

Diagnosis of Pulmonary Artery Embolism: Comparison of Single-Source CT and 3rd Generation Dual-Source CT using a Dual-Energy Protocol Regarding Image Quality and Radiation Dose

Diagnostik der akuten Lungenarterienembolie: Vergleich von Single-Source CT und Dritt-Generation Dual-Source CT unter Einsatz eines Dual-Energy Protokolls – Bildqualität und Strahlenexposition

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ZUSAMMENFASSUNG

Ziel Das Potential der Dritt-Generation Dual-Source CT (DSCT) in der Lungenemboliediagnostik wurde bis dato noch nicht ausführlich untersucht. Ziel dieser Studie war es, Strahlendosisparameter sowie subjektive und objektive Bildqualität des aktuellsten DSCT Scanners im Single-Energy und Dual-Energy (DE) Modus mit einem herkömmlichen pulmonalen Standard CTA Protokoll am 64-Zeilen CT (SSCT) zu vergleichen.

Material und Methoden Es wurden insgesamt 180 pulmonale CTA Studien in drei Patientengruppen mit jeweils 60 Patienten durchgeführt. 1. Gruppe: konventionelle 120 kV (ref.) 64-Zeilen SSCT; 2. Gruppe: 100 kV (ref.) Single-Energy DSCT; 3. Gruppe: 90/Sn150 kV DECT. Dosisparameter (CTDIvol, DLP, effektive Dosis) wurden evaluiert und die CT Abschwächung (HU) wurde an jeweils drei zentralen bzw. peripheren Lokalisationen gemessen. Das Signal-Rausch-Verhältnis (SNR) und das Kontrast-Rausch-Verhältnis (CNR) wurden berechnet. Die subjektive Bildqualität wurde von zwei Readern ausgewertet (5-Punkte Skala).

Ergebnisse CTDIvol und DLP waren in der DECT Gruppe jeweils signifikant niedriger als in der SSCT Gruppe ($p < 0,001$ [CTDIvol]; $p < 0,001$ [DLP]) und der DSCT Gruppe ($p = 0,003$ [CTDIvol]; $p = 0,003$ [DLP]). Die effektive Dosis war mit $2,79 \pm 0,95$ mSv in der DECT Gruppe signifikant geringer als in der SSCT Gruppe ($4,60 \pm 1,68$ mSv, $p < 0,001$) und der DSCT Gruppe ($4,24 \pm 2,69$ mSv, $p = 0,003$). SNR und CNR waren in der DSCT Gruppe signifikant höher ($p < 0,001$). Die subjektive Bildqualität der drei Protokolle war vergleichbar und wurde in 75 % der Fälle (135/180) als gut bzw. sehr gut bewertet mit einer Interobserver-Variabilität von 80 %.

Schlussfolgerung Die Verwendung von Dual-Energy Protokollen in der pulmonalen CTA an Dritt-Generation Dual-Source CT Scannern erlaubt eine signifikante Dosisreduktion bei erhaltener exzellenter Bildqualität und potentieller zusätzlicher Information im Sinne von Perfusions-Karten.

Kernaussagen:

- Die Verwendung von 90/Sn150 kV Dual-Energy CT-Protokollen erlaubt eine signifikante Dosisreduktion in der pulmonalen CTA.
- Die subjektive Bildqualität aller drei untersuchten CT-Protokolle (64-Zeilen SSCT, Single-Energy DSCT, 90/Sn150 kV DECT) war vergleichbar und wurde in 75 % der Fälle als gut bzw. sehr gut bewertet.

- Die Dual-Energy CT bietet potentiell zusätzliche Informationen durch die Erstellung von farbcodierten Jod-Karten.

ABSTRACT

Purpose To compare radiation dose, subjective and objective image quality of 3rd generation dual-source CT (DSCT) and dual-energy CT (DECT) with conventional 64-slice single-source CT (SSCT) for pulmonary CTA.

Materials and Methods 180 pulmonary CTA studies were performed in three patient cohorts of 60 patients each. Group 1: conventional SSCT 120 kV (ref.); group 2: single-energy DSCT 100 kV (ref.); group 3: DECT 90/Sn150 kV. CTDIvol, DLP, effective radiation dose were reported, and CT attenuation (HU) was measured on three central and peripheral levels. The signal-to-noise-ratio (SNR) and contrast-to-noise-ratio (CNR) were calculated. Two readers assessed subjective image quality according to a five-point scale.

Results Mean CTDIvol and DLP were significantly lower in the dual-energy group compared to the SSCT group ($p < 0.001$ [CTDIvol]; $p < 0.001$ [DLP]) and the DSCT group ($p = 0.003$ [CTDIvol]; $p = 0.003$ [DLP]), respectively. The effective dose in the DECT group was 2.79 ± 0.95 mSv and significantly smaller than in the SSCT group (4.60 ± 1.68 mSv, $p < 0.001$) and the DSCT group (4.24 ± 2.69 mSv, $p = 0.003$). The SNR and CNR were significantly higher in the DSCT group ($p < 0.001$).

Subjective image quality did not differ significantly among the three protocols and was rated good to excellent in 75% (135/180) of cases with an inter-observer agreement of 80%.

Conclusion Dual-energy pulmonary CTA protocols of 3rd generation dual-source scanners allow for significant reduction of radiation dose while providing excellent image quality and potential additional information by means of perfusion maps.

