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A study on CT pulmonary angiography at low kV and low-concentration contrast medium using iterative reconstruction.

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Abstract

Objective: This study is to investigate the possibility of CT Pulmonary Angiography (CTPA) at low kV and low-concentration contrast medium using iterative reconstruction technique.

Methods: Ninety suspected cases of Pulmonary Embolism (PE) scheduled for CTPA were randomly and equally divided into 3 groups (group A, B and C). The dose of the contrast medium was 270 mg/ml, 350 mg/ml and 370 mg/ml, respectively. CT values of the pulmonary trunk together with the left and right pulmonary artery were measured. The image quality was assessed based on Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR). Gender distribution and scores of image quality were compared using Kappa statistics.

Results: The three groups showed no significant difference in gender, age, height, body weight and BMI. The subjective and objective image quality of CTPA did not differ significantly among the three groups. Subjective evaluation showed a high consistence (p=0.85) and the images were all sufficient for diagnosis. The effective dose of group A was considerably lower than that of group B and C.

Conclusion: By using iterative reconstruction, CTPA images acquired at low kV and low-concentration contrast medium were of comparable quality as conventional CTPA images.

Keywords: Pulmonary artery, Contrast agent, Tomography, X-ray computer.

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Introduction

CT Pulmonary Angiography (CTPA) is an effective tool for diagnosing and evaluating the severity of Pulmonary Embolism (PE). Under the premise of ensuring the quality of the image, the radiation exposure and dose of the contrast agent should be reduced as far as possible so as to minimize the radioactive hazards to the patients. Radiation exposure can be greatly reduced by lowering tube voltage, and the use of low-concentration contrast medium can decrease iodine uptake for the patients, though this may cause a decline of image quality. Iterative reconstruction which consists of interpolation operations can reduce image noise and increase the image quality. In the present study, image quality and radiation exposure of CT Pulmonary Angiography (CTPA) at low kV and low-concentration contrast medium using the iterative reconstruction technique was performed.

Patients and Methods

Subjects

Cases scheduled for CTPA from October 2015 to June 2016 were selected, the exclusion criteria excluding those with history of allergy to contrast medium, hyperthyroidism, renal insufficiency, cardiac insufficiency, and BMI>25kg/m^2. To reduce the effect from metallic artefacts, patients with pacemaker and bypasses were also excluded. Ninety serially collected cases were finally included and were randomly and equally divided into three groups (group A, B and C), with the dose of contrast medium was 270 mg/ml, 350 mg/ml and 370 mg/ml, respectively. Prior written and informed consents were obtained from each participant and the study was approved by the ethics review board of Tianjin Medical University General Hospital.

Image collection and reconstruction

As for CT scanner, Philips 256-slice (Royal Dutch Philips Electronics Ltd., Amsterdam, Netherlands) was used. The CT scan parameters for each group were as follows: tube voltage 100 kV and tube current 190-300 mA for group A, tube voltage 120 kV and tube current 250-450 mA for group B and C, collimation 128 × 0.6 mm and tube rotation speed 0.27 s/r. The patients were scanned from head to toes, and the scan range was from the thoracic inlet to the costal margin. The contrast medium was injected according to the same procedures in the three groups: first 40-50 ml of contrast medium was injected, followed by 40 ml of normal saline, with an injection rate of 4.0-5.0 ml/s. The Region of Interest (ROI) was delineated in the pulmonary trunk and CT scan was triggered when the threshold of 60 HU was reached. The CT images were reconstructed with iDose3, with slice thickness of 1.5 mm, slice interval of 0.5 mm and matrix of 512 × 512. MIP, MPR and VR reconstructions were performed on Philips Intellispace Portal workstation.

Image quality evaluation

Subjective and objective evaluation was performed for image quality analysis. For subjective evaluation, the CTPA images were evaluated independently by two radiologists using double-blind method within 1 d after the scan. The lower score was taken as the final score in case of divergence of opinions. The image quality was assessed using a 5-point scale [1,2]. 5 points indicated high image quality without artefacts which was very useful for diagnosis; 4 points, moderately high image quality, with mild artefacts or noise; 3 points, moderate image quality with significant artefacts or noise, but still useable for diagnosis; 2 points, poor image quality with severe artefacts and only suitable for qualitative diagnosis; 1 point, completely not useable for diagnosis.

