Low kilovoltage cardiac dual-source CT: attenuation, noise, and radiation dose

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Abstract: The purpose of this study was to investigate the effect of low kilovoltage dual-source computed tomography coronary angiography (CTCA) on qualitative and quantitative image quality parameters and radiation dose. Dual-source CTCA with retrospective ECG gating was performed in 80 consecutive patients of normal weight. Forty were examined with a standard protocol (120 kV/330mAs), 20 were examined at 100 kV/330mAs, and 20 at 100 kV/220mAs. Two blinded observers independently assessed image quality of each coronary segment and measured the image parameters noise, attenuation, and contrast-to-noise ratio (CNR). The effective radiation dose was calculated using CT dose volume index and the dose-length product. Diagnostic image quality was obtained in 99% of all coronary segments (1,127/1,140) without significant differences among the protocols. Image noise, attenuation, and CNR were significantly higher for 100 kV/330mAs (26 +/- 3 HU, 549 +/- 62 HU, 25.5 +/- 3.2; each $P < 0.01$) and 100 kV/220mAs (27 +/- 2 HU, 560 +/- 43 HU, 25.0 +/- 2.2; each $P < 0.01$) when compared to the 120-kV protocol (21 +/- 2 HU, 317 +/- 28 HU, 20.6 +/- 1.7). There was no significant difference between the two 100-kV protocols. Estimated effective radiation dose of the 120-kV protocol (8.9 +/- 1.2 mSv) was significantly higher than the 100 kV/330mAs (6.7 +/- 0.8 mSv, $P < 0.01$) or 100 kV/220mAs (4.4 +/- 0.6 mSv, $P < 0.001$) protocols. Dual-source CTCA with 100 kV is feasible in patients of normal weight, results in a diagnostic image quality with a higher CNR, and at the same time significantly reduces the radiation dose.

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Abstract The purpose of this study was to investigate the effect of low kilovoltage dual-source computed tomography coronary angiography (CTCA) on qualitative and quantitative image quality parameters and radiation dose. Dual-source CTCA with retrospective ECG gating was performed in 80 consecutive patients of normal weight. Forty were examined with a standard protocol (120 kV/330mAs), 20 were examined at 100 kV/330mAs, and 20 at 100 kV/220mAs. Two blinded observers independently assessed image quality of each coronary segment and measured the image parameters noise, attenuation, and contrast-to-noise ratio (CNR). The effective radiation dose was calculated using CT dose volume index and the dose-length product. Diagnostic image quality was obtained in 99% of all coronary segments (1,127/1,140) without significant differences among the protocols. Image noise, attenuation, and CNR were significantly higher for 100 kV/330mAs (26±3 HU, 549±62 HU, 25.5±3.2; each $P<0.01$) and 100 kV/220mAs (27±2 HU, 560±43 HU, 25.0±2.2; each $P<0.01$) when compared to the 120-kV protocol (21±2 HU, 317±28 HU, 20.6±1.7). There was no significant difference between the two 100-kV protocols. Estimated effective radiation dose of the 120-kV protocol (8.9±1.2 mSv) was significantly higher than the 100 kV/330mAs (6.7±0.8 mSv, $P<0.01$) or 100 kV/220mAs (4.4±0.6 mSv, $P<0.001$) protocols. Dual-source CTCA with 100 kV is feasible in patients of normal weight, results in a diagnostic image quality with a higher CNR, and at the same time significantly reduces the radiation dose.

Keywords Dual-source CT coronary angiography · Low kilovoltage · Radiation exposure · Contrast-to-noise ratio

Introduction

Since its introduction, computed tomography coronary angiography (CTCA) has progressively advanced from a new imaging technique applied only for research purposes to a regularly used diagnostic tool that has fully entered the routine clinical practice. Multi-slice CTCA has proven in several studies [1–4] to have a high diagnostic accuracy for the detection or exclusion of coronary artery disease (CAD). Nevertheless, even with 64-slice CTCA, the vessel visibility was affected by motion artifacts and up to 12% of the coronary artery segments remained not assessable [3].

