

# Low-dose CT pulmonary angiography on a 15-year-old CT scanner: a feasibility study

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## Abstract

**Background:** Computed tomography (CT) low-dose (LD) imaging is used to lower radiation exposure, especially in vascular imaging; in current literature, this is mostly on latest generation high-end CT systems.

**Purpose:** To evaluate the effects of reduced tube current on objective and subjective image quality of a 15-year-old 16-slice CT system for pulmonary angiography (CTPA).

**Material and Methods:** CTPA scans from 60 prospectively randomized patients (28 men, 32 women) were examined in this study on a 15-year-old 16-slice CT scanner system. Standard CT (SD) settings were 100 kV and 150 mAs, LD settings were 100 kV and 50 mAs. Attenuation of the pulmonary trunk, various anatomic landmarks, and image noise were quantitatively measured; contrast-to-noise ratios (CNR) and signal-to-noise ratios (SNR) were calculated. Three independent blinded radiologists subjectively rated each image series using a 5-point grading scale.

**Results:** CT dose index (CTDI) in the LD series was 66.46% lower compared to the SD settings ( $2.49 \pm 0.55$  mGy versus  $7.42 \pm 1.17$  mGy). Attenuation of the pulmonary trunk showed similar results for both series (SD  $409.55 \pm 91.04$  HU; LD  $380.43$  HU  $\pm 93.11$  HU;  $P = 0.768$ ). Subjective image analysis showed no significant differences between SD and LD settings regarding the suitability for detection of central and peripheral PE (central SD/LD, 4.88; intra-class correlation coefficients [ICC], 0.894/4.83; ICC, 0.745; peripheral SD/LD, 4.70; ICC, 0.943/4.57; ICC, 0.919; all  $P > 0.4$ ).

**Conclusion:** The LD protocol, on a 15-year-old CT scanner system without current high-end hardware or post-processing tools, led to a dose reduction of approximately 67% with similar subjective image quality and delineation of central and peripheral pulmonary arteries.

## Keyword

Computed tomography pulmonary angiography (CTPA); low-dose imaging; CT pulmonary angiography; CT radiation exposure

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## Introduction

Computed tomographic pulmonary angiography (CTPA) is widely used to evaluate patients who are clinically suspected of having pulmonary embolism (PE) to either confirm or rule out this diagnosis (1,2).

Even though multiple techniques are designed to reduce radiation exposure, thoracic CT imaging still exposes patients to a higher amount of radiation than other imaging modalities (e.g. X-ray). However, radiation exposure in chest CT imaging has decreased remarkably in recent years using low kV imaging, iterative reconstruction algorithms, and campaigns by

radiological societies around the world, such as the “Image Wisely” campaign from the Radiological Society of North America (RSNA) and the American College of Radiology (ACR) (3–5).

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State-of-the-art CT scanners implement rapid imaging strategies to reduce radiation exposure, including wide detectors, fast gantry rotation times, two detectors, or a combination of these strategies (5–10). However, these high-definition CT systems are not available in every radiology department. Even in elderly CT machines, fast tube detector rotation times of  $\leq 0.5$  s/rotation (rot) are possible and can be used in different clinical situations (11). Concerning the collimation, sub-millimeter resolution is possible as well. Iterative reconstruction and automated tube potential selection are tools which are designed for up-to-date CT scanner generations. Although these technologies could be used in older CT systems, the software is often not designed to work on older computer systems. Therefore, the aim of this study was to investigate the influence of low-dose (LD) imaging in a 15-year-old 16-slice CT system on image quality, noise, artifacts, and radiation exposure during CTPA examinations.

## Material and Methods

### Patients and CT protocols

This single-center study was approved by the local Ethics Committee and written informed consent was obtained by all patients. Data of consecutive patients that underwent clinically indicated CT of the chest for ruling out PE between January 2013 and April 2014 were analyzed. All CT examinations included in this study were diagnostic and did not require repeating because of unsatisfactory image quality or artifacts.

