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Radiation and contrast agent doses reductions by using 80-kV tube voltage in coronary computed tomographic angiography: A comparative study

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ABSTRACT

Objective: To investigate the effects of 80-kilovoltage (kV) tube voltage coronary computed tomographic angiography (CCTA) with a reduced amount of contrast agent on qualitative and quantitative image quality parameters and on radiation dose in patients with a body mass index (BMI) <23.0 kg/m^2.
Methods: One hundred and twenty consecutive patients with a BMI <23.0 kg/m^2 and a low calcium load undergoing retrospective electrocardiogram (ECG)-gated dual-source CCTA were randomized into two groups [standard-tube voltage (120-kV) vs. low-tube voltage (80-kV)]. The injection flow rate of contrast agent (350 mg I/mL) was adjusted to body weight of each patient (4.5–5.5 mL/s in the 120-kV group and 2.8–3.8 mL/s in the 80-kV group). Radiation and contrast agent doses were evaluated. Quantitative image quality parameters and figure of merit (FOM) of coronary artery were evaluated. Each coronary segment was evaluated for image quality on a 4-point scale.
Results: Compared with the 120-kV group, effective dose and amount of contrast agent in the 80-kV group were decreased by 57.8% and 30.5% (effective dose:2.7 ± 0.5vs. 6.4 ± 1.3 mSv; amount of contrast agent:57.1 ± 3.2 vs. 82.1 ± 6.1 mL; both p < 0.0001), respectively. Image noise was 22.7 ± 2.1 HU for 120-kV images and 33.2 ± 5.2 HU for 80-kV images (p < 0.0001). Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) in the proximal right coronary artery (RCA) and left main coronary artery (LMA) were all lower in 80-kV than 120-kV images (SNR in the proximal RCA: 16.5 ± 1.8 vs. 19.4 ± 2.8; SNR in the LMA: 16.3 ± 2.0 vs.19.6 ± 2.7; CNR in the proximal RCA: 19.4 ± 2.3 vs.22.9 ± 3.0; CNR in the LMA: 18.8 ± 2.4 vs. 22.7 ± 2.9; all p < 0.0001). FOM were all significantly higher in 80-kV than 120-kV images (proximal RCA: 146.7 ± 45.1 vs. 93.4 ± 32.0; LMA: 139.1 ± 47.2 vs. 91.6 ± 31.1; all p < 0.0001). There was no significant difference in image quality score between the two groups (3.3 ± 0.8 vs. 3.3 ± 0.8, p = 0.068) despite decreased SNR and CNR of coronary artery in the 80-kV group.
Conclusion: The 80-kV protocol significantly reduces radiation and contrast agent doses in CCTA in patients with a low BMI <23.0 kg/m^2 and a low calcium load while maintaining image quality.

1. Introduction

Coronary computed tomographic angiography (CCTA) has high diagnostic performance to detect and exclude significantly obstructive coronary artery disease (CAD) [1–3]. However, the widespread use of CCTA has raised concerns regarding potential risks related to ionizing radiation [4]. To reduce the radiation dose in CCTA, electrocardiogram (ECG)-dependent tube current modulation is often used, but the decrease in radiation dose obtained by this technique is moderate [5]. Prospective ECG triggering technique allows a dramatic reduction in radiation dose [6–9]; however, it requires a patient with a regular heart rate, which cannot be obtained in all patients. The low-tube voltage technique can be used to reduce radiation dose because the radiation dose is proportional to the square of the tube voltage [10–16]. Although image noise is increased, a compensatory increase in the tube current–time product can be used to avoid an image with much noise.

Moreover, patients with an impaired renal function undergoing CCTA are at risk of contrast agent-induced nephropathy [17,18]. The low-tube voltage technique can also be used to reduce the amount of contrast agent while maintaining the attenuation coefficient value of iodine. Indeed, the mean photon energy using low-tube voltage in polychromatic X-ray beam is closer to the k-absorption edge of iodine, resulting in an increased photoelectric effect that

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translates into a higher mean attenuation coefficient value of iodine [10,16,19].

CCTA performed with 100-kilovoltage (kV) has been shown in several studies to confer a significant reduction in radiation dose while preserving image quality in nonobese patients [11–13]. CCTA using an even lower tube voltage, 80-kV, is often performed for pediatric examinations [20]. Recently, 80-kV was used in pulmonary CT angiography with significantly reduced radiation dose and amount of contrast agent [10]. However, 80-kV was not broadly used to decrease the radiation dose and amount of contrast agent in CCTA in adults.

The objective of the present study was to investigate the effects of 80-kV CCTA with a reduction in the amount of contrast agent on quantitative and qualitative image quality parameters and on radiation dose in adults by comparing low- (80-kV) with standard- (120-kV) tube voltage settings.

2. Materials and methods

2.1. Patient population

Between May and July 2012, 120 consecutive patients who were suspected for CAD were prospectively enrolled in our study. Inclusion criteria were: (1) a body mass index (BMI) <23.0 kg/m^2; (2) a body weight <75 kg; (3) a coronary calcium score <200 Agatston Units (AU). Exclusion criteria were: (1) renal dysfunction (serum creatinine level >1.3 mg/dl); (2) hyperthyroidism (TSH <0.3 mU/L); (3) hypersensitivity reaction to iodinated contrast agent; (4) serious cardiac arrhythmias; (5) history of coronary artery bypass grafting or stent placement; (6) heart failure NYHA III–IV; (7) pregnancy. All enrolled patients were randomized and subjected to two CCTA protocols based on a random number table. The two groups of 60 patients each were examined under a standard- (120-kV group) or a low-tube voltage (80-kV group).