The most recently developed dual-source CT system further improved temporal resolution to 83 ms [5]. The initial reports using dual-source CTCA have demonstrated a high diagnostic accuracy [4, 6] and improvement of the vessel depiction even at high and irregular heart rates [7]. However, the widespread use of CTCA for the evaluation of the coronary arteries has rendered the radiation exposure an increasing concern. With 64-slice CTCA, the effective radiation dose averages approximately 15 mSv when not implementing the electrocardiography (ECG)-pulsing technique for a dose reduction [8]. When making use of the ECG-pulsing technique, the radiation dose of a 64-slice CT examination is significantly lower and ranges between 10 and 14 mSv [8]. With dual-source CTCA, the effective radiation dose has been reported to be between 7 and 9 mSv [9], depending on the protocol used.

In addition to ECG-based tube current modulations, lowering of the tube voltage represents another important approach for dose reduction because the radiation dose varies with the square of the tube voltage [10]. Recently, investigations with 16- and 64-slice CT systems comparing 120- and 100-kV tube voltage CTCA protocols have shown that, by using 100 kV, the radiation dose is reduced and the image noise is increased while the contrast-to-noise ratio (CNR) remains unchanged [8].

The purpose of this study was to investigate the effect of low tube voltage in combination with a low tube current on the image quality of the coronary arteries, the image noise, the attenuation, the CNR, and the effective radiation dose of dual-source CTCA.

Materials and methods

Study population

Eighty consecutive patients (28 women, 52 men; mean age 57±10 years; range 38–79 years) were prospectively enrolled in our study. All patients had suspected or known coronary artery disease and were investigated for clinical reasons. The indications were in accordance with current guidelines and recommendations [11]. The inclusion criterion for all patients in this study was a normal body mass index, i.e., ranging between 18.5 and 25 kg/m^2. The patients were randomly assigned to three different CTCA protocols: Forty patients were examined with two different approaches for a radiation dose reduction by using 100-kV protocols (each n=20). The other 40 patients were examined with a 120-kV standard CTCA protocol and served as the control group. Our local ethics committee approved this study; written informed consent was waived.

Dual-source CTCA protocols

All CT examinations were performed on a dual-source CT system (Somatom Definition, Siemens Medical Solutions, Forchheim, Germany) using the following parameters: detector collimation 2×32×0.6 mm, slice acquisition 2× 64×0.6 mm by means of a z-flying focal spot, gantry rotation time 330 ms, and a pitch of 0.2–0.5 adapted to the heart rate. The standard CTCA protocol comprised a 120-kV tube voltage and a tube current time product of 330 mAs per rotation. We applied two different approaches to reduce the radiation dose. In the first approach, the tube voltage was reduced to 100 kV while the tube current time product was fixed at 330 mAs. In the second approach, both the tube voltage (100 kV) and the tube current time product (220 mAs) were reduced, when compared to the standard CTCA protocol.

The contrast agent application protocol was similar in all protocols. The amount of the contrast material (iodixanol, Visipaque 320, 320 mg iodine/mL, GE Healthcare, UK) was adjusted to the individual body weight of each patient (1 mL/kg body weight) and was injected at a flow rate of 5 mL/s followed by 50 mL of a 20% contrast agent/80% saline solution mixture. The contrast agent application was controlled by bolus tracking in the ascending aorta (signal attenuation threshold 140 HU). CT was performed in a craniocaudal direction from the level of the carina to the diaphragm.

ECG pulsing for radiation dose reduction was used in all patients as previously recommended [12]. For mean heart rates below 60 bpm, full tube current was applied from 60–70%, at 61–70 bpm from 60–80%, at 71–80 bpm from 50–80%, and with heart rates above 80 bpm from 30–80% of the RR interval. The CT data were reconstructed with a slice thickness of 0.75 mm, a reconstruction increment of 0.5 mm, and using a soft-tissue convolution kernel (B26 f) during mid-diastole at 70% of the RR interval. When motion artifacts were present in this dataset, additional reconstructions were performed in 5% steps within the full tube current window.

Evaluation of the diagnostic image quality of the coronary artery segments

The CT data analysis was performed by two independent observers. The coronary artery tree was subdivided into 15 segments according to the scheme proposed by the American Heart Association [13]. The right coronary artery (RCA) was defined as including segments 1–4, the left main artery (LMA) segment 5, the left anterior descending artery segments 6–10, and the left circumflex artery segments 11–15. The intermediate artery was designated as segment 16, if present. Coronary artery analysis was performed in all vessels with at least 1 mm luminal diameter, as measured with an electronic caliper tool. Both readers classified the image quality of each coronary artery segment as being either diagnostic or nondiagnostic, the latter defined as being hampered by artifacts preventing an evaluation of the segment for diagnostic purposes. In case of a disagreement in the data analysis between the two observers, a final decision was obtained by consensus.

