Received:
17 December 2015

Revised:
21 February 2016

Accepted:
22 March 2016

<http://dx.doi.org/10.1259/bjr.20151059>

Cite this article as:

Boos J, Kröpil P, Lanzman RS, Aissa J, Schleich C, Heusch P, et al. CT pulmonary angiography: simultaneous low-pitch dual-source acquisition mode with 70 kVp and 40 ml of contrast medium and comparison with high-pitch spiral dual-source acquisition with automated tube potential selection. *Br J Radiol* 2016; **89**: 20151059.

FULL PAPER

CT pulmonary angiography: simultaneous low-pitch dual-source acquisition mode with 70 kVp and 40 ml of contrast medium and comparison with high-pitch spiral dual-source acquisition with automated tube potential selection

JOHANNES BOOS, MD, PATRIC KRÖPIL, MD, ROTEM S LANZMAN, MD, JOEL AISSA, MD, CHRISTOPH SCHLEICH, MD, PHILIPP HEUSCH, MD, LINO M SAWICKI, MD, GERALD ANTOCH, MD and CHRISTOPH THOMAS, MD

Medical Faculty, Department of Diagnostic and Interventional Radiology, University Dusseldorf, Dusseldorf, Germany

Address correspondence to: Dr Johannes Boos

E-mail: johannes.boos@med.uni-duesseldorf.de

Objective: To assess the feasibility of a 70-kVp CT pulmonary angiography (CTPA) protocol using simultaneous dual-source (SimDS) acquisition mode with 40 ml of contrast medium (CM) and comparison with a high-pitch spiral dual-source (SpiralDS) acquisition protocol with automated tube potential selection (ATPS).

Methods: Following the introduction of a new 70-kVp/40-ml SimDS-CTPA protocol in December 2014 for all patients with a body mass index (BMI) below 35 kg m^{-2} , the first 35 patients were retrospectively included in this study and assigned to Group A (BMI: $27 \pm 4 \text{ kg m}^{-2}$, age: 66 ± 15 years). The last 35 patients with a BMI below 35 kg m^{-2} who had received SpiralDS-CTPA with ATPS were included for comparison (Group B) (70 ml CM; BMI: $27 \pm 4 \text{ kg m}^{-2}$, age: 68 ± 16 years). Subjective image quality (image quality) was assessed by two radiologists (from 1, non-diagnostic, to 4, excellent). Signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), volumetric CT

dose index (CTDI_{vol}), dose-length product (DLP) and effective dose were assessed.

Results: All examinations were of diagnostic image quality. Subjective image quality, SNR and CNR were comparable between Groups A and B (3.7 ± 0.6 vs 3.7 ± 0.5 , 14.6 ± 6.0 vs 13.9 ± 3.7 and 12.4 ± 5.7 vs 11.6 ± 3.3 , respectively; $p > 0.05$). CTDI_{vol} , DLP and effective dose were significantly lower in Group A than in Group B (4.5 ± 1.6 vs $7.5 \pm 2.1 \text{ mGy}$, 143.3 ± 44.8 vs $278.3 \pm 79.44 \text{ mGy cm}$ and 2.0 ± 0.6 vs $3.9 \pm 1.1 \text{ mSv}$, respectively; $p < 0.05$).

Conclusion: 70-kVp SimDS-CTPA with 40 ml of CM is feasible and provides diagnostic image quality, while radiation dose and CM can be reduced by almost 50% and 40%, respectively, compared with a SpiralDS-CTPA protocol with ATPS.

Advances in knowledge: 70-kVp SimDS-CTPA with 40 ml of CM is feasible in patients with a BMI up to 35 kg m^{-2} and can help reduce radiation exposure and CM in these patients.

INTRODUCTION

Dual-source CT scanners feature two independent X-ray tube/detector combinations, allowing for three different dual-source scan modes. The first mode, dual-energy scanning, uses different tube voltages on both tubes, allowing assessment of material compositions.¹ The second mode, dual-source high-pitch spiral acquisition mode, allows for very fast scanning with pitch settings of up to 3.4. Both X-ray tubes operate at the same tube potential. Sampling gaps appearing in single-source CT at pitch factors >2 are filled using the second X-ray tube and detector array arranged in the gantry with a 95° shift from the first detector. As the sampling gaps are scanned with only the second tube/detector array, this technique is limited by the X-ray tube output in patients who are obese. The third

mode, dual-source simultaneous acquisition, also utilizes both X-ray tubes at the same tube potential. Scanning is performed with standard pitch factors. No sampling gaps appear for either detector, and the whole field of view is covered by both tube/detector arrays. This corresponds to a doubling of the X-ray tube output of the CT system.²