Patients were divided into two groups of 30 individuals, each based on the chosen dose setting (Table 1). Both groups underwent chest CT examination on a single-source 16-slice CT (Somatom Sensation 16, Siemens Healthcare, Forchheim, Germany) with a 1.2 pitch,  $16 \times 1.5$  mm collimation, and 100 kV tube potential. The reference current was set 150 mAs (group A) in standard (SD) settings and 50 mAs (group B) in LD settings (Table 2). Gantry rotation time was 0.5 s. Automatic exposure control was used for all scans

**Table 1.** Patient demographics.

	Group A (SD)	Group B (LD)
Patients (n)	30	30
Men (n)	12	16
Women (n)	18	14
Age (years)	66.55 (37–85)	68.68 (36–78)
BMI ( $\text{kg}/\text{m}^2$ )	24.3 (19.8–29.7)	23.8 (18.9–28.8)

Values in brackets indicate ranges.  
LD, low dose; SD, standard dose.

(CARE Dose 4D, Siemens Healthcare, Forchheim, Germany). Data were acquired in the caudocranial direction during inspiratory breath-hold.

Contrast enhancement was achieved by injecting a fixed amount of 60 mL of iodinated contrast material (iodine concentration of 400 mg/mL, Imeron 400, Bracco Imaging, Konstanz, Germany), followed by a 50-mL saline chaser bolus injected through an 18–20 G intravenous access on the patient's forearm at a flow of 4 mL/s using a double-syringe power injector (Injektron CT2, Medtronic, Saarbruecken, Germany).

For a quick overview of CTA images, these were reconstructed at a slice thickness of 5-mm slice thickness and 5-mm increments using an angiographic window (center, 100 HU; width, 700 HU) with a medium-soft convolution kernel (B30f).

For further analysis, transverse 2.0-mm slices in 1.5-mm increments were reconstructed. For three-dimensional evaluation, coronal and sagittal reformations with a 2-mm slice thickness in 2-mm increments were reconstructed.

### Image analysis

One observer (with 7 years of experience reading chest CT scans), who was blinded to the scan protocol, performed attenuation measurements in regions of interest (ROI) by using transverse sections on a medical workstation (Syngo Multimodality Workplace; Siemens, Forchheim, Germany). In each patient and for each target structure, three ROIs were prescribed on three consecutive transverse sections depicting the respective target structure. For the pulmonary arteries, these measurements were performed in the bifurcation of the pulmonary trunk and in the artery of segments 1 and 10. Additional ROI evaluations were performed in the subcutaneous fat at the level of the pulmonary trunk, the major pectoral muscle and the liver. To minimize bias from single measurements, we calculated the

**Table 2.** Results of objective image analysis.

	Group A (SD)	Group B (LD)
CT settings	100 kV/150 mAs	100 kV/50 mAs
CDTI <sub>vol</sub> (mGy)	7.42 $\pm$ 1.15	2.49 $\pm$ 0.53
Pulmonary trunk (HU)	409.55 $\pm$ 91.04	380.43 $\pm$ 93.11
Muscle attenuation (HU)	53.27 $\pm$ 9.39	44.07 $\pm$ 7.98
Noise	21.60 $\pm$ 3.79	28.15 $\pm$ 11.63
CNR	18.71 $\pm$ 4.75	12.36 $\pm$ 6.07
SNR	22.69 $\pm$ 5.14	14.66 $\pm$ 2.83

Data are mean  $\pm$  standard deviation.

CNR, contrast-to-noise ratio; LD, low dose; SD, standard dose; SNR, signal-to-noise ratio.

average of three measurements. Based on these measurements, signal-to-noise ratio (SNR) and contrast-to-noise-ratio (CNR) were determined according to the following equation:  $SNR = \text{Attenuation} / \text{Background noise (BN)}$ ;  $CNR = (\text{Attenuation of pulmonary trunk} - \text{Attenuation of muscle}) / \text{BN}$ .

Subjective image evaluation was carried out by three independent radiologists, with 5, 6, and 9 years, respectively, of CT imaging experience regarding the suitability and detection of central and peripheral PE and image noise in each patient. Observers were blinded to the shown image series, but were aware of the clinical suspicion of PE. Image quality rating was performed using a five-point Likert scale (5, excellent; 4, good; 3, moderate; 2, fair; 1, unacceptable). Inter-observer agreement was calculated using intra-class correlation coefficient (ICC).