Assessment of the image noise and the contrast-to-noise ratio

The calculations of the CNR in the proximal RCA and the LMA were independently performed by both observers as previously published [14, 15]. First, the vessel contrast was calculated as the difference between the mean attenuation of contrast medium (in HU) in the contrast-enhanced vessel lumen and the mean attenuation (in HU) in the adjacent perivascular tissue. Attenuations were measured in a region of interest (ROI) in the proximal segment of the RCA and in the LMA, and were defined as large as possible, while avoiding calcifications, plaques, and stenoses. Second, the image noise was determined as being the standard deviation of the attenuation value in an ROI that was placed in the ascending aorta. Third, the calculation of the CNR was defined as the ratio of the measurement values from steps 1 and 2.

Estimation of the CT radiation dose

Dual-source CT behaves in a similar manner, when compared to conventional CT dose metrics because the radiation from both single tubes sum up in a linear manner [16]. For an estimation of the CT radiation dose, the CT volume dose index ($CTDI_{vol}$) and the dose-length product (DLP) were recorded and used for the estimations, as previously shown [9]. The $CTDI_{vol}$ averages the radiation dose over the center slice of a CT examination consisting of multiple parallel slices [17–19]. The numeric value of the $CTDI_{vol}$ is directly related to the degree of the overlap between adjacent slices in the z-axis, which is determined by the width of the individual slices and by the distance between the slices. The DLP represents the integrated radiation dose imparted by all slices of a CT examination. The DLP is defined by the data acquisition length multiplied by the $CTDI_{vol}$ [18]. The data acquisition lengths were noted in all patients.

The parameter of the effective dose is an estimate of the dose to the patients during an ionizing radiation procedure. It measures the total energy entered into the body and then takes into account the sensitivity of the organs irradiated [17]. The effective dose also allows for a direct comparison with other sources of radiation exposure and is the preferred measure of exposure with CT. The effective dose when using ECG-based tube current modulation is proportional to the average tube current [16]. The effective dose of CTCA was derived from the product of the DLP and a conversion coefficient for the chest according to a method proposed by the European Working Group for Guidelines on Quality Criteria in CT [17]. The applied conversion coefficient ($k=0.017$ mSv mGy^{-1} cm^{-1}) was averaged between male and female patients using Monte Carlo simulations.

Statistical analysis

The protocol with the use of a 120-kV tube voltage was defined as the standard CTCA protocol. All of the parameters obtained with the two 100-kV protocols were compared with the parameters of the standard protocol. The quantitative variables were expressed as mean±standard deviation and the categorical variables as frequencies and/or percentages. Weighted kappa statistics were calculated for interobserver agreements for the image quality rating and were interpreted by the guidelines of Landis and Koch [20]. Pearson's correlation coefficients were used to test for the interobserver agreement of the CNR calculation measurements. For discrete variables, comparisons were performed with the Fisher's exact test. The continuous variables were analyzed with an unpaired *t*-test. According to the Bonferroni method, the α-level of 0.05 was corrected for two planned comparisons between the standard CTCA protocol and the two dose-reduction approaches, to a statistical significance level for two-sided probability values of <0.025. All statistical testing was performed using SPSS (SPSS v. 12.0, Chicago, IL, USA) and MedCalc software (MedCalc 9.0.2, Mariakerke, Belgium).

Results

The patient characteristics are summarized in Table 1. There was no significant difference in age ($P=0.71$), body mass index ($P=0.39$), heart rate ($P=0.22$), and gender distribution ($P=0.42$) among the three patient subgroups.

Table 1 Demographic data and qualitative assessment of image quality in the subgroups of patients studied with different CTCA protocols

	CTCA protocol		
	120 kV, 330 mAs	100 kV, 330 mAs	100 kV, 220 mAs
No. of patients	40	20	20
Age (range) [years]	57.2±8.0 (50–87)	58.4±12.7 (38–79)	57.0±10.4 (39–77)
Female sex	37% (15/40)	30% (6/20)	40% (7/20)
Body mass index (range) [kg/m^2]	23.0±1.5 (19.5–24.9)	22.9±1.5 (20.3–24.9)	22.7±1.4 (19.5–24.9)
Heart rate (range) [bpm]	65.3±4.4 (49–77)	67.3±11.9 (32–90)	66.3±8.6 (49–84)