Key Points:

- Dual-energy CT with 90/Sn150 kV configuration allows for significant dose reduction in pulmonary CTA.
- Subjective image quality was similar among the three evaluated CT-protocols (64-slice SSCT, single-energy DSCT, 90/Sn150 kV DECT) and was rated good to excellent in 75% of cases.
- Dual-energy CT provides potential additional information by means of iodine distribution maps.

Citation Format

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Introduction

Pulmonary embolism (PE) is a frequent and potentially life-threatening condition [1]. Early initiation of treatment significantly reduces morbidity and mortality [2, 3]. Therefore, timely and accurate diagnosis is of utmost importance. Due to its high sensitivity and specificity, multi-detector row computed tomography pulmonary angiography (CTPA) has become the imaging modality of choice when PE is suspected [4–8].

The introduction of dual-source CT (DSCT) scanner systems and the associated rediscovery of dual-energy CT (DECT) contribute additional functional information [9]. The use of two different tube energies (kV) allows for visualization of absorption characteristics of different materials, especially of those with high atomic numbers, such as iodine and calcium [10]. The dedicated advantages and possibilities of dual-energy imaging in patients with suspected pulmonary embolism have been discussed extensively in literature [11–15].

Some data regarding the dose and image quality of CTPA of first and second generation DSCT scanners is available [16, 17]. However, the potential of the latest (third) generation scanners to further decrease radiation dose while maintaining image quality has scarcely been assessed so far [18]. Concerning first and second generation DSCT scanners, DECT was reported to carry a radiation dose similar to that of conventional single-source CT (SSCT) [10, 11, 19, 20].

We hypothesized that latest generation dual-source CT allows dose reduction in CTPA when compared to conventional single-

source CT. Thus, the aim of the present study was to evaluate the radiation dose and image quality of third generation DSCT in patients with suspected PE. Two different dual-source CTPA protocols (single-energy and dual-energy) were compared to a conventional 64-slice SSCT system, representing the clinical standard in many hospitals and radiological institutions.

Materials and Methods

Patients

The local ethics committee waived the need for individual informed consent for this study. From October 2015 through December 2015, 60 patients referred to CTPA for suspected PE were scanned on a conventional single-source 64-slice CT system (SOMATOM Definition AS 64, Siemens Healthcare, Forchheim, Germany) in a standard clinical routine setting (group 1). From January 2016 through February 2016, a total of 60 consecutive patients were examined on a third generation DSCT (SOMATOM Force, Siemens Healthcare, Forchheim, Germany) with a single-energy protocol (group 2). Since March 2016, all patients referred to CTPA have been consecutively examined with the same third generation DSCT (SOMATOM Force, Siemens) using a dedicated dual-energy pulmonary CTA protocol. The data of the first 60 patients acquired with this dual-energy protocol were included in this study (group 3). The age, gender distribution and body habitus (anteroposterior and lateral chest diameter) of the patients in the three cohorts are displayed in ► **Table 1**. Inpatients as well as

► **Table 1** Demographic data of patients referred to CTPA for suspected pulmonary embolism.

► **Tab. 1** Demografische Daten der Patienten welche mit dem Verdacht auf Lungenembolie dem CT zugewiesen wurden.

	Group 1	Group 2	Group 3	p
	SSCT	DSCT	DECT	
Age (±SD) [years]	65.1 (± 15.8)	61.3 (± 20.7)	66.6 (± 15.9)	all n.s.
Male (n)/female (n)	29 / 31	35 / 25	32 / 28	all n.s.
Lateral chest diameter (±SD) [cm]	34.7 (± 4.3)	35.9 (± 4.4)	35.0 (± 3.1)	all n.s.
AP chest diameter (±SD) [cm]	26.3 (± 3.8)	26.6 (± 4.2)	25.8 (± 3.2)	all n.s.
Pulmonary embolism (n)	13	12	11	all n.s.

CTPA = computed tomography pulmonary angiography; AP = anteroposterior; SSCT = conventional single-source computed tomography; DSCT = dual-source computed tomography; DECT = dual-energy computed tomography; SD = standard deviation; n.s. = not significant.

► **Table 2** Applied single- and dual-source/energy CT protocols. The high voltage spectrum in dual-energy scans is additionally hardened by a tin filter (Sn).

► **Tab. 2** Parameter der verwendeten Single-Source und Dual-Source / Dual-Energy CT Protokolle. Das Hoch-kV Spektrum wird durch Verwendung eines Zinn (Sn) Filters zusätzlich aufgehärtet.

	Group 1	Group 2	Group 3
CT mode	Single-source	Dual-source	Dual-source
	Single-energy	Single-energy	Dual-energy
Collimation	2x32x0.6 mm (z-flying focal spot)	2x96x0.6 mm (z-flying focal spot) both detectors	2x96x0.6 mm (z-flying focal spot) both detectors
Rotation time [s]	0.33 s	0.25 s	0.25 s
Pitch	1.4	1.55	0.55
Automatic tube current modulation (CARE Dose 4 D, Siemens)	On	On	On
Automatic tube potential control (CARE kV, Siemens)	On	On	Off
Tube potential (ref.) [kV]	120 kV	100 kV	90/Sn150 kV on tube A/B
Tube current time product (ref.) [mAs]	130 mAs	120 mAs	60/46 mAs on tube A/B

patients from our emergency room were recruited 24/7. Except for pregnancy and known severe allergic reactions to iodine-based contrast agents, no exclusion criteria were applied.