Previous studies have shown that a reduction of the tube potential in CT angiography (CTA) can result in higher intravascular iodine enhancement with reduced radiation dose in comparison with standard protocols with a higher tube voltage.^{3–11} Low tube potential CT protocols in clinical routine are, however, limited by the maximum available tube current time product, since high tube currents are necessary to counterbalance the reduced photon generation

efficiency of the tube and the lower X-ray energy, especially in patients who are overweight and obese. Since low tube potential scanning is generally limited by the maximum achievable tube current, time product the simultaneous acquisition dual-source scanning mode appears promising for use in low-peak kilovoltage (kVp) scanning, especially in patients who are bigger.

The purpose of this study was to evaluate the feasibility, image quality (image quality) and radiation dose of a 70-kVp simultaneous acquisition dual-source CT pulmonary angiography (CTPA) protocol with 40 ml of contrast medium (CM) and to compare the image quality and radiation dose to a high-pitch spiral acquisition CTPA protocol with automated tube potential selection (ATPS).

METHODS AND MATERIALS

Study setup

This retrospective study was approved by the local ethics committee. The novel scanning protocol was integrated into clinical routine in December 2014 following phantom measurements. All non-paediatric patients referred for CTPA owing to suspected pulmonary embolism with a body mass index (BMI) less than 35 kg m^{-2} are currently scanned with this protocol.

The first 35 consecutive patients who underwent CTPA using the novel protocol were analyzed in this study (Group A). For comparison, 35 consecutive patients with a BMI $<35 \text{ kg m}^{-2}$ who had received a CTPA examination using the previous high-pitch protocol (Protocol B) were included in this study (Group B). There were no further inclusion or exclusion criteria.

Scanning protocols

All scans were performed on a second-generation 128-slice (64 detector rows with double z-sampling) dual-source CT scanner (Siemens Definition Flash; Siemens Healthcare GmbH, Erlangen, Germany) equipped with a fully integrated circuit detector (Stellar®; Siemens Healthcare GmbH, Erlangen, Germany). Patients were placed in supine position with arms extended above the head. Image acquisition direction was caudocranial. The CM (Accupaque™ 300, iohexol, 300 mg iodine/ml; GE Healthcare, Munich, Germany) was injected using a power

injector (Medrad® Stellant® Injector; Bayer Vital GmbH, Leverkusen, Germany) with a flow rate of 3 ml s^{-1} in all patients. CM injection was followed by a saline flush (40 ml, 3 ml s^{-1}). The classical bolus trigger technique (CareBolus; Siemens Healthcare GmbH) (80 kVp) in the pulmonary trunk (PT) with a threshold of 130 HU was used to trigger the examinations. Breath-hold command (no deep inspiration) was given after bolus triggering. A minimal 3-s delay was applied after bolus triggering before the start of the scan.

Patients in Group A underwent CTPA with the novel protocol [simultaneous dual-source (SimDS) scanning]; both X-ray tubes were operated at 70 kVp with a low-pitch setting (labelled “dual-source obese mode” by the manufacturer). Automated tube current modulation (ATCM) (CareDose 4D; Siemens Healthcare GmbH) was activated; 40 ml of CM was injected.

Patients in Group B underwent examinations with a dual-source high-pitch spiral acquisition mode (labelled “Flash” by the manufacturer). ATPS (CareKV, Siemens Healthcare GmbH) with ATCM was activated in Protocol B to adopt tube voltage and current automatically to patient body habitus (120 kVp, $n = 29$; 100 kVp, $n = 6$, 80 and 140 kVp were not selected). 70 ml of CM was injected. Detailed scanning parameters of both protocols are listed in Table 1.

Image reconstruction

Images were reconstructed with a soft-tissue kernel in 1-mm axial slices using a medium level of iterative reconstruction (Level 3, sinogram-affirmed iterative reconstruction) (SAFIRE; Siemens Healthcare GmbH). Furthermore, coronal and sagittal multiplanar reformations and maximum intensity projections were reconstructed.

