Feasibility of Low Tube Voltage for Comprehensive Cardiac Computed Tomography in Patients with a Normal Body Mass Index: Image Quality and Radiation Dose

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ABSTRACT

The purpose of this study was to compare the image quality and radiation dose between cardiac computed tomography (CCT) protocols using low tube voltage (100 kV) and conventional tube voltage (120 kV) with a wide ECG modulation pulsing window in patients with a normal body-mass-index (BMI).

Fifty-two patients with a normal BMI (18-24 kg/m²) and coronary calcium score <400 Agatston units underwent retrospectively ECG-gated 64-slice CCT with an ECG pulsing window of 40-80% of the R-R interval. Twenty-six patients were assigned to the 100 kV group and the other twenty-six patients were assigned to the 120 kV group randomly. The image quality of the coronary arteries was assessed by a 4-point scale (1=non-diagnostic to 4=excellent). The effective radiation dose, image noise, mean CT-attenuation values, contrast-to-noise (CNR) and signal-to-noise (SNR) ratios were also evaluated.

The 100 kV group and 120 kV group showed no significant differences with respect to image quality scores, CNR and SNR. Even with an average of 38.2% dose reduction, the image quality scores were excellent in 89.6% and good in 10.4% of the coronary segments in the 100 kV group. Interobserver agreement in evaluating image quality (κ= 0.91) was good. The 100 kV group had a significantly lower effective radiation dose (mean ± SD, 7.6 ± 0.7 vs 12.3 ± 1.5 mSv), higher image noise levels and mean CT-attenuation values than those of the 120 kV group.

Although the image noise level was higher than that in the 120 kV group, the 100 kV protocol significantly reduced the radiation dose of CCT in patients with a normal BMI while its image quality scores, CNR, SNR were not significantly affected.

With advances in the multi-detector row technology of computed tomography (CT), the tremendous improvement in spatial and temporal image resolution has allowed non-invasive evaluation of coronary artery disease [1, 2]. Based on the recent guideline, coronary CT angiography (CTA) is considered “appropriate” for symptomatic patients at intermediate risk for coronary artery disease [3]. However, radiation exposure with CTA has become an important issue due to the increased risk of cancer induction [4-10]. In an average of all age groups, an estimated additional lifetime risk for developing cancer after 10 mSv exposure is approximately one in 2000 [11]. Depending on scanner technology and scanning protocols, radiation doses from 9-22 mSv for retrospectively ECG-gated CTA have been reported [5, 6]. Recently, prospectively ECG-gated CTA, especially with body mass index (BMI) adapted protocol,
has allowed marked reduction of the radiation dose to <5 mSv. However, prospective gating with radiation administration at a predefined time point provides only one cardiac phase for assessment and a low and stable heart rate is required [7-10]. There have been increasing requests for retrospectively ECG-gated cardiac CT (CCT) as a “one-stop shop” for the evaluation of cardiac structures and functions other than only coronary arteries assessment, such as aortopulmonary vessels, heart chambers and valves, cardiac motion and function, myocardial mass, perfusion and viability [12-14]. Trade-offs in reduction of radiation exposure and maintenance of good image quality for comprehensive assessment of the whole heart remain a difficult decision.

Furthermore, image quality of the coronary artery could be improved in wider ECG modulation pulsing window including systolic and diastolic phase because variation in heart rate during CCT seems inevitable in clinical practice [15-16]. Although dose-reduction protocols for retrospectively ECG-gated CTA have been reported recently [17-19], a thorough assessment on the effects of low tube voltage combined with wide ECG pulsing window for comprehensive CCT has not been well addressed. The purpose of this study was to compare the image quality and radiation dose of comprehensive CCT assessment using low tube voltage (100kV) vs conventional (120kV) protocols with 64-multidector row CT scanner and a mildly wider ECG pulsing window (40-80% of the R-R interval) in patients with a normal BMI.

