the contrast between the heart cavity and blood vessels was reduced, which would affect the subjective judgment of pulmonary artery and caused a decrease in scores. Differences in subjective image quality assessments can be found in Table 3. One set of images showing the comparison of the subjective image quality between the two groups is exhibited in Fig. 2. The kappa value of the two observers was 0.84 ($p < 0.05$).

Table 3 The results of subjective and objective evaluation

	Study group	Control group	t value	*p* value
CT value of PA (Hu)	401.24 ± 128.77	445.62 ± 115.75	1.91	0.06
SD of PA(Hu)	12.07 ± 5.54	10.86 ± 6.21	1.04	0.30
CT value of LA (Hu)	233.78 ± 128.31	414.55 ± 97.59	8.77	<0.001*
SD of LA(Hu)	14.40 ± 5.84	13.93 ± 7.47	0.36	0.72
CT value of Mu (Hu)	58.95 ± 8.94	62.45 ± 8.43	2.15	0.04*
SD of Mu (Hu)	12.45 ± 5.61	10.5 ± 4.84	1.86	0.07
P–A-CNR	44.14 ± 37.85	18.16 ± 26.97	3.83	<0.001*
P–M-CNR	76.4 ± 27.94	97.14 ± 40.56	3.02	0.004*
Overall image quality	4.47 ± 0.50	4.66 ± 0.48	4.54	<0.001*
Display ability of PA trunk	4.60 ± 0.61	3.04 ± 0.24	25.34	<0.001*
Display ability of PA branch	4.25 ± 0.85	3.01 ± 0.09	15.72	<0.001*

CNR contrast-to-noise ratio. CT computed tomography. LA left atrium. Mu left erector spinae muscle. PA pulmonary artery. P–A-CNR, CNR for the PA truck to LA. P–M-CNR, CNR for PA truck to Mu. SD standard deviation

*Significant for P < 0.05

Objective image quality evaluation

The objective evaluation results showed that the CT value of the pulmonary artery in the study group was 401.24 00B1 128.77Hu, while in the control group, it was 445.62 ± 115.75Hu. There was no statistical significance in the difference between the two groups ($p = 0.06$). The CT value of the left atrium in the study group was 233.78 ± 128.31Hu, and the CT value of the left atrium in the control group was 414.55 ± 97.59Hu ($p < 0.001$). The CT value of left erector spinae muscle in the study group was 58.95 ± 8.94Hu, and the CT value of left erector spinae muscle in the control group was 62.45 ± 8.43Hu ($p = 0.004$). The P–A-CNR of the study group was 44.14 ± 37.85, which was approximately 58.86% higher than that of the control group (P–A-CNR, 18.16 ± 26.97, $p < 0.001$). However, the P–M-CNR of the study group was 76.4 ± 27.94, significantly lower than that of the control group (P–M-CNR, 97.14 ± 40.56, $p < 0.001$).

Discussion

In this study, we aimed to evaluate the feasibility of conducting a low-dose and low-contrast CTPA on pediatric patients suspected of PEs to get high-quality images. The result indicated that this new CTPA protocol can reduce the radiation dosage and maintain a satisfying image quality. In terms of contrast agent dosage, we conventionally would administer a contrast agent of 2 ml/kg based on the pediatric cardiovascular guidelines [25], which can display pulmonary artery. However, due to a