Objective image analysis

All measurements were performed on a standard picture archiving and communication system workstation (Sectra Medical Systems GmbH, Linköping, Sweden). Objective image analysis was performed in accordance with prior studies using regions of interest (ROI) to assess the signal

Table 1. Scanning protocols and radiation dose evaluation

Parameter	Protocol A	Protocol B
Acquisition mode	Dual source, simultaneous	Dual source, high pitch
Detector collimation (mm)	64×0.6	128×0.6
Pitch	0.9	2.2
Tube voltage (kVp)	70	ATPS (120 kVp: $n = 29$, 100 kVp: $n = 6$)
Reference tube current time product (mAs_{eff})	110	118
Contrast medium volume (ml)	40	70
Mean CTDI_{vol} (mGy)	4.5 ± 1.6	7.5 ± 2.2
Mean DLP (mGy cm)	143.3 ± 44.8	278.3 ± 79.4
Estimated effective radiation dose (mSv)	2.0 ± 0.6	3.9 ± 1.1

ATPS, automated tube potential selection; CTDI_{vol} , volumetric CT dose index; DLP, dose-length product. All values are given as mean $\pm$ standard deviation.

Table 2. Patient data

Characteristics	Group A	Group B	<i>p</i> -value
<i>n</i>	35	35	–
Age (years)	65.7 ± 15.3	68.2 ± 16.0	0.46 (95% CI: –4.7 to 10.2)
Sex (M/F)	13/22	15/20	0.32
Body height (cm)	168.2 ± 8.0 (145–185)	172.3 ± 10.1 (150–192)	0.07 (95% CI: –8.4 to 0.27)
Body weight (kg)	75.7 ± 11.7 (45–96)	79.3 ± 12.8 (55–105)	0.22 (95% CI: –2.22 to 9.53)
BMI (kg m ^{–2})	26.8 ± 3.9 (21–34)	26.8 ± 4.2 (20–35)	0.98 (95% CI: –1.89 to 1.94)
Incidence of pulmonary embolism	10	12	0.06

BMI, body mass index; F, female; M, male.

Ranges are provided in parenthesis for both groups for height, weight and BMI; 95% CI: 95% confidence intervals for *p*-values.

All values are given as mean ± standard deviation.

intensity (SI) in Hounsfield units and noise index (NI standard deviation of SI in Hounsfield units).^{8,9} ROIs were placed in the PT in a lower lobe segmental artery (LLSA) and in the paravertebral muscle (BACKGROUND). The size of the ROIs was adapted to the size of the corresponding structures to avoid partial volume effects.

Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated for the PT and the LLSA:

$$\text{SNR} = \text{SI}/\text{NI}$$

$$\text{CNR} = (\text{SI} - \text{BACKGROUND})/\text{NI}$$

Subjective image analysis

Subjective image quality was assessed separately by two independent readers (CT and JB; with 8 and 2 years' experience in reading CTPA) on a four-point scale: (1) non-diagnostic, (2) suboptimal, (3) adequate and (4) excellent. Image evaluation was based on vascular attenuation, image noise, artefacts and diagnostic confidence. Non-diagnostic was defined as a lack of interpretability of the segmental arteries. Examinations were rated suboptimal, when the sub-segmental arteries could not be evaluated properly. Adequate was defined as minor artefacts or image noise, while all pulmonary arteries showed an optimal contrast. Excellent was defined as excellent vascular enhancement in all pulmonary arteries (PT to subsegmental arteries) and the absence of artefacts and image noise.

Both readers were blinded to image assessment parameters and clinical information.

For subjective analysis, all images were provided on a picture archiving and communication system workstation. Axial images (slice thickness of 1 mm) as well as sagittal and coronal multi-planar reformations and maximum intensity projections were evaluated. Modulation of the CT window was at the discretion of the individual readers.

Both readers independently assessed the frequency of pulmonary embolism. Interreader agreement for the diagnosis of pulmonary embolism was assessed.

Radiation dose

Volumetric CT dose index and dose–length product (DLP) were extracted from the patient protocol. Effective dose was calculated using a conversion factor of 0.014.¹²

Statistical analysis

Data analysis was performed using MedCalc (MedCalc Software, Ostend, Belgium). Data are given as mean ± standard deviation, together with range. Statistical significance was set to $p < 0.05$. 95% confidence intervals (95% CI) and interquartile ranges are provided. Normal distribution was tested with Kolmogorov test. Student's *t*-test was performed for all normally distributed parameters. Mann–Whitney *U* test and χ^2 test were performed as non-parametric tests. A κ value was calculated to evaluate interobserver agreement and interpreted as follows: excellent ($\kappa > 0.81$), good ($\kappa = 0.61$ – 0.80), moderate ($\kappa = 0.41$ – 0.60), fair ($\kappa = 0.21$ – 0.40) and poor ($\kappa \leq 0.20$).¹³

RESULTS

Patient demographics

There were no statistical differences in sex, patient age, body weight, BMI and frequency of pulmonary embolism between both protocols (all $p > 0.05$) (Table 2). Pulmonary embolism was diagnosed in 31% of all patients (Group A: 10 (29%) cases and Group B: 12 (34%) cases; $p = 0.06$). Interobserver agreement for the diagnosis of pulmonary embolism was 100%.