MATERIALS AND METHODS

Patients

Between 2009 January to 2009 March, a total of 52 patients with an intermediate pre-test probability of coronary artery disease underwent comprehensive CCT assessment and were prospectively enrolled in this study. The inclusion criteria were as follows: (i) atypical chest pain, (ii) positive risk factors (hypertension, hypercholesterolemia, diabetes) of coronary artery disease, (iii) normal BMI (18-24 kg/m²), (iv) an inconclusive, non-specific or borderline positive treadmill ECG-stress test, and (v) coronary artery calcium scoring <400 Agatston Units. Exclusion criteria were as follows: (i) allergy to iodinated contrast agent, (ii) renal insufficiency (blood creatinine level > 1.27 mg/dL or glomerular filtration rate <60 mL/min/1.73 m²), (iii) non-sinus rhythm, (iv) history of asthma or chronic obstructive pulmonary disease, (v) implanted pacemaker or automatic implantable cardioversion defibrillator, (vi) hemodynamic instability, (vii) history of coronary artery bypass grafting or interventional management, and (viii) pregnancy. The study protocol was approved by the institutional review board of our hospital and informed consent was obtained from all patients. The patients were randomly assigned to the 100 kV group (n=26) and 120 kV group (n=26).

CCT Examination

All CCT examinations were performed with a 64-multidector row CT scanner (Aquilion, Toshiba Medical Systems Corporation, Tochigi-ken, Japan) with retrospective ECG-gating.

Patients with a heart rate >65 bpm (beats per minute) and no documented contraindications were given 5-10 mg of oral propanolol (Inderal, AstraZeneca UK Limited, Cheshire, UK) every 45-60 minutes until a target heart rate (<65 bpm) was achieved. All patients received a single dose of 0.6 mg sublingual nitroglycerin (Nitrostat, Pfizer Pharma, Vega Baja, Puerto Rico) 2 minutes prior to the scan.

Before scanning, the patients were instructed for breath compliance. The scan was performed in a cranio-caudal direction ranging from the pulmonary artery bifurcation to the base of the heart and the scanning length was recorded for each patient.

The scanning parameters were as followed: collimation, 64 × 0.5 mm; gantry rotation time, 0.4 second; pitch, 0.225; ECG-gating and modulation with full tube current limited to 40-80% of the R-R interval. Tube voltage was set at 100 kilovoltage (kV) (26 patients) or 120 kV (26 patients). Tube current (mAs) was adjusted according to the patient's weight (533–711 mAs for the 120 kV group, and 533–622 mAs for the 100 kV group).

Based on the weight of the patients we injected 60-70 ml of non-ionic contrast medium (Omnipaque 350, GE Healthcare Ireland, Cork, Ireland) via an antecubital vein at a flow rate of 4.5 ml/s followed by flushing with 30 ml saline at 4 ml/s. Automatic triggering was applied by putting a circular region of interest (ROI) at the ascending aorta with a threshold level of 150 Hounsfield units (HU).

Radiation Dose

The radiation dose parameters including the dose-length product (DLP) and volumetric CT dose index (CTDIvol) were recorded from the scanner. The DLP and CTDIvol represented the average radiation dose in the x-, y-, and z-axes. The calculated effective radiation dose was derived from the product of the DLP and a conversion coefficient (k=0.017 mSv/mGy-cm) (19).

Post-processing and Image Reconstruction

After the examination, the raw data were reconstructed in 10 phases (10% increments) with a standard kernel (FC43), adequate field-of-view, 512 × 512 matrix size and slice thickness of 1 mm with reconstruction increment of 0.8 mm. Further fine reconstructions of the axial images of the best phase(s) for evaluation of coronary artery with a slice thickness of 0.5 mm and an interval of 0.3 mm were performed. Then all data were transmitted to
a workstation (Vitrea 2, Vital Images Inc, MN, USA) for post-processing. Reconstructions of the coronary arteries in volume rendering curved multiplanar reformation, appropriate subvolume oblique images and measurements of image quality parameters of CCT were accomplished in random order by two independent observers who were blinded to patient identity and unaware of which protocol was being used.

