

Effects of the Sn100 kVp Tube Voltage Mode on the Radiation Dose and Image Quality of Dual-Source Computed Tomography Pulmonary Angiography

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Objective: This study aimed to investigate the effects of the Sn100 kVp tube voltage mode on the image quality and radiation dose of computed tomography pulmonary angiography (CTPA).

Methods: A total of 145 patients who underwent CTPA were randomly divided into five groups: control group (120 kVp, 150 mAs), test group A (Sn100 kVp, 270 mAs), test group B (120 kVp, 30 mAs), test group C (70 kVp, 150 mAs), and test group D (80 kVp, 70 mAs). After image post-processing, the image quality and radiation dose of each group were analyzed.

Results: The computed tomography values of images in the four test groups were more than 250 HU, which met the criteria for diagnosis. The signal-to-noise ratio and contrast-to-noise ratio of the images in the four test groups were lower than those in the control group. The radiation dose in each test group was lower than in the control group. The radiation dose was lowest in test group A.

Conclusion: The Sn100 kVp energy spectrum purification protocol can meet the requirements for clinical diagnosis, ensure image quality, and reduce the dose of radiation that patients receive.

Keywords: Sn100 kVp, CTPA, radiation dose, pulmonary embolism, dual-source CT

Introduction

Pulmonary embolism (PE) is a common clinical finding with a high death rate.¹⁻³ Computed tomography pulmonary angiography (CTPA) has become the first choice for the clinical diagnosis of pulmonary embolism due to its rapidity, non-invasive features, and high diagnostic accuracy.⁴ Given the widespread use of CTPA, more attention is being focused on problems associated with radiation.

Results of previous studies show that the doses of radiation from and contrast agent used in CTPA scanning can be greatly reduced by using dual-source, coarse-pitch CT in combination with low tube voltage technology.⁵ Energy spectrum purification technology, Sn100 kVp, has weak penetration, which is suitable for scanning the lungs.^{6,7} Therefore, this study discusses the image quality and dose of radiation from CTPA under the Sn100 kVp tube voltage mode to provide reference information for its future clinical application.

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Data and Methods

Phantom Studies

Equipment and Phantom

The scanning equipment was a third-generation, dual-source CT (SOMATOM Definition Force; Siemens Healthcare, Forchheim, Germany) with a detector array of 192 rows \times 0.6 mm. The phantom was a Catphan[®] 500 from the American phantom laboratory, testing high-contrast resolution (spatial resolution), noise, and other modules, and using a spatial resolution module containing 1–21 LP/cm of precise line pairs. The Catphan[®] 500 phantom was placed in the center of the CT frame for scanning.

Scan Protocol

The layer thickness was 0.75 mm. The scanning field of view was the gross scanning field with a display field of view of 30 cm, a matrix of 512 \times 512, and a voxel display of 0.6 mm³. The pitch was 2.5, the tube ball rotation time was 0.25 s, and the convolution kernel was Br36. The scan parameters showed that the tube voltage was 120 kVp, 80 kVp, 70 kVp and Sn100 kVp, respectively. The tube current was 10–300 mA in 10 mA steps. Separate scans were performed using different tube voltage combinations. The high-resolution line logarithm and radiation dose of the combined images of all scanning parameters were observed and recorded after scanning.

Image Analysis

The GE picture archiving and communication system (PACS) was used for film reading. The spatial resolution, noise, and scanning dose of each scanning parameter were measured and recorded. The CTPA low-dose scan protocol was determined. The spatial resolution was represented by LP/cm and observed with a window width of 0 HU and a window position of 900–1000 HU. Adjacent line pairs with no adhesion under visual inspection, and the same line pair with no fractures, were taken as the evaluation standard. The spatial resolution was represented by calculating the maximum value of the line pair. Noise was represented by the standard deviation of the CT value in the region of interest (ROI). An ROI with an area of 100 mm² was set in the center of the scanned image for measurement. The scanning dose was expressed as CT dose index volume (CTDI_{vol}), which was automatically displayed by the CT machine after setting the scanning parameters. In the scan results, a spatial resolution of 5 LP/cm was used as the standard. Scanning parameters satisfying these conditions were used in the clinical trials.