CT protocols

Patient studies were performed on a conventional 64-slice CT system and on a third generation DSCT system, the latter comprising a selective photon shield tin filter (+Sn). This latest generation CT system differs from previous DSCT generations by offering a greater FOV (35.3 cm instead of 33.0 cm [SOMATOM Definition Flash, Siemens] and 28.0 cm [SOMATOM Definition, Siemens], respectively), enabling high-pitch spiral and DE acquisition in larger patients, too. The use of higher tube energies (90 kV/

Sn150 kV instead of 100 kV/Sn140 kV [SOMATOM Definition Flash] and 80 kV/140 kV [SOMATOM Definition, Siemens], respectively) results in superior spectral differentiation.

Automatic topogram and real-time-based anatomical tube current modulation (CARE Dose 4 D, Siemens) was applied per default in all patients. In addition, automated tube potential control (CARE kV, Siemens) was applied in group 1 and group 2. Due to the preassigned kV ratio between the two tubes, this was not applicable in the dual-energy cohort (group 3). All CT images were acquired in caudocranial orientation between the lung apices and costophrenic recesses within a single inspiratory breath hold. The caudocranial scan length (mm) was recorded.

Transverse images were reconstructed at a slice thickness of 1 mm with a position increment of 1 mm using a medium soft ker-

nel (B30f). By default, three image sets were reconstructed for the dual-energy examinations: One series each for the low (90 kV) and the high (Sn150 kV), and one mixed series merging information of both data sets to create an image impression comparable to a 120 kV examination. For that purpose, 60 % of the 90 kV data and 40 % of the hardened Sn150 kV spectrum data were blended (so-called M_06 series). Blending ratios followed the vendor's recommendations.

An automated injector (CT motion™, Ulrich medical, Ulm, Germany) was used to administer an iodinated contrast medium (45 mL in group 1; 40 mL in group 2; 40 mL in group 3) with 350 mgI/mL (Imeron® 350, Bracco, Konstanz, Germany) with a flow of 3.5 mL/s followed by a 40 mL NaCl chaser bolus. In the case of advanced obesity, up to 90 mL of contrast medium was administered. Automated bolus tracking (CARE Bolus, Siemens) was used with a trigger attenuation of 120 HU within the pulmonary trunk and a 5 second delay preceding diagnostic image acquisition.

CT protocol settings of each patient cohort were chosen according to the manufacturer's recommendations (► **Table 2**):

1. For conventional 64-slice SSCT, the parameters were: 120 reference (ref.) kV tube voltage, 130 ref. mAs, 2x32x0.6 mm collimation with z-flying focal spot, 0.33 seconds gantry rotation time, and 300 mm/s table speed at a pitch factor of 1.4.
2. For single-energy DSCT, the following parameters were used: 100 ref. kV tube voltage, 120 ref. mAs, 2x96x0.6 mm collimation with z-flying focal spot, 0.25 seconds gantry rotation time, and 400 mm/s table speed at a pitch factor of 1.55.
3. For DECT acquisition, the parameters were: 90 kV tube voltage (A tube) / 150 kV tube voltage (B tube), 60 ref. mAs (A tube) / 46 ref. mAs (B tube), 2x96x0.6 mm collimation with z-flying focal spot, 0.25 seconds gantry rotation time, and 200 mm/s table speed at a pitch factor of 0.55. The dual-energy FOV was limited to 35.3 cm because of the smaller x-y axis coverage of the B detector.

Radiation dose

For estimation of the applied radiation dose, the volume computed tomography dose index (CTDI_{vol} [mGy]) and the dose length product (DLP [mGy*cm]) were manually recorded from the patient protocol, which is automatically stored in the PACS (Merlin, Phönix-PACS, Freiburg, Germany). As recommended by Schenzle et al., we used a conversion factor of 0.018 mSv/mGy*cm for estimation of the effective radiation dose [19].

Image quality analysis

The subjective image quality was rated independently by two blinded radiologists (B.P. and A.K., with 8 and 3 years of experience in cardiovascular radiology, respectively) according to a five-point scale (1 = excellent image quality extending to the very peripheral branches, no artifacts, excellent diagnostic confidence; 2 = good image quality, minor artifacts and/or little subjective image noise, feasible evaluation of PE to subsegmental level, good diagnostic confidence; 3 = moderate image quality, feasible evaluation of PE to segmental level, still of diagnostic quality; 4 = poor image quality, severe artifacts and/or high subjective image noise,

limited diagnostic confidence; 5 = non-diagnostic image quality) in a randomized fashion.

For the assessment of objective image quality, the mean pulmonary artery CT attenuation (in Hounsfield units [HU]) and image noise (standard deviation of HU) were measured within regions of interest (ROI) at three different locations (pulmonary trunk, right lower lobe pulmonary artery, left upper lobe pulmonary artery) by one observer (B.P.). ROIs were drawn as large as anatomically possible. In the case of the presence of an embolus, the corresponding contralateral vessel was used for density measurements. In addition, the background noise (BN) was determined as the standard deviation of air measured anteriorly to the sternum on the level of the pulmonary trunk. Based on these measurements, the signal-to-noise ratio (SNR) and contrast-to-noise-ratio (CNR) were calculated as follows:

$$\text{SNR} = \text{intrapulmonary artery attenuation (HU)} / \text{image noise (SD of HU)}$$

$$\text{CNR} = [\text{intrapulmonary artery attenuation (HU)} - \text{density of 70 HU}] / \text{image noise (SD of HU)}$$

According to previous studies, we assumed a maximum value of 70 HU for a fresh blood clot [21–23]. In group 3 all measurements and ratings were performed in the blended virtual 120 kV series.