Image quality of coronary arteries was semi-quantified by the same two reviewers with a 4-point Likert ranking scale according to the 16-segment classification recommended by the American Heart Association/American College of Cardiologists (1 = poor quality with prominent artifacts; 2 = acceptable quality with moderate artifacts; 3 = good quality with mild artifacts; 4 = excellent quality with no artifacts; Fig. 1). A score of 2 or higher was considered acceptable image quality for clinical diagnosis. All segments with a diameter of at least 1.5 mm at their origin were included. The mean CT-attenuation values (M) in HU, noise, i.e., standard deviation (SD) of the mean CT-attenuation values, contrast-to-noise ratios (CNR) and signal-to-noise ratios (SNR) were measured by putting a circular ROI of 100 mm² on axial reconstructed images at the following regions: (i) the ascending aorta (AAo) at the level of the left main coronary artery (CA); (ii) the center of the left atrium (LA) at the level of the right inferior pulmonary vein; and (iii) the center of the left ventricle (LV) at the mid-ventricular level. Then similar measurements were done by putting two circular ROI of 3-5 mm², as large as possible but excluding plaques, at the left main coronary and the proximal part of the right coronary artery, and the mean of these two measurements was calculated. The perivascular fatty (PVF) tissues near the left main and the proximal right coronary arteries were also assessed by putting two circular ROIs of 3-5 mm² at these regions and the mean of these measurements was calculated. The CNR and SNR were defined as follows:

**Figure 1.** Curved multi-planar reconstruction images of RCA illustrate the use of four-point image quality score (images are partly from our routine practice). **a.** Excellent vessel opacification, no motion artifacts or blurring, and no structural discontinuity (score 4). **b.** Good vessel opacification, minor motion artifacts or mild blurring (white arrow), and no structural discontinuity (score 3). **c.** Fair vessel opacification, some motion artifacts or blurring (white arrow), and minimal structural discontinuity (score 2). **d.** Poor vessel opacification, marked motion artifacts, and structural discontinuity (white arrow), resulting in absence of diagnostic information (score 1).
CNR = (M_{ROI} − M_{PVF})/ SD_{ROI}
SNR = M_{ROI}/ SD_{ROI}

Statistical analysis
Statistical analysis was performed with SYSTAT software (SPSS™, 17.0, SPSS Inc., Chicago, IL, USA). Continuous data were expressed as mean ± SD. The baseline patient data and radiation dose were analyzed and compared between the 100 kV and 120 kV groups using the Mann-Whitney U test for continuous variables and Fisher’s exact test for categorical variables. A p-Value <0.05 was considered to indicate statistical significance.

Differences in the subjective image quality score (1–4) between the 100 and 120 kV group were tested with the Wilcoxon test. The agreement between the two observers in assessing image quality was calculated by means of Cohen’s kappa statistics. Kappa results were interpreted as the following - poor agreement (κ < 0), slight agreement (κ = 0.0-0.20), fair agreement (κ = 0.21-0.40), moderate agreement (κ = 0.41-0.60), substantial agreement (κ = 0.61-0.80), or almost perfect agreement (κ = 0.81-1.00). Statistical significance was assumed for an α level of <0.05.

RESULTS
The baseline data, the average heart rate, heart rate variability and tube current (mAs) during the CCT scan for patients examined with the 100 kV protocol compared to those scanned with the 120 kV protocol are summarized in Table 1. The 100 kV group and 120 kV group showed no significant differences with respect to age, sex, BMI, heart rate, heart rate variability, tube current, scan length during CCT scanning and calcium score.

Comparison of Radiation dose
The radiation dose measurements are summarized in Table 2. The 100 kV group had significantly lower DLP and CTDI.vol and thus significantly lower effective radiation doses (mean ± SD, 7.6 ± 0.7 vs 12.3 ± 1.5 mSv) than those of the 120 kV group (Fig. 2). Compared with 120 kV group, the 100 kV group had an average of 38.2% reduction in the radiation dose.