Clinical Trial Standard

According to WS 519–2019, when an image has a standard⁸ CT Dose Index Weighted $<$ 50 mGy and line pairs $>$ 5.0 LP/cm, it meets clinical diagnostic requirements. This was determined as the clinical trial group and compared with the conventional scanning parameters, 120 kVp and 150 mAs.

Clinical Studies

General Data

A total of 145 patients, who were treated in Beijing Chaoyang Hospital from November 2018 to December 2018 and suspected to have pulmonary embolism, were enrolled in the study for the CTPA examination. Patients were randomly divided into five groups, including, control group (120 kVp, 150 mAs), test group A (Sn100 kVp, 270 mAs), test group B (120 kVp, 30 mAs), test group C (70 kVp, 150 mAs), and test group D (80 kVp, 70 mAs), using a simple random grouping method.

Exclusion criteria: Pregnant or lactating women; patients with iodine contrast allergy; and patients with severe heart, liver, kidney, or respiratory dysfunction.

This study was approved by the Ethics Committee of Beijing Chaoyang Hospital (Ethical approval numbers: 2020-ke-26). This study was conducted in accordance with the Declaration of Helsinki. All patients signed an informed consent form before examination.

Scan Method

At the beginning of the scan, a breath-holding image of the chest was performed, with a scanning range from the thoracic entrance to the level of the diaphragm. The contrast agent used was Iopamiro[®] (iohexol containing 370 mg/mL of iodine, Bracco Diagnostics), which was injected into the anterior elbow vein using a double-tube, high-pressure syringe. A mass injection of contrast agent tracking technology was used. A monitoring point was set in the main pulmonary artery. When the density of the monitoring point reached the threshold value, the scanning was automatically triggered. In the control group, 50 mL of the contrast agent was injected at a rate of 4.5 mL/s. When the density of the monitoring point reached 80 HU, the scan was automatically triggered, with a scan delay time of five seconds. In test groups A, B, C, and D, 30 mL of the contrast agent was injected at a rate of 4 mL/s. Then 30 mL of normal saline was injected at the same rate. When the density of the monitoring point reached 50

HU, the scan was automatically triggered, with a scan delay time of five seconds.

The scanning parameters of each group were determined according to the results of the phantom scanning. The tube voltage and reference milliamperere per second were Sn100 kVp and 270 mAs in test group A (n = 30), 120 kVp and 30 mAs in test group B (n = 28), 70 kVp and 150 mAs in test group C (n = 28), 80 kVp and 70 mAs in test group D (n = 29), and 120 kVp and 150 mAs in the control group (n = 30), respectively. The other scanning parameters were the same in each group, with a reconstruction layer thickness and layer spacing of 3 mm each. The image reconstruction algorithm was the advanced modeled iterative reconstruction (ADMIRE), with an iterative intensity of three, a convolution core value of Bv36, a reconstruction layer thickness of 1 mm, and interlamellar spacing of 0.7 mm.

Image Post-Processing

The thin-layer image data were transferred to the Siemens post-processing workstation (syngo.via VA30). Volume reproduction, maximum density projection, and multi-plane reconstruction were performed on the lesion site using post-processing software to display the anatomy of the pulmonary arteries, local characteristics of the lesion, and other relevant image information accurately and intuitively.

Image Quality Analysis

Objective analysis: The measurement of the ROI in the objective quality assessment of images was carried out on a PACS workstation. It was completed by a physician with more than three years' experience in the Radiology Department. The CT values in the lumen of the pulmonary artery trunk, the pulmonary artery at the apical segment of the superior lobe of the right lung (the S1 segment), and the pulmonary artery at the posterior basal segment (the S6 segment) were measured using circular measurement tools and the CT values of the back muscles in the same layer as the main pulmonary artery. As far as possible, the ROI avoided the embolism site. If necessary, the ROI was measured in the lumen of the corresponding pulmonary arteries on the opposite side. The standard deviation of the air in the front of the thorax was measured as background noise. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the images were calculated using the following formulae: $SNR = \text{intraluminal mean CT value} \div \text{background noise}$ and $CNR = (\text{intraluminal mean$

$CT \text{ value} - \text{mean CT value of the back muscles}) \div \text{background noise}$.