Statistical analysis

The interobserver agreement between subjective image quality ratings was calculated with Cohen's weighted kappa statistics. The significance of differences between the groups was tested with the Mann-Whitney U-test for independent samples. Binary data was analyzed with the chi-square test. Differences in age and chest diameters between the groups were tested with the one-way ANOVA. All statistical analyses were performed using statistical software (IBM SPSS Statistics for Windows, Version 23.0, Armonk, NY, USA); *p*-values < 0.05 were considered significant.

Results

The age, gender distribution and body habitus (anteroposterior and lateral chest diameter) of the patients in the three different cohorts did not differ significantly (► **Table 1**). A total of 36 acute pulmonary embolisms (20 % of the patients) were diagnosed (13 in group 1; 12 in group 2; 11 in group 3) (► **Table 1**).

Radiation dose

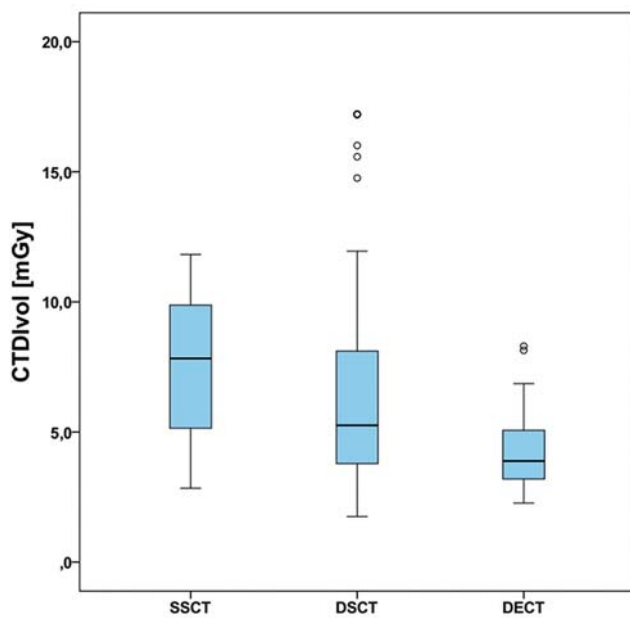
The scan length, effective tube current, and effective tube potential (median and range) for each of the three CT protocols are shown in ► **Table 3**. The mean CTDI_{vol} and DLP were significantly lower in the dual-energy group compared to both the SSCT group (*p* < 0.001 [CTDI]; *p* < 0.001 [DLP]) and the single-energy DSCT group (*p* = 0.003 [CTDI]; *p* = 0.003 [DLP]). When comparing group 1 and 2, significantly lower radiation dose levels were found in the DSCT group (*p* = 0.013 [CTDI]; *p* = 0.032 [DLP]). In detail, CTDI_{vol} was 7.63 ± 2.72 mGy for group 1, 6.78 ± 4.37 mGy for group 2, and 4.32 ± 1.43 mGy for group 3 (► **Fig. 1**). The DLP was 255.7 ± 93.2 mGy*cm for group 1, 235.6 ± 149.4 mGy*cm for group 2,

► **Table 3** Computed tomography pulmonary angiography: Radiation dose parameters.

► **Tab. 3** Pulmonale CT-Angiografie: Dosis Parameter.

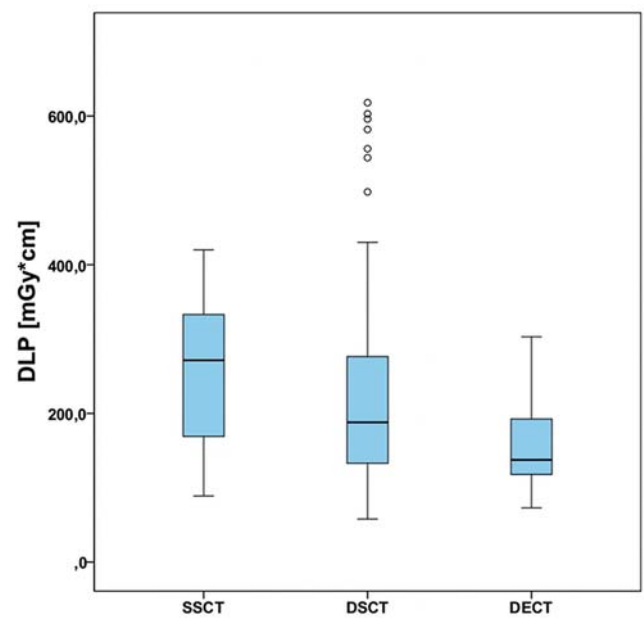
	Group 1	Group 2	Group 3
	SSCT	DSCT	DECT
Scan length (±SD) [mm]	310 (± 30)	331 (± 38)	321 (± 30)
Tube potential [effective kV]	120 [median] / 100 – 120 [range]	90 [median] / 70 – 120 [range]	90/Sn150 on tube A/B
Tube current (±SD) [effective mAs]	115.1 (± 23)	266.9 (± 53.6)	93.9 (± 36.6) / 54 (± 13) on tube A/B

SSCT = conventional single-source computed tomography; DSCT = dual-source computed tomography; DECT = dual-energy computed tomography; SD = standard deviation



► **Fig. 1** Radiation dose parameters of computed tomography pulmonary angiography. Box and whisker plots (median and 50% of cases within the boxes) demonstrate differences of CTDIvol [mGy] between the three protocols. SSCT = conventional single-source computed tomography; DSCT = dual-source computed tomography; DECT = dual-energy computed tomography; CTDIvol = volume computed tomography dose index.