Image quality of the coronary artery segments in relation to the protocol

A total of 1,140 coronary artery segments with a vessel diameter of at least 1 mm were available for evaluation. The interobserver agreement was excellent (kappa=0.89). An overall diagnostic image quality was found in 98.9% of all segments (1,127/1,140), while 1.1% of segments (13/1,140) were non-evaluative in 6.3% of patients (5/80). There were no significant differences in the rate of nondiagnostic segments either for the 100 kV/330 mAs protocol (1.0%, 3/291, $P=0.38$) or the 100 kV/220 mAs protocol (1.1%, 3/270, $P=0.73$) when compared to the 120 kV protocol (1.2%, 7/579) nor for comparison of the two 100 kV protocols ($P=0.88$; Table 2).

Image noise and the contrast-to-noise ratio in relation to the protocol

The interobserver agreements were excellent for measurements of the attenuation of contrast medium in the ascending aorta, RCA, and LMA (mean difference 15±13 HU, range 1–39 HU, $R=0.88$, $P<0.001$), the attenuation of the perivascular tissue (mean difference 7±5 HU, range 0–19 HU, $R=0.81$, $P<0.01$), and excellent for measurements of the standard deviation of the attenuation of contrast medium in the ascending aorta (mean difference 1.2±0.8 HU, range 0–2 HU, $R=0.84$, $P<0.01$). Thus, the mean of measurements from both observers was used for further calculations (Table 3).

The image noise (i.e., the standard deviation of the attenuation of contrast medium in the ascending aorta) was significantly higher for both 100-kV protocols (100 kV, 330mAs: 25.8±3.0 HU, range 22–31 HU, $P<0.01$; 100 kV, 220mAs: 27.3±1.5 HU, range 22–33 HU, $P<0.01$), when compared to the 120-kV standard protocol (20.7±1.7 HU, range 17–26 HU) (Fig. 1). No significant difference was found between the two 100-kV protocols ($P=0.09$; Fig. 2a).

The average attenuation of contrast medium in the ascending aorta, in the LMA, and in the RCA was significantly higher for the 100-kV protocols (100 kV, 330mAs: 549±62 HU, range 427–629 HU, $P<0.001$; 100 kV, 220mAs: 560±43 HU, range 452–640 HU, $P<0.001$), when compared to the 120-kV protocol (317±28 HU, range 254–390 HU; Fig. 2b). There was no significant difference of attenuation of contrast medium between the two 100-kV protocols ($P=0.79$).

The CNR (mean CNR of the LMA and RCA) was significantly higher for the 100-kV protocols (100 kV, 330mAs: 25.5±3.2, range 18.2–30.0, $P<0.01$; 100 kV, 220mAs: 25.0±2.2, range 22.1–27.6, $P<0.01$), when compared to the 120-kV protocol (20.6±1.7, range 17.2–24.2, Fig. 2c). The difference in CNR between the two 100-kV protocols was not statistically significant ($P=0.50$).

Radiation dose estimates in relation to the applied CTCA protocol

The radiation dose parameters under the different CTCA protocols are summarized in Table 4. Using the 120-kV protocol, the estimated radiation dose was 8.9±1.2 mSv (range 7.2–10.6 mSv). The use of a reduced tube voltage of 100 kV with a tube current time product of 330 mAs resulted in a significant reduction in the effective dose to 6.7±0.8 mSv (range 5.6–8.2 mSv, $P<0.01$), corresponding to a 25% radiation dose reduction.

The use of the protocol with 100-kV tube voltage and a reduced 220 mAs tube current time product further reduced the estimated radiation dose by 34% to 4.4±0.6 mSv (range 3.7–5.7 mSv, $P<0.001$; Fig. 2d). When comparing these estimates with the 120-kV protocol, reducing both the tube voltage and the tube current resulted in an overall radiation dose reduction of 51%.