Subjective assessment: A three-grade rating system was used,³ in which Grade 1 meant that the image quality was excellent, the contrast agent was filling the pulmonary artery lumen well, and the diagnosis was made with full confidence. Grade 2 meant that the image quality was moderate, the contrast agent was filling the pulmonary artery lumen fairly well, and, while its CT value was lower than Grade 1, the image could meet diagnostic requirements. Grade 3 meant that the image quality was poor, and the contrast agent was sparse in the pulmonary artery lumen, so it was impossible to make a diagnosis. The image quality was scored independently by two doctors, each with more than three years' experience in the Radiology Department, using a double-blind method.

Radiation dose: The dose data in the dose report automatically generated by the CT machine, such as $CTDI_{vol}$ and dose-length production (DLP), were recorded. The effective dose (ED) per patient to complete this test was $DLP \times K$, where K refers to chest weight factor ($K = 0.014$) [$mSv \div (mGy \cdot cm)$].

Statistical Analysis

SPSS 22.0 statistical software was used. A one-way analysis of variance was used to compare the age, body mass index, radiation dose, CT value, and differences in SNR and CNR between the groups. A chi-squared test was used to compare the sex and PE distribution between the groups. A rank sum test was used to compare the subjective image quality scores between the groups. The K value was calculated to evaluate consistency ($K = 0.81-1.00$, excellent consistency; $K = 0.61-0.80$, good consistency; $K = 0.41-0.60$, average consistency; $K < 0.40$, poor consistency) of the image quality scores between the different observers. $P < 0.05$ was considered to be statistically significant.

Results

Scanning Dose and Image Quality in Phantom Studies

The combined spatial resolution was 6 LP/cm when tube voltage = 120 kVp and tube current ≥ 150 mAs, tube voltage = Sn100 kVp and tube current ≥ 270 mAs, tube voltage = 120 kVp and tube current ≥ 30 mAs, tube voltage = 70 kVp and tube current ≥ 150 mAs, and tube voltage = 80 kVp and tube current ≥ 70 mAs. See Table 1 for details of scanning dose

Table 1 Comparison of Scanning Dose and Image Quality of Different Combined Phantom Scans

	70kv,150mAs	80kv,70mAs	Sn100kv,270mAs	120kv,30mAs	120kv,150mAs
Spatial resolution	6	6	6	6	6
Noise	7.39	6.268	5.473	5.137	2.26
CTDI _{vol}	1.35	1.03	0.93	1.59	7.97
DLP	20.8	16.7	14.4	24.6	122.9
ED	0.28	0.23	0.20	0.34	1.72

Abbreviations: CTDI_{vol}, CT volume dose index; DLP, effective dose length product; ED, effective dose.

Table 2 Comparison of Basic Information of Subjects in Each Group

	Control Group	Test Group A	Test Group B	Test Group C	Test Group D	p
Age (years)	62.83 (35~84)	66.06 (35~83)	62.67 (32~85)	56.89 (32~78)	65.79 (34~91)	0.81
Weight (kg)	66.13 (43~10)	64.33 (47~80)	63.85 (42~92)	70.60 (48~100)	67.03 (42~90)	0.37
Height (m)	1.65 (1.55~1.80)	1.65 (1.50~1.78)	1.6 (1.50~1.78)	1.67 (1.51~1.82)	1.66 (1.57~1.82)	0.87
BMI	23.92±4.12	23.50±2.5	23.41±4.05	25.23±3.76	23.96±3.38	0.35

and spatial resolution results. In the phantom scanning, the scanning with a radiation dose of Sn100 kVp and 270 mAs was 88% lower than that of 120 kVp and 150 mAs. In addition, the spatial resolution of the image was maintained. At the same time, the noise was significantly lower than that of the low-dose groups, with 70 kVp and 80 kVp, and slightly higher than that of the group with 120 kVp and 30 mAs.