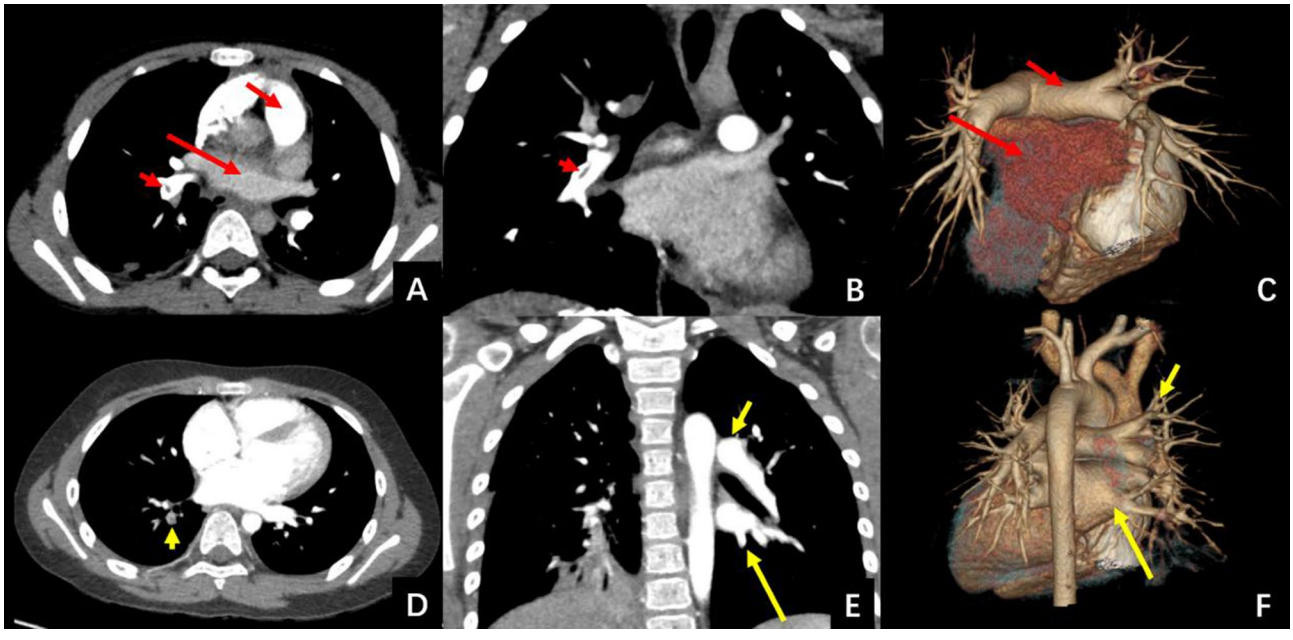

Fig. 2 Low-dose, low-contrast CTPA and conventional-dose, conventional-contrast CTPA. **A**–**C** shows the axial image (**A**), coronal multi-plane reconstruction image (2B), and three-dimensional reconstruction image (**C**) of low-dose and low-contrast CTPA. The image has more noise, but it can meet the diagnostic requirements, and the subjective overall image quality score is 3 points. The red arrowhead indicated the location of the thrombus. The short red arrow indicated a pulmonary artery and the long red arrow showed a pulmonary vein, Arterial and branch scores were 4 points. **D**–**F** showed the Axial images (**D**), multiplane reconstructed coronal images (**E**), and three-dimensional reconstructed image (**F**) undergoing conventional CTPA. The image noise is low, and the subjective overall image quality score is four points. Yellow arrowhead indicated the location of the thrombus. The short yellow arrow indicated a pulmonary artery and the long yellow arrow showed a pulmonary vein, Vascular contrast was low, indistinguishable from pulmonary veins, and arterial and branch scores were three points

large amount of contrast agent it uses and the long injection time, it will eventually show the image of the entire heart cavity and thus affect the image of the pulmonary artery. By reviewing the literature [17, 19], we achieved the goal of reducing the contrast agent while meeting diagnostic requirements by shortening the contrast agent injection time and making sure the pulmonary artery was enhanced by the contrast media in a clear way. As we applied the low-dose contrast agent protocol, the low-voltage scanning was also applied simultaneously. We utilized the characteristic of iodine ions to enhance CT values at low electron energy, which could improve image contrast and achieve the goal of maintaining image quality [26]. Based on these, in this study, we set the contrast agent dosage to 0.8 ml/kg and maintained the conventional contrast agent injection rate to ensure the flow rate of fluid into the blood vessels. In order to make the contrast agent reach the heart cavity rapidly, we injected a large amount of saline at the same rate after infecting the contrast agent, which can continuously accelerate the contrast agent to ensure that as much contrast agent as possible would enter the heart cavity for development in the form of bolus shaping. In terms of the scanning method, In order to supplement the loss of CT value caused by reducing the amount of contrast agent, we used low tube voltage to improve the CT value of iodide ions and ensure the image quality [27]. we reduced the scanning voltage to the lowest of 80kV to improve the contrast of the image and compensate for the decrease in CT value since the amount of contrast agent dosage decreased, The results showed that, on the premise that we reduced the dosage of the contrast agent by 53.31% and combined with the use of 80 kV, there was no statistically significant difference in the CT values of the pulmonary arteries between the study group and the control group.