As for objective evaluation: CT values of ROI in the pulmonary trunk and the left and right pulmonary arteries without embolism were measured and the ROI was100 ± 5 mm^2. The values were taken on three planes continuously and the average was taken. Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) were measured from the images, using the following method: CT values were measured for the ROI in the right pulmonary artery, paravertebral muscles, and precordial region. When the emboli were larger in the right pulmonary artery, the starting position of the right pulmonary artery was measured. The CT value measured in the right pulmonary artery was taken as the signal intensity, and the standard deviation of noise in the precordial region as the background noise. CT values were measured continuously from three planes and the average was taken as the final result. SNR and CNR were calculated using the following formulae: SNR=signal intensity/background noise; CNR=(signal intensity-CT value of paravertebral muscles)/background noise [3,4]. Signal intensity, SNR and CNR were measured for the three groups.

Calculation of radiation exposure and iodine dose

Scan length and volume CT dose index were automatically measured by the CT scanner. Dose length product (DLP, DLP=L × CTDI vol) and effective dose (ED, mSv; ED=k × DLP, k=0.014) were calculated for each patient [5,6]. Amount (40-50 ml) and concentration of the contrast medium were recorded to calculate the iodine dose: iodine dose (mg)=concentration (mg/ml)×injected amount of contrast medium (ml).

Statistical analysis

SPSS 16.0 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Continuous variables were expressed as mean ± standard deviation. Analysis of variance was used to compare the difference in age, DLP, ED, signal intensity, noise, SNR and CNR among the three groups. Gender distribution and scores of image quality were compared using Kappa statistics. p<0.05 indicated significant difference.

Results

Baseline information

In order to make sure there were no significant differences in general situation among patients in the three groups, comparison was performed before CTPA scans. Table 1 shows the baseline information of the patients. It is clear that the three groups had no significant difference in age, gender, height, weight and BMI. The result argued that the group division is reasonable.

Table 1. *Comparison of the general data of patients in the 3 groups.*

	A (n=30)	B (n=30)	C (n=30)	P value
Sex (male/female)	43087	43058	17/13	0.87
Age	55.87 ± 14.61	57.93 ± 14.99	58.27 ± 13.30	0.78
Height	168.23 ± 6.49	167.90 ± 5.67	167.47 ± 5.92	0.88
Weight	61.10 ± 6.77	59.70 ± 6.20	61.00 ± 6.74	0.66
BMI	21.67 ± 2.87	21.19 ± 2.05	21.74 ± 2.00	0.62

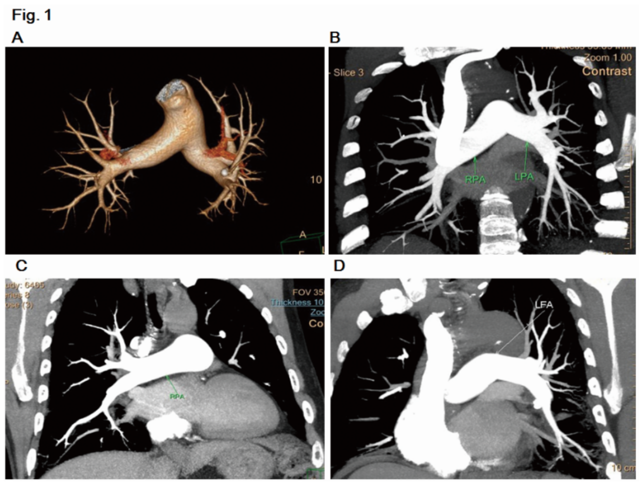

Figure 1. *CTPA imaging acquired with 100 kV tube voltage and 270 mg/ml concentration contrast agent. (A) VR image (positive); (B) Coronal MIP image of double pulmonary artery; (C and D) The right and left pulmonary artery trunk and related branches (RPA: Right Pulmonary Artery; LRP: Left Pulmonary Artery).*

CTPA results

To confirm whether the subject had PE, the subjects were examined by CTPA. Volume Rendering (VR) and Maximum Intensity Projection (MIP) were performed in order to show the enhancement of the main pulmonary artery and the left and right pulmonary arteries and branches. CTPA results are illustrated in Figure 1, and Figures 1A and 1B showed the condition of the main pulmonary artery and pulmonary artery contrast agent filling and vascular enhancement. Contrast agent filling and vascular enhancement in bilateral pulmonary arteries and related branches was demonstrated in Figures 1C and 1D.