Comparison of General Data

In the clinical study, differences in sex, age, and body mass index (BMI) were not statistically significant ($P > 0.05$) between the five groups. See [Table 2](#) for the demographic information for each group.

Comparison of Image Quality and Radiation Dose Between the Test Groups and the Control Group

The difference in CT values for the main pulmonary artery and the S1 segment of the right lung was not significant between the control group and test groups A and B ($P > 0.05$). The CT values of test groups C and D were significantly higher than those of the control group, and the difference was statistically significant ($P < 0.05$). When the CT values of the S6 segment of the right lung were compared between the five groups, the difference was statistically significant ($P < 0.05$) between test groups A,

C, D, and the control group. Only test group B had the same CT value as the control group ($P > 0.05$). The CT values of the images of the four test groups were more than 4 HU, which met the criteria of diagnosis. When the SNR and CNR were compared among the five groups, the difference was statistically significant ($P < 0.05$) between the test groups A, B, C, D, and the control group. The SNR and CNR of the four test groups were lower than those of the control group. The differences in CTDI_{vol}, DLP, and ED values were not statistically significant ($P < 0.05$) between the test groups and the control group. The results showed that the radiation dose of each test group was lower than that of the control group when the image quality met the CTPA diagnosis; the radiation dose of test group A (Sn100 kVp) was the lowest, and the image met the diagnostic requirements. Details are shown in [Table 3](#).

Comparison of Subjective Image Quality and Consistency

The subjective scores of images by two doctors were consistent (Kappa = 0.868, $P < 0.05$). Details are shown in [Table 4](#).

Discussion

At present, CTPA is one of the main methods for the diagnosis of pulmonary embolism. The quality of the CTPA image is closely related to the enhancement of the

Table 3 Comparison of Image Quality and Radiation Dose Between Test Groups and Control Group

	Control Group	Test Group A	Test Group B	Test Group C	Test Group D	χ^2	p
CT values for the main pulmonary artery	406.53 (155.00–670.00)	376.97 (252.00–531.00)	430.03 (211.00–648.00)	695.82 (403.00–1078.00)*	600.24 (351.00–1184.00)#	70.22	0.0001
CT values for the S1 segment of the right lung	370.46 (206.00–90.00)	378.53 (268.00–550.00)	361.64 (195.00–662.00)	557.57 (330.00–811.00)*	508.38 (264.00–720.00)#	51.77	0.0001
CT values of the S6 segment of the right lung	288.63 (157.00–480.00)	336.57 [†] (152.00–557.00)	295.39 (220.00–590.00)	394.17 (227.00–637.00)*	382.45 (152.00–598.00)#	21.45	0.0001
SNR	70.90 (4.00–215.00)	36.07 (17.00–58.00) [†]	38.21 (9.00–89.00) [‡]	43.75 (19.00–98.00)	33.10 (13.00–88.00)#	12.65	0.013
CNR	59.66 (3.00–200.10)	31.20 (14.00–54.00) [†]	32.25 (6.00–78.00) [‡]	38.96 (16.00–89.00)	28.97 (10.00–78.00)#	11.79	0.019
CTDI _{vol} (mGy) [#]	7.99 (7.97–8.00)	0.92 (0.74–0.95) [†]	1.59 (1.59–1.59) [‡]	1.34 (1.11–1.35)*	1.02 (1.02–1.02) [#]	1141.70	0.0001
DLP (mGy cm)	244.82 (181.20–289.20)	29.81 (18.90–35.10) [†]	45.94 (34.30–62.00) [‡]	39.22 (30.20–50.50)*	31.09 (23.90–35.80) [#]	119.16	< 0.0001
ED (mSv)	3.42 (2.54–4.05)	0.42 (0.26–0.49) [†]	0.64 (0.48–0.87) [‡]	0.55 (0.42–0.71)*	0.44 (0.33–0.50) [#]	119.10	0.0001

Notes: [†]Represents a statistically significant difference between test group A and the control group; [‡]represents a statistically significant difference between test group B and the control group; *represents a statistically significant difference between test group C and the control group; [#]represents a statistically significant difference between the test group D and the control group.