► **Abb. 1** Dosis Parameter der einzelnen CT Angiografie Protokolle. Der Box-Whisker-Plot (Median und 50% der Fälle innerhalb der Box) zeigt die Unterschiede des CTDIvol [mGy] zwischen den einzelnen Gruppen.



► **Fig. 2** Radiation dose parameters of computed tomography pulmonary angiography. Box and whisker plots (median and 50% of cases within the boxes) demonstrate differences of DLP [mGy*cm] between the three protocols. SSCT = conventional single-source computed tomography; DSCT = dual-source computed tomography; DECT = dual-energy computed tomography; DLP = dose length product.

► **Abb. 2** Dosis Parameter der einzelnen CT Angiografie Protokolle. Der Box-Whisker-Plot (Median und 50% der Fälle innerhalb der Box) zeigt die Unterschiede des DLP [mGy*cm] zwischen den einzelnen Gruppen.

and 155.2 ± 52.6 mGycm for group 3 (► **Fig. 2**). The mean effective radiation dose of 2.79 ± 0.95 mSv found in the dual-energy group was significantly lower compared to the two other groups, i.e. the single-energy DSCT group (mean effective radiation dose 4.24 ± 2.69 mSv; $p = 0.003$) as well as the conventional SSCT group (mean effective radiation dose 4.60 ± 1.68 mSv; $p < 0.001$) (► **Fig. 3**).

Subjective image quality

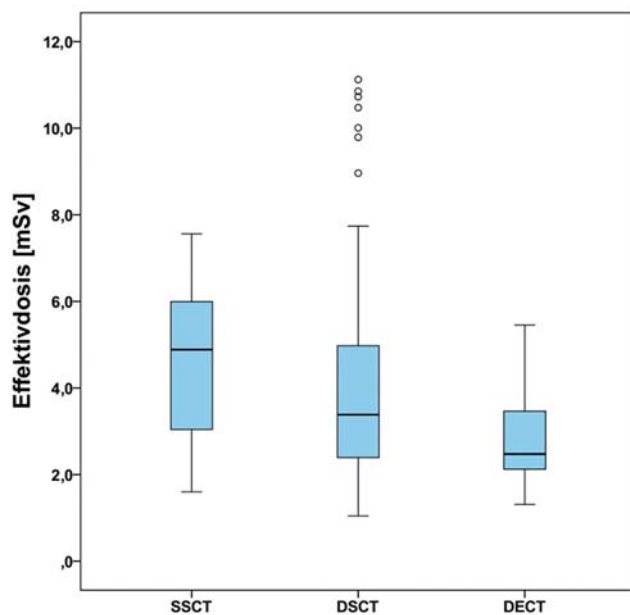
The overall interobserver agreement rate was 80.0% (linear-weighted kappa 0.64; 95% CI 0.54 – 0.74). Summarizing scores 1 – 2 as “fully diagnostic” and scores 3 – 4 as “partially diagnostic”, the interobserver agreement rate was improved to 95.0% (linear-weighted kappa 0.82; 95% CI 0.69 – 0.94). One pulmonary CTA

► **Table 4** Computed tomography pulmonary angiography: SSCT, DSCT, DECT. Subjective image quality.

► **Tab. 4** Pulmonale CT-Angiografie: Subjektive Bildqualität der drei verwendeten Protokolle (SSCT, DSCT, DECT).

	Score	Group 1	Group 2	Group 3
		SSCT	DSCT	DECT
Observer 1	1	31 (51.7%)	35 (58.3%)	39 (65.0%)
	2	20 (33.3%)	19 (31.7%)	14 (23.3%)
	3	6 (10.0%)	5 (8.3%)	7 (11.7%)
	4	2 (3.3%)	1 (1.7%)	0
	5	1 (1.7%)	0	0
Observer 2	1	31 (51.7%)	37 (61.7%)	40 (66.6%)
	2	19 (31.6%)	18 (30%)	12 (20%)
	3	7 (11.7%)	3 (5%)	7 (11.7%)
	4	2 (3.3%)	2 (3.3%)	1 (1.7%)
	5	1 (1.7%)	0	0

1 = excellent image quality; 2 = good image quality; 3 = moderate image quality; 4 = poor image quality; 5 = non-diagnostic image quality. SSCT = conventional single-source computed tomography; DSCT = dual-source computed tomography; DECT = dual-energy computed tomography



► **Fig. 3** Effective radiation dose parameters of computed tomography pulmonary angiography. Box and whisker plots (median and 50% of cases within the boxes) demonstrate differences of effective radiation dose [mSv] between the three protocols. SSCT = conventional single-source computed tomography; DSCT = dual-source computed tomography; DECT = dual-energy computed tomography; mSv = Millisievert.