Discussion

Any diagnostic test that utilizes ionizing radiation should be performed in accordance with the “As Low As Reasonably Achievable” (ALARA) principle. Therefore, a reduction in the radiation delivered during CTCA to the lowest acceptable dose must be the goal for every examination. This study shows that lowering of the tube voltage to 100 kV from 120 kV and lowering of the tube current to 220 mAs from 330 mAs in patients of normal weight allows reducing the radiation dose up to 51% while maintaining diagnostic quality of the coronary artery segments. The attenuation of contrast medium is increased at 100 kV in comparison with a standard 120-kV CTCA

Table 2 Qualitative assessment of image quality in the subgroups of patients studied with different CTCA protocols

	CTCA protocol		
	120 kV, 330 mAs	100 kV, 330 mAs	100 kV, 220 mAs
Total no. of coronary artery segments	579	291	270
Segments with diagnostic image quality	98.8% (572/579)	99.0% (288/291)	98.9% (269/270)
Non-evaluative segments	1.2% (7/579)	1.0% (3/291)	1.1% (3/270)

Table 3 Image noise, attenuation of contrast medium, and contrast-to-noise ratio in the subgroups of patients studied with different CTCA protocols

	CTCA protocol		
	120 kV, 330 mAs	100 kV, 330 mAs	100 kV, 220 mAs
Image noise (range) [HU]	20.7±1.7 (17–26)	25.8±3.0 (22–31)	27.3±1.5 (22–33)
Attenuation of contrast medium in the ascending aorta (range) [HU]	322±33 (265–390)	561±62 (427–611)	559±39 (475–630)
Attenuation of contrast medium in the RCA (range) [HU]	315±24 (256–380)	535±67 (395–628)	560±54 (452–628)
Attenuation of contrast medium in the LMA (range) [HU]	314±26 (254–383)	527±60 (437–629)	561±35 (489–640)
CNR RCA (range)	20.5±1.6 (17.4–23.5)	25.4±3.4 (19.6–30.0)	25.0±1.6 (22.1–27.6)
CNR LMA (range)	20.6±1.7 (17.2–24.2)	25.6±3.3 (18.2–29.9)	25.1±1.1 (23.1–27.0)

RCA Right coronary artery, *LMA* left main artery, *CNR* contrast-to-noise ratio

protocol to a greater proportion than the increase in the image noise, resulting in an overall increase in the CNR, which represents one of the most important image quality parameters.

Various techniques have focused on reducing the radiation dose delivered during CTCA studies by modulating the tube current. Modulation of the tube current according to the ECG during examination (also referred to as ECG pulsing) delivers a peak tube output during a selected pulsing window and a reduction in the tube output to 25% during other parts of the cardiac cycle [9, 12]. This technique, however, has not often been used in 64-slice CT studies [1–3] for two main reasons. The former conventional ECG pulsing algorithms applies the phase of normal tube current by estimating the length of the upcoming RR interval by an analysis of the patient's preceding heart beats. In cases of arrhythmia or ectopic heart beats, this estimation is rendered incorrect and may lead to a mismatch of the interval of the full tube current and the desired reconstruction interval and thus to image quality degradation [12]. Modern ECG-pulsing algorithms are able to detect arrhythmia and automatically switch off the ECG pulsing during the ectopic heart beats. The second reason is that the temporal resolution of the 64-slice CT systems is still limited and requires the reconstruction of images at different phases when diagnostic image quality during mid- to end-diastole cannot be achieved [21–24]. Recently, the feasibility of applying ECG pulsing has been shown for dual-source CTCA and recommendations have been made for the dynamic selection of the ECG-pulsing window width in relation to the patient heart rate [12]. Following these recommendations, Stolzmann et al. [9] could show that despite using wider pulsing windows at higher heart rates, the radiation dose of dual-source CT decreased as heart rate increased. This was explained by the increasing pitch values being the major contributor to a lower radiation dose.

Another approach to tube current modulation was introduced into CTCA studies that accounts for the differences in body shape and density by automatically adjusting the tube current to the size and attenuation of the body region (i.e., CareDose 4D) [25]. The authors reported