### Radiation exposure

To estimate patient radiation dose, we recorded the volume CT dose index ( $CTDI_{vol}$ , mGy) and dose length product (DLP, mGy·cm) from the patient CT protocol.

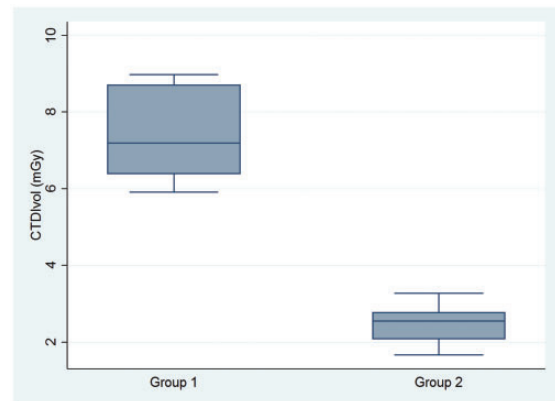
### Statistical analysis

Analyses were performed computer-based with dedicated software (STATA 13 IC, StataCorp LP, College Station, TX, USA). Continuous variables were expressed as median and range. Continuous variables were tested for normal distribution using the Kolmogorov Smirnov–Lilliefors test, corrected according to Dallal–Wilkinson as appropriate. Statistical significance was investigated with the Student's t-test for unpaired samples, if values followed a normal distribution. Otherwise, the U-test according to Wilcoxon–Mann–Whitney was applied. A  $P$  value  $<0.05$  was considered statistically significant.

Furthermore, the inter-rater reliability was calculated using the ICC. The ICC value was interpreted in the following way: ICC  $<0.20$ , slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.0, almost perfect agreement.

### Results

Sixty consecutive individuals with suspected PE underwent CTPA without complications. No significant differences were observed in age (SD  $66.55 \pm 12.79$ ; LD  $68.68 \pm 11.66$ ), and gender (SD 12 men, 18 women; LD 16 men, 14 women) between individuals included in groups A (SD) and B (LD). Patient demographic data are shown in Table 1. All examinations were



**Fig. 1.**  $CTDI_{vol}$  (mGy) values between the groups.

considered to reach an image quality level high enough to rule out PE (Fig. 1). A total of eight cases of PE were found in our study cohort, respectively (3 in group A, 5 in group B). All PEs were detected by all readers without significant difference in size or distribution between both groups.

The radiation dose ( $CTDI_{vol}$ ) was significantly lower in LD conditions compared to SD parameters ( $2.49 \pm 0.55$  mGy versus  $7.42 \pm 1.17$  mGy) (Fig. 1).

### Objective image evaluation

Evaluation of image noise as an objective image quality parameter showed that the SD protocol resulted in significantly less image noise compared to LD parameters ( $P < 0.01$ ). The attenuation of the pulmonary trunk showed similar results in both groups (SD  $409.55 \pm 91.04$  HU; LD  $380.43$  HU  $\pm 93.11$  HU;  $P = 0.768$ ). Hence, there were no significant differences of the attenuation of the major pectoral muscles (SD  $53.27 \pm 9.39$  HU; LD  $44.07 \pm 7.98$  HU;  $P = 0.584$ ).

The highest calculated CNR of the pulmonary was found in the SD series ( $18.71 \pm 4.75$ ); the CNR in the LD settings was significantly lower ( $12.36 \pm 6.07$ ;  $P < 0.01$ ). All details from objective image analysis are summarized in Table 3.

The SNR was highest in the SD settings, followed by the LD series (SD  $22.69 \pm 5.14$ ; LD  $14.66 \pm 2.83$ ;  $P < 0.01$ ).

### Subjective image evaluation

Summarization of image quality scores from all three observers are shown in Table 3.

The evaluation of the subjective ratings revealed no significant differences between the SD and LD settings in regard of the suitability of the detection of central and peripheral lung embolisms. Both ratings showed excellent suitability (central SD/LD, 4.88;

ICC, 0.894/4.83; ICC, 0.745; peripheral SD/LD, 4.70; ICC, 0.943/4.57; ICC, 0.919; all  $P > 0.4$ ).