In terms of radiation dose, according to the latest North American DRL standards [15] and China's DRL standards [16], we have managed to reduce the radiation dose of CTPA successfully. Moreover, pediatric PE is generally secondary to basic diseases such as Mycoplasma infection and patients are usually with a higher average age. Considering that the focus of CTPA is on the pulmonary blood vessels, which have higher contrast with lungs and show a higher enhancement than the CNR of mediastinal tissue, we further have appropriately reduced the radiation dose of older children. And that radiation dose is lower than that of the corresponding research.

Our research showed that through the low-dose and low-contrast CTPA protocol, although the contrast agent dosage was reduced by more than 50% compared to the control group, the CT value of the pulmonary artery was still more than 400Hu, which was lower than the control group only by 9.96%, with no statistically significant difference. Although we couldn't find the exact CT value requirements for pediatric CTPA, previous studies related to children's coronary arteries had shown that a CT value higher than 250Hu would meet the diagnostic requirements [17], and our CT value also corresponded to the results of another article [28]. Therefore, the CT value of the study group in our article can satisfy the diagnostic requirements. During the diagnostic process, non-enhanced pulmonary artery thrombosis can be identified obviously from the surroundings enhanced by the contrast agent, which leads to an accurate diagnosis. In terms of CNR, we found that the P–A-CNR of the study group was improved by 58.86% compared to the control with statistical significance. P–A-CNR is an index reflecting the difference in contrast between the pulmonary artery and pulmonary vein. Thus, the increase in the P–A-CNR value would mean the improving ability to distinguish the pulmonary artery and with pulmonary vein in the field, which would improve the speed and diagnostic accuracy of the pulmonary embolism. This result is in accordance with the subjective evaluation that the pulmonary artery branch score in the study group was higher than that in the control group. This is also one of the advantages of shortening the contrast agent injection time. Although the P–M-CNR of the study group decreased by 21.35% compared to the control group, originating from the decrease in CT values of the pulmonary artery in the study group and the increase in image noise caused by low radiation dose scanning, it didn't influence the identification of the embolism. Conclusively, in the evaluation of CTPA, the P–A-CNR value has shown more practical clinical meanings compared to the P–M-CNR value. These results indicated that though low-dose and low-contrast scanning increased image noise and reduced overall image quality as we found, it was more conducive to the evaluation of the pulmonary artery trunk and branch. It partly corresponded to a previous study aiming to apply the low-dose and low-contrast CTPA strategy on adult PE, which indicated the noise and attenuation were both higher in the study group but still had reliable diagnostic quality [22]. In terms of image noise, there was no statistical difference in PA, LA, and Mu noise. Considering that children's lung soft tissue components were less, it was easier to reduce the generation of image noise. Therefore, when the radiation dose of the study group was reduced, the noise of the noise image was increased (PA noise increased by 13%, LA noise increased by 9%, Mu noise increased by 17%). However there was no significant statistical difference. The objective evaluation results showed that the CT values of the pulmonary artery trunk in the control group were slightly higher than those in the study group. The subjective evaluation results showed that the overall image quality was mainly based on the image noise, and thus was most related to

the scanning radiation dose. The image quality of both groups was high (4.47 ± 0.5 and 4.66 ± 0.48, respectively), but the quality was higher in the control group with statistical significance ($p < 0.001$). Although the radiation dose in the study group decreased by more than 20%, the subjective score was still high, indicating that the overall image quality of the study group was also satisfying but still there was room for optimization and further investigation towards the topic. However, the subjective scores of pulmonary artery trunk and pulmonary branch in the study group were 4.6 ± 0.61 and 4.25 ± 0.85, both higher than those in the control group (3.04 ± 0.24, 3.01 ± 0.09, respectively) with statistical significance ($p < 0.001$). Even though the objective evaluation results showed that the CT values of pulmonary artery trunk in the control group were slightly higher than those in the study group, the contrast between the heart cavity and blood vessels was reduced, which would affect the subjective judgement of pulmonary artery and caused a decrease in scores. Therefore, it can be inferred that when judging the PE, the better way is to separate the image of the pulmonary artery so that the display of other blood vessels would be avoided as much as possible. It can be further inferred that the control of contrast agent injection time is necessary for the benefit of improving the subjective image quality of PE. Moreover, there was no statistically significant difference in the CT values of the pulmonary artery between the two groups. This indicated that the use of low contrast agents combined with 80kV low voltage scanning and short-term injection protocol did not significantly change the CT value of the pulmonary artery.