► **Abb. 3** Effektive Dosis Parameter der einzelnen CT Angiografie Protokolle. Der Box-Whisker-Plot (Median und 50% der Fälle innerhalb der Box) zeigt die Unterschiede der effektiven Dosis [mSv] zwischen den einzelnen Gruppen.

(from group 1) had to be repeated due to severely reduced image quality (score value 5).

Details of the subjective assessment of image quality by both observers are summarized in ► **Table 4**. For group 1 the image quality was rated 1.70 ± 0.91 [1] and 1.72 ± 0.92 [2]; $k = 0.81$ with $p < 0.001$; 95% CI 0.61 – 1.9; for group 2 the image quality was rated 1.53 ± 0.72 [1] and 1.50 ± 0.75 [2]; $k = 0.90$ with $p < 0.001$; 95% CI 0.71 – 1.1; for group 3 the image quality was rated 1.47 ± 0.70 [1] and 1.48 ± 0.77 [2]; $k = 0.77$ with $p < 0.001$; 95% CI 0.52 – 1.0.

The mean subjective image quality was rated similar between group 1 and 2 ($p = 0.264$) as well as between group 2 and group 3 ($p = 0.423$). The mean subjective image quality tended to be lower in group 1 compared to group 3, although this was not significant ($p = 0.076$).

Objective image quality

The attenuation within the pulmonary trunk was significantly higher in group 2 (376 ± 144 HU) compared to group 1 (309 ± 124 HU) ($p = 0.006$) and group 3 (303 ± 72 HU) ($p = 0.004$). The corresponding SNR for the pulmonary trunk was also significantly higher in group 2 (29.69 ± 9.25) compared to group 1 (20.79 ± 6.19) ($p < 0.001$) and group 3 (20.16 ± 4.77) ($p < 0.001$). The CNR for the pulmonary trunk was also significantly higher in group 2 compared to the two other groups ($p < 0.001$ for both groups). All three image parameters (attenuation level, SNR and CNR) showed no statistical differences between group 1 and group 3. Regarding the right lower lobe and left upper lobe segmental arteries, observations were equal to the results from pulmonary trunk measurements. The BN was significantly lower ($p < 0.001$) in group 1 compared to group 3. Differences between group 1

► **Table 5** Computed tomography pulmonary angiography: SSCT, DSCT, DECT. Objective image quality assessed by signal-to-noise ratio, contrast-to-noise ratio, and background noise.

► **Tab. 5** Pulmonale CT-Angiografie: Objektive Bildqualität der drei verwendeten Protokolle (SSCT, DSCT, DECT) bewertet durch das Signal-Rausch-Verhältnis, das Kontrast-Rausch-Verhältnis und das Hintergrundrauschen.

	Group 1	Group 2	Group 3	p
	SSCT	DSCT	DECT	
CT attenuation pulmonary trunk (HU) (±SD)	309 (± 124)	376 (± 144)	303 (± 72)	1 vs. 2: 0.006 1 vs. 3: n.s. 2 vs. 3: 0.004
CT attenuation right lower lobe (HU) (±SD)	297 (± 107)	348 (± 131)	290 (± 69)	1 vs. 2: 0.03 1 vs. 3: n.s. 2 vs. 3: 0.014
CT attenuation left upper lobe (HU) (±SD)	299 (± 115)	352 (± 136)	288 (± 70)	1 vs. 2: 0.022 1 vs. 3: n.s. 2 vs. 3: 0.007
SNR pulmonary trunk (±SD)	20.79 (± 6.19)	29.69 (± 9.25)	20.16 (± 4.77)	1 vs. 2: <0.001 1 vs. 3: n.s. 2 vs. 3: <0.001
SNR right lower lobe (±SD)	20.48 (± 7.44)	28.52 (± 12.08)	20.44 (± 5.52)	1 vs. 2: <0.001 1 vs. 3: n.s. 2 vs. 3: <0.001
SNR left upper lobe (±SD)	21.72 (± 9.80)	27.96 (± 11.64)	21.95 (± 8.54)	1 vs. 2: <0.001 1 vs. 3: n.s. 2 vs. 3: 0.002
CNR pulmonary trunk (±SD)	15.76 (± 6.01)	23.67 (± 8.90)	15.45 (± 4.63)	1 vs. 2: <0.001 1 vs. 3: n.s. 2 vs. 3: <0.001
CNR right lower lobe (±SD)	15.38 (± 6.76)	22.42 (± 11.27)	15.44 (± 5.03)	1 vs. 2: <0.001 1 vs. 3: n.s. 2 vs. 3: <0.001
CNR left upper lobe (±SD)	16.43 (± 8.81)	21.96 (± 10.88)	16.59 (± 7.73)	1 vs. 2: 0.002 1 vs. 3: n.s. 2 vs. 3: 0.004
Background noise (HU) (±SD)	6.66 (± 1.05)	6.97 (± 2.04)	7.23 (± 0.79)	1 vs. 2: n.s. 1 vs. 3: <0.001 2 vs. 3: n.s.