Similar to the objective measured noise levels, the subjective noise rating consecutively resulted in a significant difference between SD and LD settings (4.88; ICC, 0.708 versus 3.71; ICC, 0.728;  $P < 0.01$ ) (Figs 2 and 3).

## Discussion

All CT examinations were conducted without any problems or side effects. Patient demographics were

**Table 3.** Results of subjective image analysis.

	Group A (SD)	Group B (LD)
CT settings	100 kV/150 mAs	100 kV/50 mAs
Suitability of central lung embolisms	4.88 (4:5) [ICC: 0.894]	4.83 (4:5) [ICC: 0.745]
Suitability of peripheral lung embolisms	4.70 (3:5) [ICC: 0.943]	4.57 (3:5) [ICC: 0.919]
Noise	4.88 (4:5) [ICC: 0.708]	3.71 (3:5) [ICC: 0.728]

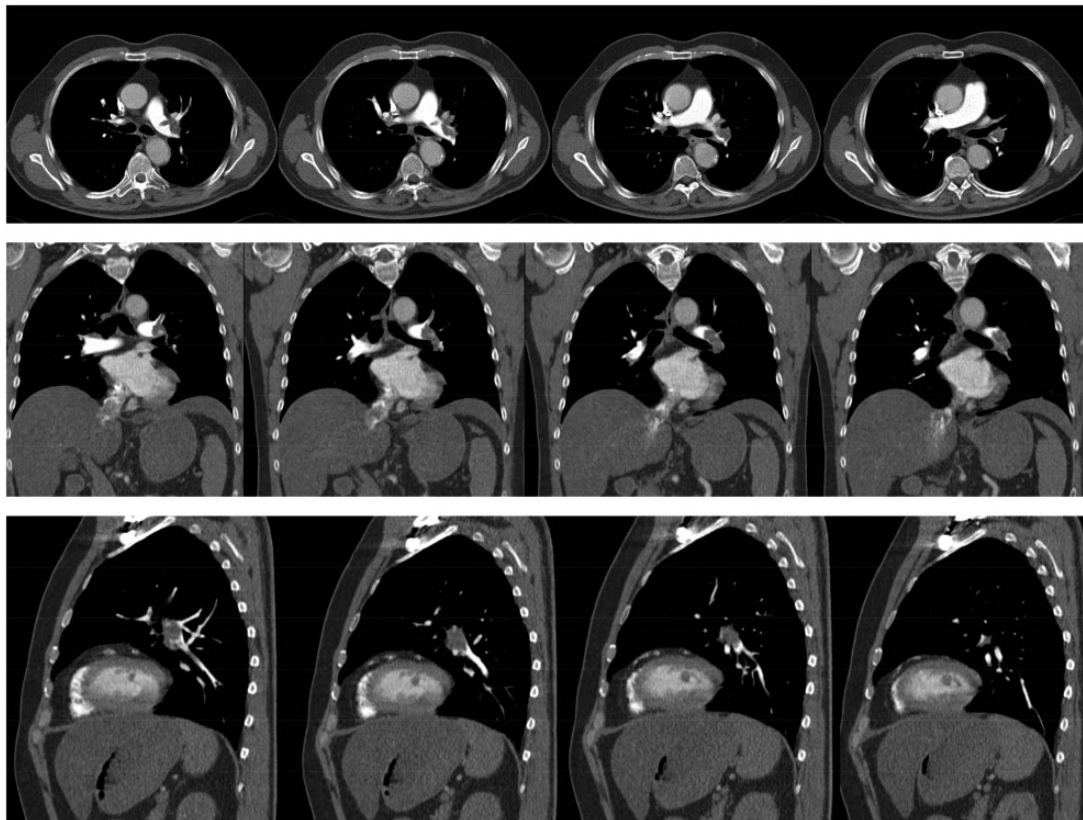
Data based on ratings from all three observers.

Global ICC: 0.925.