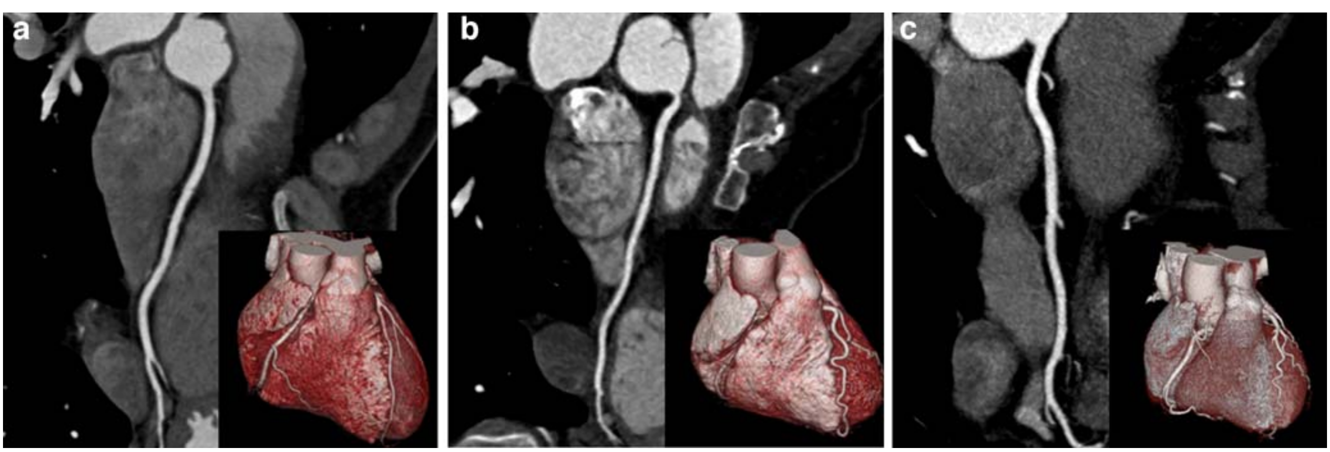

Fig. 1a–c Curved-planar reconstruction of the right coronary artery and volume-rendered images (*insets*) demonstrating the image quality of the three CTCA protocols: **a** tube voltage 120 kV, tube current 330 mAs; **b** tube voltage 100 kV, tube current 330 mAs; and **c** tube voltage 100 kV, tube current 220 mAs. The image noise is increased when tube voltage and tube current is decreased (**c**), while the image quality of the coronary segments remains diagnostic