This prospective study received an institutional ethic review board approval. Informed consent was obtained from all patients before they entered the study.

2.2. CCTA examination

CT data were acquired using a dual-source CT system (Somatom Definition; Siemens Medical Solutions, Forchheim, Germany) with z-flying focus techniques, 64 × 0.6 mm slice acquisition and 0.33 s gantry rotation time. Tube voltage was set at 120-kV (n = 60 patients) or 80-kV (n = 60 patients). Automatic exposure control (CARE dose 4D, Siemens Medical Solutions) was used in the 120-kV group, and the quality reference tube current–time product was 320 mAs. In the 80-kV group, the tube current–time product was adjusted (range 300–360 mAs, without CARE dose 4D) according to patient's BMI. Retrospective ECG-gated technique was used to synchronize data acquisition with the ECG signal in both groups. The ECG-pulsing protocol setting was dependent on patient's heart rate and heart rhythm in the two groups. The ECG-pulsing window was set to 61–77% R–R interval for patients with a stable heart rate <70 bpm, 32–49% R–R interval for patients with a stable heart rate >80 bpm, and 30–78% R–R interval for the other patients, respectively. A reduction of tube current to 4% outside the ECG-pulsing window was used. The pitch was adapted to patient's heart rate (0.23–0.43 in the 120-kV group, and 0.22–0.42 in the 80-kVgroup). Three minutes before scanning, each patient received 0.5 mg of nitroglycerin (Nitropen; JingYi, Beijing, China) sublingually to dilate the coronary artery. The scan ranged from the pulmonary artery bifurcation to the base of the heart. For all patients, the iodine contrast agent with an iodine concentration of 350 mg/mL (Iohexol-350; Beilu Pharmaceutical, Beijing, China) was delivered via a 20-gauge catheter inserted into an antecubital vein, and the injection flow rate was depended on patient's body weight in the120-kV group (4.5–5.5 mL/s) or in the 80-kV group (2.8–3.8 mL/s) (Table 1). Contrast administration was followed by an injection of 45 mL (120-kV group) or 35 mL (80-kV group) of a saline solution at the same injection flow rate as the contrast agent. Automatic bolus tracking software was used with a Hounsfield unit threshold of 100 HU in the ascending aorta. Axial images were reconstructed using the following parameters: section thickness, 0.75 mm; increment, 0.4 mm; medium-to-smooth convolution kernel, b26f.

Table 1
Injection flow rate of contrast agent according to patients' weight.

	Flow rate (mL/s)			
	45–50 kg	51–60 kg	61–70 kg	71–74 kg
120-kV	4.5	4.8	5.2	5.5
80-kV	2.8	3.2	3.6	3.8

Abbreviations: kg = kilogram; kV = kilovoltage.

2.3. Evaluation of CT radiation dose and amount of contrast agent

Heart rate, heart rate variation during scanning, scan length, CT volume dose index (CTDIvol), and dose length product (DLP) were recorded. The injection flow rate and amount of contrast agent were also recorded. The effective dose of CCTA was derived from the product of the DLP and a conversion coefficient for the chest according to European Commission guidelines on quality criteria in CT (k = 0.014 mSv mGy^{-1} cm^{-1}) [21].

2.4. Image quality and FOM analysis

All images were reviewed and interpreted on a post-processing workstation (Syngommvvp VE31A, Siemens Medical Solutions) by two radiologists with 4 and 5 years of cardiac CT experience. Coronary arteries were evaluated using axial source images, curved multiplanar reformations, and volume-rendered reconstructions. The observers were blinded to the scan protocol and identity of patients. These following measurements were performed on axial source images by the two radiologists: (1) mean CT attenuation value in the root of ascending aorta, proximal right coronary artery (RCA) and left main coronary artery (LMA); round regions of interest were placed in these vessels, and the round regions of interest were drawn as large as the artery lumen diameter, carefully avoiding the wall and calcification; (2) contrast enhancement in the proximal RCA and LMA, calculated as the difference between the mean CT attenuation value in the coronary artery lumen and the adjacent perivascular fatty tissue; (3) image noise, determined as the standard deviation of the mean CT attenuation value in the root of ascending aorta; and (4) signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) in the proximal RCA and LMA, calculated as SNR = mean CT attenuation value/image noise, and CNR = contrast enhancement/image noise. In addition, figure of merit (FOM) in the proximal RCA and LMA was calculated as the ratio of CNR^2 to the effective dose for the two groups. The FOM value represents normalized image quality characteristics considering the radiation exposure dose; this facilitates the assessment of CNR changes independent of the effective dose [22]. These quantitative image parameters and FOM were compared between the two groups.

Coronary segments of the three main coronary arteries and their major side branches down to a minimal diameter of 1.5 mm were defined according to the 15-segment American Heart Association guidelines [23]. A 4-point Likert scale [24] was used to grade image quality as follows: score 1, non-interpretable (impaired image quality that preclude evaluation of the coronary arteries); score 2,