Radiation dose

Mean tube current time product was significantly higher in Group A than in Group B (268 ± 91 mAs, range 100–397 mAs, vs

Table 3. Subjective ratings for both readers and both groups

Rating	Reader 1		Reader 2	
	Group A	Group B	Group A	Group B
Excellent	24	26	28	25
Adequate	8	8	5	9
Suboptimal	3	1	2	1
Non-diagnostic	0	0	0	0

Table 4. Attenuation, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and subjective image quality

Imaging characteristics	All patients	Group A	Group B	<i>p</i> -value
Attenuation trunk (HU)	338.1 ± 138.8	414.3 ± 149.4	259.6 ± 69.7	<0.0001 (99–211)
Attenuation LLSA (HU)	337.3 ± 136.4	416.4 ± 139.3	256.0 ± 75.0	<0.0001 (107–214)
SNR _{Trunk}	14.2 ± 5.0	14.6 ± 6.0	13.9 ± 3.7	0.56 (−3.1 to 1.7)
SNR _{LLSA}	13.5 ± 7.2	15.1 ± 8.9	12.0 ± 4.5	0.08 (−0.36 to 6.4)
CNR _{Trunk}	12.0 ± 4.7	12.4 ± 5.7	11.6 ± 3.3	0.48 (−3.0 to 1.4)
CNR _{LLSA}	11.4 ± 6.7	12.9 ± 8.5	10.0 ± 4.1	0.08 (−6.0 to 0.4)
Subjective image quality	3.7 ± 0.6	3.7 ± 0.6	3.7 ± 0.6	0.98

LLSA, left lower segmental pulmonary artery; Trunk, pulmonary trunk. 95% confidence intervals for *p*-values are provided in parenthesis. All values are given as mean ± standard deviation.

144 ± 35 mAs, range 82–211 mAs; $p < 0.0001$, 95% CI: 91–158 HU). Volumetric CT dose index and DLP were significantly lower in Group A than in Group B (4.5 ± 1.6 mGy vs 7.4 ± 2.2 mGy and 143.3 ± 44.8 mGy cm vs 272.3 ± 80.4 mGy cm; $p < 0.0001$, 95% CI: 2.18–3.97 HU and 104–166 HU, respectively) (Table 1). On an average, radiation dose was lowered by 48% in Group A compared with Group B.

Image quality

None of the CT studies were rated as non-diagnostic by any of the two readers (Table 3). There was no significant difference in the subjective image quality between Groups A and B (3.7 ± 0.6 vs 3.7 ± 0.6 ; median 4, interquartile range 3–4, respectively; $p = 0.98$) (Table 4).

The CT numbers showed a statistically significant difference between Group A and Group B for the PT (range 202–1018 HU vs 149–456 HU, $p < 0.0001$, 95% CI: 99–211 HU) and the LLSA (range: 211–948 HU vs 130–454 HU, $p < 0.0001$, 95% CI: 107–214 HU). There was no significant difference between Group A and Group B for SNR (SNR in the pulmonary trunk: 14.6 ± 6.0 vs 13.9 ± 3.7 and SNR in the LLSA: 15.1 ± 8.9 vs 12.0 ± 4.5) and CNR (CNR in the pulmonary trunk 12.4 ± 5.7 vs 11.6 ± 3.3 and CNR in the LLSA 12.9 ± 8.5 vs 10.0 ± 4.1) (all $p > 0.05$) (Table 4).

Examples of image quality for Group A are shown in Figures 1 and 2 (Figure 1: overweight patient, BMI of 30 kg m^{-2} and effective dose of 2.3 mSv; Figure 2: normal weight patient, BMI of

24 kg m^{-2} and effective dose of 0.7 mSv). An example for diagnostic image quality in a patient who is obese with a BMI of 34 kg m^{-2} in Group A is shown in Figure 3. Comparison between both protocols is demonstrated in Figure 4.