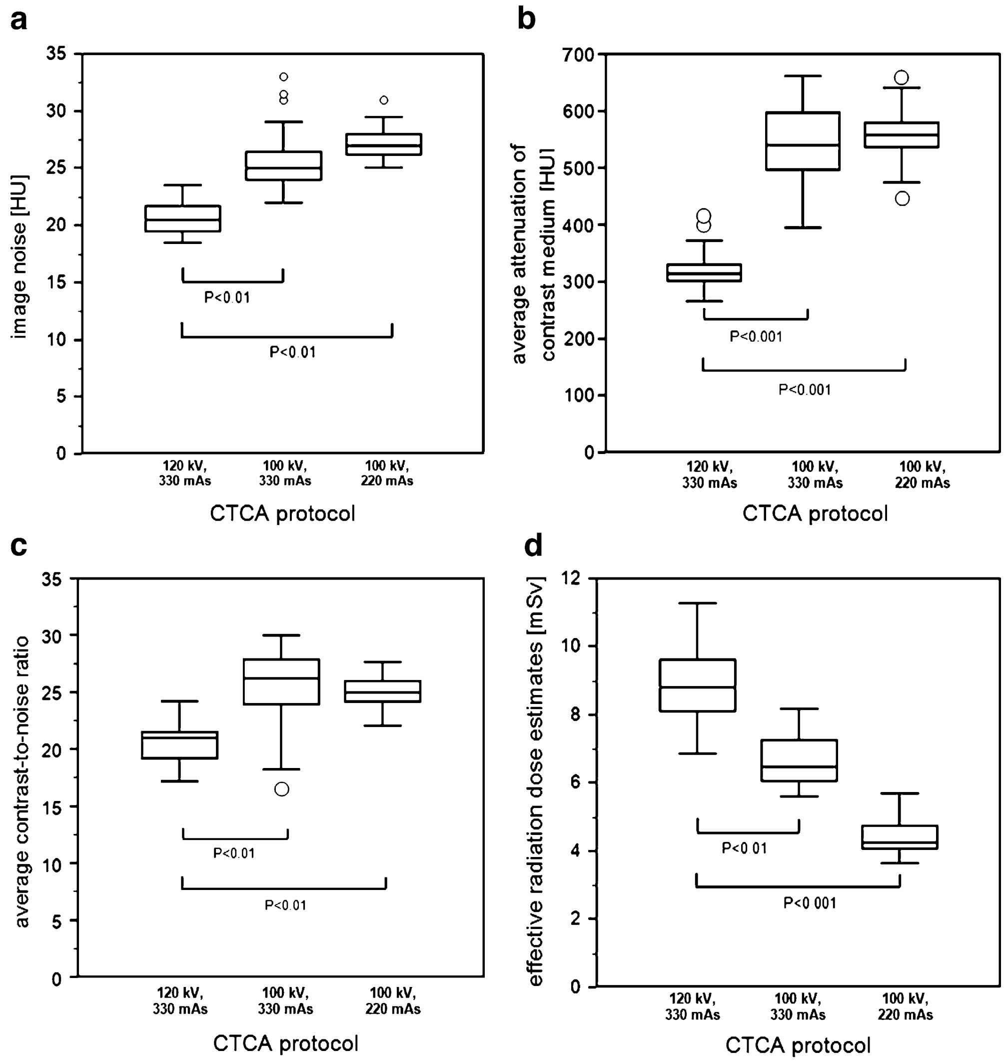

Fig. 2a–d Boxplots showing the image noise, the average attenuation of contrast medium, the contrast-to-noise ratio, and the effective radiation dose estimates in the subgroups of patients examined with the different protocols. The *box* indicates the first to third quartiles, the *bold line* indicates the median of measurements, the *whiskers* correspond to minimum and maximum values, and the *circles* indicate outliers. **a** The image noise was significantly higher in both 100-kV protocols (each $P<0.01$) compared with the standard 120-kV CTCA protocol. There was no significant difference in the image noise between the two 100-kV CTCA protocols. **b** The attenuation of contrast medium (average measurements in the ascending aorta, the right coronary artery, and the left main artery) was significantly higher when applying a tube voltage of 100 kV ($P<0.01$ for each protocol) as compared to the 120-kV protocol. There was no significant difference in the attenuation of contrast medium between the two 100-kV CTCA protocols. **c** The average contrast-to-noise ratio (average of measurements in the right coronary artery and left main artery) was significantly higher for both 100-kV protocols (each $P<0.01$) as compared to the 120-kV protocol. There was no significant difference in the contrast-to-noise ratio between the two 100-kV CTCA protocols. **d** The effective radiation dose estimates were significantly lower at 100 kV and 330 mAs (6.7±0.8 mSv, $P<0.01$) and 100 kV and 220 mAs (4.4±0.6 mSv, $P<0.001$) when compared with the standard CTCA protocol using 120 kV and 330 mAs (8.9±1.2 mSv)

a radiation dose reduction potential of 42.8% in a dedicated CTCA protocol. However, the influence on the image quality and the CNR when applying the attenuation-based tube current modulation algorithm was not systematically evaluated. While this algorithm was not applied in our study, we investigated the effect of CTCA at a fixed low tube current time product of 220 mAs and a tube voltage of 100 kV, which resulted in an estimated radiation dose reduction of 34% compared to patients in whom CTCA was performed with 100 kV and 330 mAs.

Another strategy to reduce the radiation dose during CTCA is to apply a lower tube voltage. All modern CT systems routinely operate at 120 kV for standard CTCA examinations. Altering the tube voltage might be an important radiation dose reduction approach because the radiation dose varies with the square of the tube voltage

Table 4 Effective radiation dose estimates in the subgroups of patients studied with different CTCA protocols

	CTCA protocol		
	120 kV, 330 mAs	100 kV, 330 mAs	100 kV, 220 mAs
Data acquisition length (range) [mm]	121±10 (115–135)	123±7 (111–140)	123±6 (117–137)
$CTDI_{vol}$ (range) [mGy × cm]	43.1±4.7 (36.9–46.2)	31.8±2.7 (28.7–34.6)	21.2±2.6 (18.5–24.5)
DLP (range) [mGy × cm^{-1}]	522±69 (424–623)	391±46 (330–481)	261±34 (216–335)
Radiation dose estimate (range) [mSv]	8.9±1.2 (7.2–10.6)	6.7±0.8 (5.6–8.2)	4.4±0.6 (3.7–5.7)

$CTDI_{vol}$ CT volume dose index, *DLP* dose length product

[10]. However, one disadvantage of CT with a lower tube voltage is the parallel increase in image noise [26, 27]. Hausleiter et al. [8] have investigated the image quality and the radiation dose in different CTCA protocols with 16- and 64-slice machines. They reported an increase in image noise in CTCA studies obtained at 100 kV in comparison to the standard 120-kV protocol. However, the CNR was not affected by the increased image noise. Moreover, the effective radiation dose could be reduced by using a low tube voltage and ECG pulsing, when compared to the 120-kV protocol with ECG pulsing by 22% for 16-slice CTCA and 43% for 64-slice CTCA [8].