Table 4 Comparison of Subjective Image Quality and Consistency

	Control Group	Test Group A	Test Group B	Test Group C	Test Group D	p
Consistency	3.96 (1.02–3.96)	1.00 (1.00–2.00)	1.59 (1.59–1.59)	1.35 (1.11–1.35)	1.02 (1.02–1.02)	<0.0001
Subjective Image Quality	114.65 (30.70–140.90)	1.00 (1.00–2.00)	1.00 (1.00–2.00)	1.00 (1.00–2.00)	1.00 (1.00–2.00)	<0.0001

pulmonary artery. The more iodinated contrast agent that enters the pulmonary artery within a given time, the better the enhancement of the lumen and the better the image quality. However, an increase in the contrast agent may increase the incidence of contrast-induced nephropathy.⁹ The development of CT-related technology, such as coarse-pitch CT, increases the speed of data acquisition and shortens the best display time for the pulmonary artery, thereby reducing the amount of contrast agent needed.¹⁰

Bae et al¹¹ reported that when the CT value of the pulmonary artery was greater than 250 HU it would meet the diagnostic criteria for a pulmonary embolism. In this study, 30 mL of iodinated contrast agent was used in the test group. The CT value of the lumen of each pulmonary artery branch was greater than 250 HU. This is the same as the image quality achieved using 50 mL of contrast agent in the control group. Pulmonary artery CTA is usually performed by elbow vein administration. As it does not

pass through the systemic circulation, it is not necessary to calculate the dosage of contrast agent according to body weight.¹² This also provides a basis for the use of 30 mL of low-dose contrast agent.

CTPA requires a good contrast between the inside and the outside of the pulmonary artery. Usually, a 120 kVp scan is recommended.^{13–15} Low-dose scanning includes various methods, such as reducing tube current, reducing tube voltage, coarse-pitch scanning, automatic tube voltage modulation, automatic tube current modulation, and the use of noise reduction filters and iterative reconstruction algorithms. Some studies⁸ suggest that the dose of radiation has a linear relationship with the tube current and an exponential relationship with the tube voltage. Therefore, reducing the tube voltage can decrease the dose of radiation more effectively than reducing the tube current. However, the research of Tang et al¹⁶ shows that reducing the tube voltage decreases the CNR of the image.

In this study, the voltage of tube A in the test group was Sn100 kVp of energy spectrum purification, which was significantly lower than the 120 kVp used in the control group. The radiation dose in the Sn100 kVp group was the lowest, when compared with the other test groups. At the same time, Siemens Force dual-source CT (the third-generation, dual-source CT) can selectively filter low-energy photons with a tin filter plate placed in front of the x-ray ball tube, which improves the x-ray utilization rate and thus reduces the dose absorbed by the human body.¹⁰ This can better separate the low kVp and high kVp spectra, thereby improving the CNR of the image. After reconstruction with ADMIRE technology, image noise is gradually reduced with a gradual increase in reconstruction intensity. A gradual increase in the SNR and CNR of the image compensates for the increase in noise after the kVp reduction. This has the potential to significantly reduce noise and improve image quality.

Conclusions

In the present study, the Sn100 kVp energy spectrum purification protocol was used for adult CTPA. The results revealed that the CTDI_{vol}, DLP, and ED were significantly lower in test group A than in the scanning protocols of the other four groups ($P < 0.05$). This suggests that energy spectrum purification technology can significantly reduce the dose of radiation absorbed by the human body. In CTPA, using the Sn100 kVp energy spectrum purification protocol can meet the needs of clinical diagnosis, ensure image quality, and reduce the dose of radiation that patients receive.

Ethics Statement

Ethical approval numbers: 2020-ke-26.

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Disclosure

The authors report no conflicts of interest in this work.

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