Table 2. *Comparison of subjective evaluation of CTPA image quality in the three groups.*

Score/group	A	B	C
5	19 (63.4%)	20 (66.6%)	21 (70%)
4	9 (30%)	8 (26.7%)	8 (26.7%)
3	1 (3.3%)	2 (6.6%)	1 (3.3%)
2	1 (3.3%)	0	0
1	0	0	0

Comparison of image quality

In order to evaluate the effect of low radiation dose and low concentration contrast agent on CTPA imaging ability for pulmonary artery, image quality in the three groups was compared. Subjective evaluation of image quality showed a high consistence (p=0.85), and all images could be used for diagnostic purposes.

There were 63.4%, 66.7% and 70% of the images scored 5 points in the three groups, respectively; 30%, 26.7% and 26.7% of the images scored 4 points in the three groups, respectively. The image quality was poor in bilateral lower lungs for only 1 case in group A due to poor breath holding. This image scored 2 points but was still sufficient for diagnosis. All images scored 3 points in the three groups were caused by artefacts arising from the contrast medium in the superior vena cava (Table 2).

Table 3 shows the objective evaluation of image quality. There was no significant difference in CT values, background noise, SNR and CNR of the pulmonary trunk, and the left and right pulmonary artery between the three groups. To sum up, the results demonstrated that the ability of CTPA imaging to pulmonary artery in low dose group is consistent with the conventional dose groups; both could get the image quality that meets the diagnostic requirements.

Comparison of radiation exposure and iodine dose

Table 4 shows the comparison of radiation exposure and iodine dose between the three groups. There was no significant difference in scan length, but mAs, DLP and ED differed considerably between the three groups. mAs of group A was 190.10 ± 51.33, which was slightly lower than that of group B and C.

DLP was 219.49 ± 24.61 mGy.cm in group A, which was also lower than that of group B and C. ED of group A that used 100 kV tube voltage was much lower than that of group B and C. ED of group A was 40% and 40.13% of that of group B and C respectively.

The total injected amount of contrast medium was not significantly different between the three groups. Since low-concentration contrast medium was used in group A, the total iodine dose of this group was much lower while compared with group B and C.

Table 3. *Comparison of objective evaluation of CTPA image quality in the three groups.*

		A	B	C
CT value (HU)	Pulmonary trunk	332.46 ± 93.88	338.15 ± 89.70	352.01 ± 94.33
	Right pulmonary artery	332.63 ± 93.76	337.59 ± 89.57	351.15 ± 93.20
	Left pulmonary artery	333.98 ± 94.13	339.47 ± 89.46	354.24 ± 94.41
	Muscle	43.55 ± 9.20	42.63 ± 7.79	44.63 ± 8.00
SNR	Image noise (Air SD value)	8.25 ± 1.42	8.52 ± 1.41	8.87 ± 1.59
	Pulmonary trunk	40.13 ± 7.71	39.83 ± 8.17	39.91 ± 8.87
	Right pulmonary artery	40.15 ± 7.68	39.76 ± 8.14	39.82 ± 8.80
	Left pulmonary artery	40.31 ± 7.70	39.99 ± 8.17	40.16 ± 8.84
CNR	Pulmonary trunk	34.69 ± 7.83	34.70 ± 8.02	34.68 ± 8.81
	Right pulmonary artery	34.71 ± 7.80	34.64 ± 7.99	34.59 ± 8.73
	Left pulmonary artery	34.87 ± 7.82	34.86 ± 8.02	34.93 ± 8.78

Table 4. *Comparison of radiation dose parameters and iodine dosage between the three groups.*

	A	B	C
Scanning length (cm)	290.38 ± 47.90	294.46 ± 46.10	293.83 ± 46.41
DLP (mGy.cm)	280.27 ± 32.92	437.38 ± 32.54	443.41 ± 31.12
ED (mSv)	3.92 ± 0.46	6.12 ± 0.46	6.21 ± 0.44

mAs	190.10 ± 51.33	212.00 ± 18.22	216.00 ± 24.45
Dosage of contrast agent (ml)	45.33 ± 3.92	44.83 ± 4.04	45.00 ± 3.71
Dosage of iodine (g)	12.24 ± 1.06	15.69 ± 1.42	16.65 ± 1.37

Discussion

In this study, we performed a prospective analysis on CTPA scans using different concentrations and doses of the contrast medium. For scans with low-concentration contrast medium (270 mg/ml), the tube voltage of 100 kV was used and 12 kV tube voltage was used for contrast medium concentrations of 350 mg/ml and 370 mg/ml. All CTPA images obtained from the three groups were qualified for the diagnostic purpose. ED was lower under the scan using 270 mg/ml contrast medium and 100 kV voltage tube, and the total iodine uptake was also lower.