LD, low dose; SD, standard dose.

not significantly different in both groups in terms of gender, body habitus, and age (Table 1). Our results show that sufficient LD examinations are possible on an old CT scanner system without affecting image quality too much. A lot of promising new techniques have been introduced to reduce radiation exposure while preserving image quality (12,13). However, some of these techniques are not available for old scanner generations such as the model we used in our analysis. To buy a new CT scanner is a huge investment for a radiology department and buying a new CT scanner takes often years of budget planning as well as discussions with hospital managers and manufacturers. To date, techniques frequently in use are: automated tube potential selection, iterative reconstruction algorithms, high-pitch CT imaging, and low-kV imaging (14–17). In particular, low-kV imaging is often used in combination with some of the mentioned other techniques, especially iterative reconstruction algorithms to reduce image noise (10,18). Iterative reconstruction algorithms help to reduce these effects and to gain sufficient image quality even in images that might appear too noisy in conventional filtered back projection (FBP).

In one recent paper Laqumani, et al. analyzed an 80 kV protocol on a 256-slice CT scanner using iterative



**Fig. 2.** PE in the left main pulmonary artery. LD CT protocol (axial, coronal, and sagittal view).



**Fig. 3.** Central PE in an obese patient. Normal dose CT protocol was used (axial and coronal view).

reconstruction algorithms in a selected patient cohort (body weight <80 kg) (19). A  $CTDI_{vol}$  of  $2.3 \pm 0.8$  mGy was reported, which is a good value in CT imaging of the pulmonary vascular system. However, comparing this study to our data is challenging because no iterative reconstruction algorithms were used and tube-detector systems made substantial improvements over the past decade.

A study by Montet et al. compared a FBP reconstructed protocol with a new iterative reconstruction protocol. The examinations were carried out on a high-end CT scanner system (Discovery 750 HD, GE Healthcare, Milwaukee, WI, USA) (17). The FBP protocol was adjusted to 100 kV, 250 Ref. mAs resulting in a mean  $CTDI_{vol}$  of  $8.0 (\pm 1.8)$  mGy. Compared to these values, our protocols remained below the presented  $CTDI_{vol}$  (Table 1). However, using iterative reconstruction algorithms in this study decreased the radiation exposure to a mean  $CTDI_{vol}$  of 0.59 mGy. We could show a median  $CTDI_{vol}$  of  $2.49 \pm 0.53$  mGy in our LD cohort. Compared to the 8 mGy in the FBP group on this high-end CT system, we think our values are a good choice for LD CT imaging on an elderly CT system.

Another recent study by Pontana et al. analyzed a reduced dose setting for ruling out PE on a dual-source CT (20). From the full-dose setting they calculated a LD dataset of 120 kV and 66 mAs in the LD group. A mean  $CTDI_{vol}$  of  $2.76 (\pm 0.79)$  mGy was reported in the LD group, which is comparable to the values of our analysis. Acute PE was sufficiently ruled out even in the LD protocol using FBP. However, since the focus of this analysis was the evaluation of iterative reconstruction on image quality, the segmental and sub-segmental analysis, in particular, revealed a better delineation of the thrombotic material within the vessels using iterative reconstruction algorithms.

Comparing the dose values of recent literature to those presented in our current study, our radiation

dose values seem to be in line even with latest generation CT systems using FBP image reconstruction. As a main result of our study, dose reduction in CTPA is possible and can be achieved easily. To adjust the CT scanner system for the first time to LD values can be challenging because of the fear of gaining insufficient image quality. We wanted to relieve the readers of this manuscript from this fear and want to encourage the use of LD CT protocols even in older CT systems.

Some limitations of our study need to be addressed. First, the overall number of patients in our study was small; further studies with a larger cohort are required. Second, we did not investigate iterative reconstruction algorithms as well as effects of newer tube potential selection in our study. However, since we wanted to show how to deal with an older CT system, these software and hardware tools were simply not available when the CT system was built. Third, additional analysis of reduced contrast material would have been desirable, this will be part of upcoming future investigations.

In conclusion, our results demonstrate that using a LD protocol on a 15-year-old CT scanner system in CTPA allows for a dose reduction of approximately 67% with similar subjective image quality and delineation of central and peripheral pulmonary arteries in clinical routine.

#### Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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