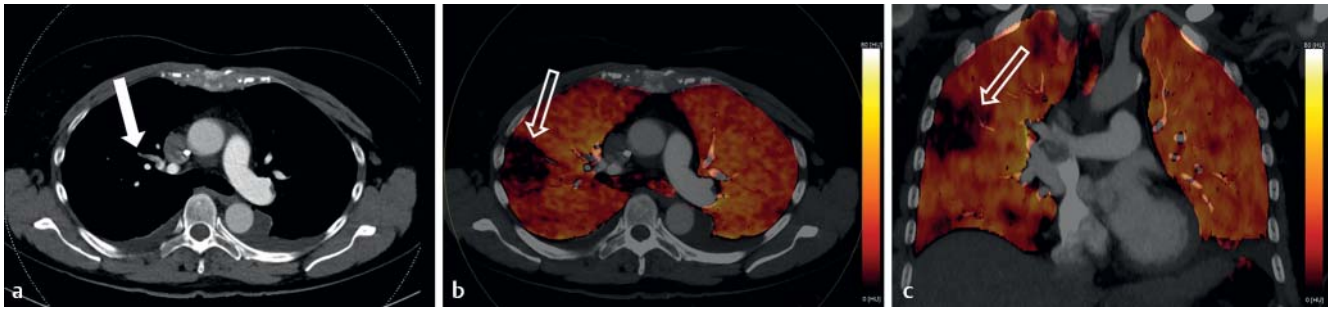
SSCT = conventional single-source computed tomography; DSCT = dual-source computed tomography; DECT = dual-energy computed tomography; SNR = signal-to-noise ratio; CNR = contrast-to-noise ratio; HU = Hounsfield units; SD = standard deviation; n.s. = not significant

and 2 and group 2 and 3 were not significant ($p = 0.270$ and $p = 0.410$). The data is summarized in ► **Table 5**.

Discussion

Patients undergoing DECT are exposed to a significantly lower effective radiation dose than patients examined with the other CTPA protocols. Third generation DSCT provides comparable subjective diagnostic image quality using single-energy and dual-energy scan mode in this study. In contrast, the SNR and CNR as indicators of objective image quality were significantly higher in the single-energy DSCT group compared to the other groups.

Today, CT is considered the reference standard for the diagnosis of pulmonary embolism [24–27]. During the last decade, CT angiography scanning time has decreased. Nowadays, substantial improvements in the spatial and temporal resolution of CTPA allow analysis of the pulmonary arteries down to the subsegmental level within less than 1 second. Recent research focuses on gaining additional functional information from CT scans. Thereby, DECT holds the potential to provide simultaneous information on the presence of endoluminal thrombus and lung perfusion impairment by generating iodine distribution maps of the lung parenchyma (► **Fig. 4**) [11, 12, 14, 20, 28, 29]. The most recent technical advancements in DECT include a new powerful X-ray tube (Vec-tron tube, Siemens) in third generation scanners which allows for dual-energy examinations utilizing a new 90/Sn150 kV scan



► **Fig. 4** Dual-energy CTPA of a 60-year-old female with suspected pulmonary embolism (PE). Axial blended virtual 120 kV angiographic image **a** indicates segmental PE (arrow). Axial **b** and coronal **c** reconstructions visualize the corresponding wedge-shaped perfusion defect in the color-coded iodine maps (open arrows).

► **Abb. 4** Dual-Energy CT Angiografie einer 60-jährigen Patientin mit Verdacht auf Lungenembolie (LE). Die virtuelle gemischte 120 kV Serie **a** zeigt eine segmentale LE (Pfeil). Die axiale **b** und koronare **c** farbcodierte Jod-Karte zeigt das korrespondierende periphere Perfusionsdefizit (offene Pfeile).

mode. In this case the tin filter increases energy separation by up to 30 %, enabling more precise tissue and material decomposition. In combination with a 35.3 cm field of view, dual-energy information can also be gained in challenging patients.

Besides accurate diagnoses and high image quality, minimizing radiation dose according to the ALARA principle (“as low as reasonably achievable”) is one of the major goals in radiology. Although there is strong evidence that DECT is not associated with an increased radiation dose level [30], the question remains as to whether third generation DSCT scanners might offer the opportunity for dose reduction when operated in dual-energy mode. In a first phantom study using 1st and 2nd generation DSCT scanners, Schenzle et al. showed no additional dose burden or compromises in image quality in comparison to a 120 kV standard protocol [19]. Zordo et al. systematically compared the radiation dose of second generation DSCT in single-energy mode with dual-energy mode (100/Sn140 kV) and conventional single-source single-energy 128-MDCT at 120 kV and 100 kV in 321 patients with suspected pulmonary embolism [17]. Their study revealed a significantly lower radiation dose of dual-energy acquisition when compared to conventional single-energy 128-MDCT at 120 kV. However, DSCT in single-energy mode and conventional single-energy 128-MDCT at 100 kV showed significantly lower radiation dose values when compared to the dual-energy mode. Another study by Bauer et al. postulates that the use of second generation DSCT in 80/Sn140 kV configuration allows for a significant dose reduction with an image quality similar to standard 64-MDCT at 120 kV, while a 100/Sn140 kV configuration is not capable of achieving dose reduction compared to standard CTPA at 120 kV. Concerning third generation DSCT scanners, there is currently only one study by Sabel et al. demonstrating that high-pitch CTPA in single-energy mode is feasible with this scanner generation, even though no distinct decrease in radiation dose was observed compared to standard pitch cohorts [18]. Independent of the vendor, scanner generation, and protocol used, several basic strategies have been proposed for effectively decreasing radiation exposure in chest examinations, for example limiting the scan volume from the aortic arch to the right diaphragm [31, 32].