Both the temporal and spatial resolutions of CT scan have been improved dramatically in the past decade, making the imaging of sub-segmental pulmonary artery easier and clearer in CTPA. Currently, CTPA is considered as the first-line choice for the diagnosis of PE. The latest development of CTPA is the use of iterative reconstruction to compensate for potentially poor image quality at low kV, which is intended for reducing the radiation exposure of the patients [1,5,7,8]. Our study showed that CTPA scans under low kV and low-concentration contrast medium can obtain high quality images.

The risks of allergy to contrast medium and contrast-induced nephropathy are increasing along with the popularization of CTPA. The incidence of contrast-induced nephropathy is greatly related to the repeated use of high-dose and hypertonic contrast medium. The hazards can be reduced by reducing the injected amount and concentration of the contrast medium, hence decreasing the uptake of radioactive iodine. In this study, we used iodixanol (270 mg/ml), a hypotonic contrast medium, to reduce the impact on cardiovascular parameters, blood system, endothelial system, and kidney. CTPA can reduce the beam-hardening artefacts in the superior vena cava. Dual-phase scans were performed with the injection of low-concentration contrast medium followed by normal saline so as to reduce the impact of residual contrast medium in the superior vena cava on the image quality. All images scored 3 points in subjective evaluation were related to severe artefacts in the superior vena cava. Threshold-triggered CTPA might lead to excessively high concentration of contrast medium in the superior vena cava or sub-clavian vein considering the inter-individual difference in circulation time. This is an important reason for hardening artefacts. Moreover, the injection rate of contrast medium and normal saline also has an impact on the concentration of contrast medium in the superior vena cava or sub-clavian vein. This problem can be addressed by reducing the injective amount of contrast medium and injecting normal saline at a high flow rate subsequently. The injection of hypotonic contrast medium at a low flow rate can also reduce the discomfort for the patients. Our result indicated that the image quality did not differ significantly under different contrast medium injection schemes.

The patients are challenged by higher radiation exposure because of an extensive application of CT scans. It is necessary to minimize the radiation exposure according to ALARA principle. The ED is about 3-8 mSv [9,10] at 120 kV tube voltage, and radiation exposure is usually reduced by decreasing the tube voltage and tube current. It is reported that the radiation exposure can be reduced by about 30-50%, or even as high as 70%, by reducing the tube voltage in CTPA [9,11]. Among the three groups, the radiation exposure of group A decreased by 35.95% and 36.88% as compared with group B and C, respectively. This agrees with other similar studies [9,11]. CTPA scans at lower tube voltage and tube current can effectively reduce the radiation exposure for the patients. Since we were concerned with the total radiation exposure, the scan length was not normalized in the calculation of the radiation exposure.

Low-concentration contrast medium contains less radioactive iodine, which may result in low contrast of the vessels and poor image quality [12]. However, CT values for unit iodine concentration will increase due to low tube voltage [11,13]. Thus the combined use of low-concentration contrast medium and low tube voltage will not reduce CT values of the vessels on the whole. But the defects such as poor image quality and high noise may occur, and iterative reconstruction can be applied to these defects. Iterative reconstruction simulates the shape of the target organs that the X-ray photons penetrate, so as to reduce the image noise and enhance the image contrast [12,14]. In this study, by using the iterative reconstruction technique, high quality images were obtained under low-concentration contrast medium for all three groups.

Our study was restricted in the following aspects: firstly, the patients chosen had a BMI generally below 25kg/m^2 and whether the scan scheme with 100 kV tube voltage and 270 mg/ml contrast medium can achieve satisfactory effects for patients with higher BMI is unknown. Secondly, the potential impacts from high BMI, cardiac insufficiency, and pacemaker were precluded, but not the impact from PE. Finally, repeated scans with different schemes were performed for the same patients to collect the images, which would increase the radiation exposure of patients.

Collectively, by using the iterative reconstruction technique, CTPA images qualified for the diagnostic purpose can be obtained at 100 kV tube voltage and low-concentration contrast medium (270 mg/ml). More importantly, this scan scheme considerably reduces the radiation exposure and total iodine uptake for the patients.

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Disclosure of Conflict of Interest

None.

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