DISCUSSION

This study demonstrated the feasibility of 70-kVp CTPA using a dual-source CT protocol with low-pitch dual-source simultaneous acquisition mode and 40 ml of CM. Furthermore, the new protocol provided subjective image quality, SNR and CNR comparable with a high-pitch spiral acquisition dual-source CT protocol with ATPS, while the radiation dose was reduced by almost 50%.

A variety of previous studies investigated CTPA protocols with different dose reduction techniques. Dose reduction has been reported through reduction of milliamperes seconds,^{4,14,15} reduction of kVp^{16–18} or application of iterative reconstruction.^{19,20} Furthermore, high-pitch protocols in combination with automated tube potential selection have been shown to enable a significant dose reduction compared with standard protocols.⁷ Out of these options, reduction of kVp is especially valuable in CTA because the evaluability of the vessels is mainly driven by iodine enhancement. We found comparable SNR and CNR in both CTPA protocols, while radiation dose and CM dose were reduced in Group A. This reduction of radiation dose when lowering kVp can be achieved only if the tube current time product does not completely counterbalance the dose reduction gained by the reduced kVp. The decrease in

Figure 1. A 71-year-old female patient who is obese (height 162 cm, 78 kg and body mass index 29.7 kg m^{-2}) with suspected pulmonary embolism. Examination was performed with 70 kVp and 40 ml of contrast medium. Effective radiation dose was 2.3 mSv. Axial image (a) and coronal maximum intensity projection (b) demonstrating excellent image quality. A, anterior view.

Figure 2. A 92-year-old patient who is slim (height 162 cm, 63 kg and body mass index 24 kg m^{-2}) with suspected pulmonary embolism. Examination was performed with the 70-kVp protocol with 40 ml of contrast medium. Effective radiation dose was 0.7 mSv.

overall radiation inevitably leads to an increase in image noise. However, lowering the kVp also leads to an increase in vascular attenuation, which arises from higher relative iodine attenuation with its k -edge of 33.2 keV.³ The higher attenuation enables either radiation dose reduction, CM dose reduction or, as investigated in this study, a combination of both. The overall increase in vascular attenuation helps overcome the increased image noise and leads to a comparable SNR and CNR in CTA. In addition, ATCM is an effective dose reduction technique in low-pitch CT studies, whereas its performance is limited in high-pitch CT. This can increase the radiation dose reduction of low-pitch SimDS mode compared with high-pitch spiral acquisition. Initial studies evaluating kVp reduction in CTPA compared 120-kVp with 100-kVp studies and demonstrated a dose reduction of up to 50%.⁸ Mean vessel attenuation as well as a SNR were comparable with our results (463 HU and 12, respectively), but the overall iodine load and the iodine delivery rate were markedly higher than in our 70-kVp protocol (21 g at 1833 mg L^{-1} compared with 12 g at 900 mg L^{-1} in our

study). More recent studies investigated 80-kVp CTPA in combination with iterative reconstructions and reported a significant dose reduction.¹⁷ A DLP of 73 mGy cm for the 80-kVp CTPA protocol was reported,¹⁷ which is lower than that in our 70-kVp protocol. However, patients weighting only up to 80 kg were included in their 80-kVp CTPA protocol and the amount of CM was twice as high compared with our study.

Initial results were reported for 70-kVp CT examinations of different body regions; e.g. for CTA,^{6,11,18,21} chest CT,²² paediatric CT²³ and cranial CT.²⁴ These studies also showed feasibility, diagnostic image quality and a potential for reduction of radiation dose and CM. Up to date, only two studies have reported the results for dual-source 70-kVp CTPA.^{18,20}

Li et al²¹ investigated the feasibility of a 70-kVp high-pitch CTPA protocol with 40 ml of CM and reported sufficient image quality at a mean DLP of 28 mGy cm. Because they were not able to report the height, weight and BMI of the patients, Li et al²¹ used diameter measurements to compare groups. Nevertheless, no ranges for diameter measurements were reported and therefore, limitations of their protocol in regard to X-ray tube output in patients who are larger cannot be appraised. Although a 70-kVp CTPA protocol was investigated, the protocol used by Li et al²¹ cannot be compared with our 70-kVp protocol. The feasibility of using a reduced amount of CM in high-pitch CTPA is mainly limited by image quality (and therefore maximal tube current time product) and not by the amount of CM. Because of the fast table movement, high-pitch protocols do not require a large CM bolus, but depend on a perfect timing to start the examination. The major limitation of these protocols, when performed with low kVp, is image quality in patients who are overweight and obese because of the limitations in X-ray tube output. In contrast, our protocol enables a higher X-ray tube output because both X-ray tubes are used simultaneously for image acquisition.