The effective radiation dose of current conventional SSCT protocols for CTPA is estimated at 3.58 to 5.81 mSv when using a conversion factor of 0.018 mSv/mGycm [17, 19]. Zordo et al. estimated a mean radiation dose of 4.2 mSv in their dual-energy group when using 2nd generation DSCT [17]. This is the first study investigating the radiation dose of dual-energy CTPA with third generation DSCT. Our findings show that 3rd generation DECT with the 90/Sn150 kV dual-energy configuration allows for a significant reduction of patient dose in the clinical routine. When using the same conversion factor of 0.018 mSv/mGycm, an estimated mean effective radiation dose of 2.79 mSv was found in our dual-energy DSCT group [19]. Compared to our single-energy DSCT group (mean effective radiation dose 4.24 mSv) and to conventional SSCT at 120 kV (mean effective radiation dose 4.60 mSv), this indicates a potential reduction of effective radiation dose ranging between 34.2 % and 39.4 %, respectively. However, when interpreting our results, one must be aware that different tube potentials were applied in our protocols and that radiation dose varies with the square of the tube potential [33].

Nearly equal subjective image quality was found in the single-energy DSCT and the DECT group of this study, which was rated good to excellent by both readers. The mean subjective image quality tended to be rated lower in the conventional SSCT group by both readers, while continuing to provide good to excellent image quality in most patients. However, the above mentioned lower image quality in group 1 did not reach statistical significance ($p = 0.076$). The overall interobserver agreement of 80.0 % emphasizes the results of previous CTPA investigations [17].

SNR and CNR were significantly higher in the DSCT group compared to the two other groups. On the one hand, the reduction of tube potential in the DSCT group increases the photoelectric effect and consequently the attenuation of iodinated contrast medium. On the other hand, image noise increases with lowered tube potential. However, the increase in the attenuation of contrast medium was found to outweigh the increase in the image noise when using 100 kV. Furthermore, the new Stellar detector (Siemens Healthcare, Forchheim, Germany) installed in the Force CT produces less electronic noise than the standard detector installed in the 64-slice scanner. However, we observed an increase

in background noise in the DECT group, when compared to single-energy DSCT. This effect of DECT was reported earlier by Kerl et al. and Johnson et al. and is due to cross-scatter radiation [10, 34].

To achieve a similar image impression with the 90/Sn150 kV dual-energy configuration, the 90 kV data in group 3 needed to be blended with the hardened Sn150 kV data at a ratio of 60/40. Lowering the tube potential to 90 kV (instead of typically 100 kV in second generation DECT) will move the X-ray spectrum more toward the k-edge of iodine and thus increase CT numbers and vascular opacification. On the other hand, a tube potential of 90 kV will influence image noise negatively when compared to a standard tube potential of 100 kV or 120 kV. As one can change the composition of the acquired 90/Sn150 kV dataset, it is possible to use DECT to increase the vascular attenuation of the contrast medium by adding more of the 90 kV data to the blended images. While Bauer et al. reported a significantly higher SNR in their single-energy 64-MDCT group compared to second generation DECT in 100/Sn140 kV configuration, we found a similar SNR and CNR in our conventional SSCT and DECT groups. Additionally, the higher spectral separation achieved with the 90/150Sn kV configuration used in our study accounts for better material quantification, potentially strengthening the impact and trustworthiness of iodine perfusion maps.

We have to acknowledge several study limitations. Due to installation of the third generation DECT scanner, the study is not designed in a randomized fashion. The data of group 1 was retrospectively investigated on the previous SSCT scanner, whereas the investigations in group 2 and 3 were of prospective nature and performed on the third generation DECT scanner. Nevertheless, since there were no exclusion criteria except pregnancy and severe allergic reactions to contrast media, the three cohorts were indeed similar. However, we cannot completely eliminate all levels of confounding influence by sex, age, patient habitus or cardiovascular status. Furthermore, the direct comparison between the two single-energy groups is hindered by the use of different ref. tube potentials in group 1 and 2. Since readers were not blinded to the CT scanner/protocol used, we cannot exclude a selection bias. Moreover, the injection protocol and therefore the iodine delivery rate are slightly different in group 1 compared to the other two groups (on average 5 ml more contrast media was injected in group 1), which might have an effect on the opacification of pulmonary arteries and potentially limit comparison between the groups.

Conclusion

Third generation DECT in 90/Sn150 kV configuration allows for a significant decrease in radiation exposure compared to other protocols in the clinical routine, while maintaining excellent image quality and enabling additional contemporaneous lung perfusion assessment. Pulmonary perfusion data by means of iodine maps acquired with DECT has become feasible with a decreased radiation dose when using the latest generation dual-source CT scanners.

CLINICAL RELEVANCE OF THE STUDY

- Timely and accurate diagnosis of pulmonary embolism is of utmost importance
- Due to its high sensitivity and specificity, computed tomography pulmonary angiography is the image modality of choice when pulmonary embolism is suspected
- New dual-source CT scanners enable the use of dual-energy CT protocols which allow for a significant dose reduction compared to other protocols in the clinical routine

Conflict of Interest

The authors declare that they have no conflict of interest.

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