In our study, we tested 100-kV protocols with two different tube current time product settings. Similar to the study of Hausleiter et al. [8], we observed an increase in image noise at 100 kV, when compared to the 120-kV protocol. In addition, the CNR was significantly higher at 100 kV than at 120 kV, while there was no difference between the two 100-kV protocols. Besides the reduction in effective radiation dose, one major advantage of using CTCA protocols at 100 kV is the increase in attenuation of contrast medium. This is caused by an increase in the photoelectric effect at lower tube voltages, particularly in examinations of structures with a high atomic number, such as iodinated contrast material. On the other hand, Compton scattering increases with higher tube voltages, and thus most X-rays interact less with soft tissue [26]. Therefore, a reduction in the tube voltage leads to an increase in the attenuation of iodinated contrast material as the photoelectric effect increases and Compton scattering decreases [28]. Consequently, we observed a higher mean attenuation of the contrast-filled vascular structures at 100 kV than at 120 kV. The calculation of the CNR incorporates the attenuation of contrast medium, the attenuation of perivascular fat tissue, and the image noise. As a result, applying 100 kV improved the CNR in our study due to the fact that the increase in attenuation of contrast medium outweighed the increase in the image noise. The increase in attenuation of contrast medium at 100 kV might be used to reduce the total amount of the administered contrast agent as previously proposed for chest [29] and abdominal CT [26].

When comparing the two 100-kV CTCA protocols, the increase in the image noise and the decrease in the CNR were not significant when the tube current time product was lowered to 220 mAs. This might indicate an overexposure of radiation in the protocol with 100 kV and 330 mAs because image quality parameters are only improved to a minor extent. The radiation dose could therefore be further reduced by approximately 30% when using the lowered tube current CTCA protocol. Most importantly, the rate of acceptable image quality of the coronary artery segments was comparable in all three investigated CTCA protocols.

Recently, Abada et al. [30] investigated the combined effect of lowering the tube voltage to 80 kV and applying ECG pulsing in a 64-slice CTCA study. They reported a reduction in the radiation dose by up to 88% without impairing the image quality. However, investigations were only performed in 11 slim patients with a body weight below 60 kg. When compared to the results in our study, the reported image noise (i.e., 64 HU on average) was higher and the CNR (i.e., 11 HU on average) was lower.

The following study limitations must be acknowledged. First, the small number of patients in the individual subgroups may restrict the informational value of our results. Second, we included only patients with a normal body mass index into our study. It is generally known that CTCA images of obese patients are of poorer quality due to the decreased signal-to-noise ratio, which is caused by the scattering and absorption of radiation [10, 31, 32]. Therefore, it must be assumed that the benefits of 100-kV protocols cannot be transformed to obese or even overweight patients. Third, we altered the ECG-pulsing window width depending on the heart rate during examination, as recently recommended [12], rather than using a fixed window width. Most recently, Stolzmann et al. [9] reported a decreased radiation dose at higher heart rates when applying the recommended ECG-pulsing window settings. Therefore, differences in radiation dose estimates between the different CTCA protocols might be partly explained by the individual ECG-pulsing window widths. However, the average heart rate was comparable in all three protocols, which allowed for a reasonable comparison of the radiation dose between the different CTCA protocols. Fourth, we did not assess the diagnostic accuracy of the 100-kV protocols as compared to the standard 120-kV protocol for the diagnosis of coronary artery disease. Finally, additional radiation dose-reduction techniques are available which were not applied in the present study. A reduction of the tube current to 4% instead of 25% of the nominal output has been shown to further reduce the radiation dose [9].

Conclusion

Dual-source CTCA with a tube voltage of 100 kV is feasible in patients of normal weight, it does not deteriorate the diagnostic image quality of the coronary arteries, and it significantly reduces the radiation dose delivered to the patient from 8.9 mSv at 120 kV to 6.7 mSv at 100 kV. Although the image noise is increased at 100 kV, when compared to a standard 120-kV CTCA protocol, the attenuation of contrast medium and the CNR of the coronary arteries are increased. An additional reduction of the tube current when using a 100-kV tube voltage can be recommended because a radiation dose reduction down to 4.4 mSv can be achieved while maintaining diagnostic image quality.

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