To our knowledge, only one other study reported the utilization of simultaneous acquisition dual-source CT for the detection of pulmonary embolism.¹⁸ Wichmann et al¹⁸ compared a standard 100-kVp protocol with a single-source 70-kVp protocol and

Figure 3. A 63-year-old patient (height 168 cm, 96 kg and body mass index 34.0 kg m^{-2}); axial image (a) and coronal maximum intensity projection (b) were examined with the 70-kVp protocol with 40 ml of contrast medium. Effective dose was 2.2 mSv (mean tube current time product: 366 mAs and volumetric CT dose index: 6.1 mGy). Bilateral pulmonary embolism was diagnosed (white arrows).

Figure 4. (a) A 76-year-old female patient [height 173 cm, 80 kg and body mass index (BMI) 26.7 kg m^{-2}] with suspected pulmonary embolism. The patient was examined with the high-pitch protocol (Group B) with 100 kVp. Pulmonary embolism was detected in the right lower lobe segmental arteries (white arrows). (b) A 74-year-old female patient (158 cm, 56 kg and BMI 22.4 kg m^{-2}) with D-dimers above 30 and suspected pulmonary embolism. The patient was examined with the 70-kVp dual-source CT pulmonary angiography protocol (Group A). Bilateral central pulmonary embolism was detected (white arrows).

a dual-source 70-kVp protocol with simultaneous acquisition mode. Although a dual-source simultaneous acquisition CTPA protocol was performed just as in our study, 70 ml of 300 mgI ml^{-1} CM was used. Mean attenuation values of the PT were slightly higher than that in this study ($490 \pm 148 \text{ HU}$), which is most likely the result of the larger amount of CM (1.75 times the amount used in this study), resulting in a higher iodine delivery rate (1200 mgI s^{-1} , overall iodine load 21 g).¹⁶ Although it has been reported that the image quality for 70 kVp was comparable with that for 100 kVp, a limitation of their study was the missing data on height, weight and BMI, which restrict comparison with our results. Furthermore, no statement can be made from their study about the feasibility of further CM reduction in 70-kVp CTPA using the SimDS mode, which is demonstrated in our study.

The downside of the CT dual-source simultaneous acquisition mode arises from its major strength: the simultaneous acquisition enables high X-ray tube outputs but also limits the pitch factor. While the high-pitch factor provided by modern CT scanners has led to feasibility of CTPA with 20 ml of CM when using a test bolus scan, the reduction of CM may be limited in SimDS acquisition mode, owing to the short bolus transit time.²² Even with perfect timing using bolus triggering or a test bolus, the CM bolus may not be too small to enable scanning at a low pitch. Nevertheless, using 40 ml of CM was feasible in our study and led to diagnostic image quality in patients with a BMI of up to 35 kg m^{-2} .

It would be possible to decrease the injection rate or dilute the CM to increase the length of the CM bolus transit time; however, both methods are limited by the resulting reduction of image quality. For further studies, reduction of injection rate in combination with a higher iodine concentration CM could be used to extend the CM bolus transit time without reducing vascular attenuation and therefore maintaining image quality, when using the simultaneous acquisition dual-source mode in patients who are overweight and obese.

This study has certain limitations. Since initial results are reported, the number of patients is limited. Further prospective

studies with larger cohorts have to be performed to confirm the results presented here, including larger subgroups with patients who are extremely obese. Subjective image quality was rated by two independent readers, but we did not assess intrareader variability. As this was a retrospective study, no interindividual comparison was available. Because we wanted to use a high-pitch protocol with ATPS for comparison in this study, acquisition parameters between both protocols are diverse. Therefore, our results in regard to dose reduction may not be generalizable to other CTPA protocols. Nevertheless, high-pitch protocols have been described for CTPA,^{19,21} and our main goal was to show the feasibility of 70-kVp CTPA using the low-pitch dual-source simultaneous acquisition mode in patients with a BMI up to 35 kg m^{-2} . We did not evaluate the extent of chest coverage of both protocols and the impact on secondary findings. The second detector of the herein used dual-source CT scanner has an x - y width of 33.2 cm. Thus, using the high-pitch dual-source protocol, reconstruction is limited to a circular field of view of about 33 cm in the centre of the gantry. In the low-pitch simultaneous acquisition mode, the whole field of view is covered by the first (larger) detector. Full dose and full image quality are available only at the central 33-cm field of view. This limitation is partly compensated by the fact that image noise in CT examinations is generally lower in the periphery than at the centre. Although we did not include a detailed evaluation of volume coverage and its impact on secondary findings, all subsegmental pulmonary vessels were visible in all patients. Correct placement of the patient at the centre of the gantry can minimize the risk of incomplete coverage of parts of the chest. This has to be kept in mind when using the dual-source acquisition technique in chest CT.