Zamboni et al. applied an 80kVp and 295mAs scanning in the test group to test the diagnostic ability of a low dose, low voltage protocol in the adult pulmonary embolism. They found that the CTDIvol and DLP were significantly lower in the test group, which corresponded to our study. The attenuation measurements and noise in the vessels were both higher in the test group, which also corresponded to our findings since noise might hamper the total image quality. However, Zamboni et al. didn't focus on the independent doctors' subjective evaluation [22]. Heyer et al. conducted a study aiming to prospectively compare the image quality and radiation dose between a 100kVp CT protocol and a 120kVp CT protocol. They also compared the signal-to-noise ratio (SNR), and CNR. The result showed that there was no significant difference between the vessel attenuation, image noise, SNR and CNR. However the CTDIvol and DLP were also significantly reduced compared to the control group (Patient Group B) [21]. The difference in results might be attributed to the different sets of radiation doses in the study group. Matsuoka et al. also conducted a study comparing the vascular enhancement and image quality of CTPA performed with 130 or 120kVp and 110 or 100kVp. The result showed that in the low peak kilovoltage group (110 or 100kVp), the attenuation and image noise were both higher significantly compared to the standard peak kilovoltage group [29].

There were some shortcomings in this study. Firstly, due to the hardware limitations, there existed a 6–7 s interval between triggering and starting the scanning device, which limited the set of trigger points, and we had to move the trigger point forward to the right atrium. Meanwhile, to ensure the right time of triggering, we used manual supervision triggering, which had certain requirements for the operator's technique skill. Therefore, in the future, we are planning to move the trigger point to the location of the pulmonary artery and to trigger the scanning automatically according to the device situation to reduce the difficulty of operation, at the same time, experiments are carried out on different devices to study more suitable trigger schemes. Secondly, post-processing algorithms could effectively reduce image noise and improve image quality. In this article, we didn't compare the influence of different algorithms on the image quality and reduction of dosage. In the future, more advanced post-processing algorithms should be adopted to further reduce the radiation dose. Thirdly, in the following research, we could attempt to explore further protocol to reduce radiation dose and contrast agent dosage based on age or weight stratification.

In the future, we called on more researchers to work on the optimization of the CTPA protocol for pediatric PE situations, since nowadays pediatric PE is no longer taken as a rare situation but there is still a lack of research around it. Applying new post-processing algorithms and conducting sub-group research based on age or weight stratification might be the future focus of this topic.

Conclusion

In this article, we have applied a new strategy to reduce both the radiation dose and contrast agent dose while maintaining the image quality. We found that short-time contrast agent injection combined with low voltage scanning could meet diagnostic requirements and improve the displaying ability of pediatric CTPA under the condition of reducing contrast agent dosage by 50% and radiation dose by 20%.

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Author contributions
Conceptualization, KHY, JHS, YDZ; Data Curation, YDZ, XY, LFS, and LW; Writing-Original Draft Preparation, KHY, JHS, YDZ; Writing-Review & Editing, YL and SLS; Supervision, YL and SLS; Project Administration, YL and SLS.

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Data availability
The data used or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
All author assumes full responsibility for all aspects of the work, ensuring that any issues related to the accuracy or completeness of any part of the work are thoroughly investigated and resolved. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki (as amended in 2024). This article was a prospective cohort study approval by the Ethical Committee of Children's Hospital Affiliated of Zhengzhou University, with the registering number LHGJ20210690.

Consent for publication
An informed consent to publish this data was obtained from all of the participants of this study.

Clinical trial number
not applicable.

Competing interests
The authors declare no competing interests.

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