CONCLUSION

In conclusion, the 70-kVp dual-source CTPA protocol using simultaneous acquisition of both X-ray tubes with 40 ml of CM is feasible in patients with a BMI up to 35 kg m^{-2} and allows for a reduction of radiation dose by almost 50% and a reduction of CM dose by 40% compared with a spiral acquisition high-pitch CTPA protocol with ATPS, while maintaining diagnostic image quality.

REFERENCES

- Johnson TR, Krauss B, Sedlmair M, Grasruck M, Bruder H, Morhard D, et al. Material differentiation by dual energy CT: initial experience. *Eur Radiol* 2007; **17**: 1510–7. doi: <http://dx.doi.org/10.1007/s00330-006-0517-6>
- Petersilka M, Bruder H, Krauss B, Stierstorfer K, Flohr TG. Technical principles of dual source CT. *Eur J Radiol* 2008; **68**: 362–8. doi: <http://dx.doi.org/10.1016/j.ejrad.2008.08.013>
- Megyeri B, Christe A, Schindera ST, Horkay E, Sikula J, Cullmann JL, et al. Diagnostic confidence and image quality of CT pulmonary angiography at 100 kVp in overweight and obese patients. *Clin Radiol* 2015; **70**: 54–61. doi: <http://dx.doi.org/10.1016/j.crad.2014.09.014>
- Heusch P, Lanzman RS, Aissa J, Schimmöller L, Antoch G, Krix M, et al. Evaluation of a high iodine delivery rate in combination with low tube current for dose reduction in pulmonary computed tomography angiography. *J Thorac Imaging* 2014; **29**: 293–7. doi: <http://dx.doi.org/10.1097/RTI.0000000000000099>
- Chen CM, Chu SY, Hsu MY, Liao YL, Tsai HY. Low-tube-voltage (80 kVp) CT aortography using 320-row volume CT with adaptive iterative reconstruction: lower contrast medium and radiation dose. *Eur Radiol* 2014; **24**: 460–8. doi: <http://dx.doi.org/10.1007/s00330-013-3027-3>
- Meyer M, Haubenreisser H, Schoepf UJ, Vliegenthart R, Leidecker C, Allmendinger T, et al. Closing in on the K edge: coronary CT angiography at 100, 80, and 70 kV-initial comparison of a second- versus a third-generation dual-source CT system. *Radiology* 2014; **273**: 373–82. doi: <http://dx.doi.org/10.1148/radiol.14140244>
- Lurz M, Lell MM, Wuest W, Eller A, Scharf M, Uder M, et al. Automated tube voltage selection in thoracoabdominal computed tomography at high pitch using a third-generation dual-source scanner: image quality and radiation dose performance. *Invest Radiol* 2015; **50**: 352–60. doi: <http://dx.doi.org/10.1097/RLI.0000000000000133>
- Szucs-Farkas Z, Strautz T, Patak MA, Kurmann L, Vock P, Schindera ST. Is body weight the most appropriate criterion to select patients eligible for low-dose pulmonary CT angiography? Analysis of objective and subjective image quality at 80 kVp in 100 patients. *Eur Radiol* 2009; **19**: 1914–22. doi: <http://dx.doi.org/10.1007/s00330-009-1385-7>
- Nyman U, Björkdahl P, Olsson ML, Gunnarsson M, Goldman B. Low-dose radiation with 80-kVp computed tomography to diagnose pulmonary embolism: a feasibility study. *Acta Radiol* 2012; **53**: 1004–13. doi: <http://dx.doi.org/10.1258/ar.2012.120327>
- Björkdahl P, Nyman U. Using 100- instead of 120-kVp computed tomography to diagnose pulmonary embolism almost halves the radiation dose with preserved diagnostic quality. *Acta Radiol* 2010; **51**: 260–70. doi: <http://dx.doi.org/10.3109/02841850903505222>
- Zhang LJ, Zhao YE, Schoepf UJ, Mangold S, Felmly LM, Li X, et al. Seventy-peak kilovoltage high-pitch thoracic aortic CT angiography without ECG gating: evaluation of image quality and radiation dose. *Acad Radiol* 2015; **22**: 890–7. doi: <http://dx.doi.org/10.1016/j.acra.2015.03.007>
- McCullough CH, Primak AN, Braun N, Kofler J, Yu L, Christner J. Strategies for reducing radiation dose in CT. *Radiol Clin North Am* 2009; **47**: 27–40. doi: <http://dx.doi.org/10.1016/j.rcl.2008.10.006>
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; **33**: 159–74. doi: <http://dx.doi.org/10.2307/2529310>
- Tack D, De Maertelaer V, Petit W, Scillia P, Muller P, Suess C, et al. Multi-detector row CT pulmonary angiography: comparison of standard-dose and simulated low-dose techniques. *Radiology* 2005; **236**: 318–25. doi: <http://dx.doi.org/10.1148/radiol.2361040190>
- Montet X, Hachulla AL, Neroladaki A, Lador F, Rochat T, Botsikas D, et al. Image quality of low mA CT pulmonary angiography reconstructed with model based iterative reconstruction versus standard CT pulmonary angiography reconstructed with filtered back projection: an equivalency trial. *Eur Radiol* 2015; **25**: 1665–71. doi: <http://dx.doi.org/10.1007/s00330-014-3563-5>
- Apfalter P, Sudarski S, Schneider D, Nance JW Jr, Haubenreisser H, Fink C, et al. Value of monoenergetic low-kV dual energy CT datasets for improved image quality of CT pulmonary angiography. *Eur J Radiol* 2014; **83**: 322–8. doi: <http://dx.doi.org/10.1016/j.ejrad.2013.11.005>
- Laqmani A, Regier M, Veldhoen S, Backhaus A, Wassenberg F, Sehner S, et al. Improved image quality and low radiation dose with hybrid iterative reconstruction with 80 kV CT pulmonary angiography. *Eur J Radiol* 2014; **83**: 1962–9. doi: <http://dx.doi.org/10.1016/j.ejrad.2014.06.016>
- Wichmann JL, Hu X, Kerl JM, Schulz B, Frellesen C, Bodelle B, et al. 70 kVp computed tomography pulmonary angiography: potential for reduction of iodine load and radiation dose. *J Thorac Imaging* 2015; **30**: 69–76. doi: <http://dx.doi.org/10.1097/RTI.0000000000000124>
- Pontana F, Henry S, Duhamel A, Faivre JB, Tacelli N, Pagniez J, et al. Impact of iterative reconstruction on the diagnosis of acute pulmonary embolism (PE) on reduced-dose chest CT angiograms. *Eur Radiol* 2015; **25**: 1182–9. doi: <http://dx.doi.org/10.1007/s00330-014-3393-5>
- Kaul D, Grupp U, Kahn J, Ghadjar P, Wiener E, Hamm B, et al. Reducing radiation dose in the diagnosis of pulmonary embolism using adaptive statistical iterative reconstruction and lower tube potential in computed tomography. *Eur Radiol* 2014; **24**: 2685–91. doi: <http://dx.doi.org/10.1007/s00330-014-3290-y>
- Li X, Ni QQ, Schoepf UJ, Wichmann JL, Felmly LM, Qi L, et al. 70-kVp high-pitch computed tomography pulmonary angiography with 40 ml contrast agent: initial experience. *Acad Radiol* 2015; **22**: 1562–70. doi: <http://dx.doi.org/10.1016/j.acra.2015.08.026>
- Bodelle B, Klement D, Kerl JM, Lehnert T, Frellesen C, Bauer R, et al. 70 kV computed tomography of the thorax: valence for computer-assisted nodule evaluation and radiation dose—first clinical results. *Acta Radiol* 2014; **55**: 1056–62. doi: <http://dx.doi.org/10.1177/0284185113513258>
- Niemann T, Henry S, Duhamel A, Faivre JB, Deschildre A, Colas L, et al. Pediatric chest CT at 70 kVp: a feasibility study in 129 children. *Pediatr Radiol* 2014; **44**: 1347–57. doi: <http://dx.doi.org/10.1007/s00247-014-3027-8>
- Cho ES, Chung TS, Ahn SJ, Chong K, Baek JH, Suh SH. Cerebral computed tomography angiography using a 70 kVp protocol: improved vascular enhancement with a reduced volume of contrast medium and radiation dose. *Eur Radiol* 2015; **25**: 1421–30. doi: <http://dx.doi.org/10.1007/s00330-014-3540-z>