Comparison of objective image quality
The quantitative image quality parameters of CCT are summarized in Table 3. All measurements were carefully

| Table 1. Demographic data of patients underwent CCT with 100 kV and 120 kV protocols |
|---------------------------------|----------------|----------------|----------------|
|                                | 100 kV (n=26) | 120 kV (n=26) | P-value        |
| Age (yrs)                      | 55.4 ± 6.8    | 57.2 ± 11.3   | 0.840          |
| Gender (male)                  | n=9 (35%)     | n=14 (54%)    | 0.163          |
| Body weight (kg)               | 56.5 ± 6.1    | 58.8 ± 5.8    | 0.174          |
| BMI (kg/m²)                    | 22.1 ± 1.3    | 22.4 ± 1.1    | 0.370          |
| Heart rate (bpm)               | 63.0 ± 5.9    | 62.5 ± 7.6    | 0.647          |
| Heart rate variability (beats/min) | 1.5 ± 0.8   | 1.4 ± 0.9     | 0.796          |
| Tube current (mAs)             | 593.2 ± 39.6  | 608.5 ± 41.3  | 0.075          |

*=Mann-Whitney test, ^=Chi-square test

| Table 2. Radiation dose measurements of patients underwent CCT with 100 kV and 120 kV protocols |
|-------------------------------------------------|----------------|----------------|----------------|
|                                                | 100 kV (n=26) | 120 kV (n=26) | P-value*       |
| Scan length (cm)                               | 12.6 ± 0.9    | 12.4 ± 1.1    | 0.249          |
| DLP (mGy.cm)                                   | 448.8 ± 41.0  | 723.4 ± 90.0  | <0.0001        |
| CTDI vol. (mGy)                                | 35.7 ± 3.4    | 58.3 ± 4.0    | <0.0001        |
| Effective radiation dose(mSv)                 | 7.6 ± 0.7     | 12.3 ± 1.5    | <0.0001        |

*Mann-Whitney U test was used.
Table 3. Quantitative image quality parameters of patients underwent CCT with 100 kV and 120 kV protocols

<table>
<thead>
<tr>
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<th>100 kV (n=26) mean ± SD</th>
<th>120 kV (n=26) mean ± SD</th>
<th>P-value*</th>
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<tr>
<td><strong>Mean CT-attenuation (HU)</strong></td>
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<tr>
<td>Aorta</td>
<td>540.2 ± 71.1</td>
<td>444.1 ± 45.2</td>
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<td>Left atrium</td>
<td>549.7 ± 84.1</td>
<td>448.0 ± 53.5</td>
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<td>Left ventricle</td>
<td>554.6 ± 96.7</td>
<td>459.2 ± 49.4</td>
<td>&lt;0.001</td>
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<td>Coronary arteries</td>
<td>573.3 ± 66.2</td>
<td>472.9 ± 54.1</td>
<td>&lt;0.001</td>
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<td><strong>Image noise (HU)</strong></td>
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<tr>
<td>Aorta</td>
<td>22.5 ± 4.1</td>
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<td>&lt;0.001</td>
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<tr>
<td>Left atrium</td>
<td>26.8 ± 5.6</td>
<td>22.3 ± 3.8</td>
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<td>Left ventricle</td>
<td>30.0 ± 5.2</td>
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<td>20.3 ± 5.5</td>
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<td>Perivascular fat tissue</td>
<td>18.1 ± 4.5</td>
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<td><strong>Contrast-to-noise Ratio</strong></td>
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<td>Coronary arteries</td>
<td>39.4 ± 10.1</td>
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<tr>
<td><strong>Signal-to-noise Ratio</strong></td>
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<tr>
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<td>Coronary arteries</td>
<td>30.1 ± 8.3</td>
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<td>0.855</td>
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*Mann-Whitney U test was used.

Figure 2. Box-and-Whisker plot shows the comparison between the effective radiation doses (mSv) of 100 kV group versus 120 kV group. Box = 1st to 3rd quartiles, mid-line = median and whiskers = minimum and maximum values.
low tube voltage cardiac CT

done within a full tube current window (40-80% of the R-R interval). The 100 kV group had significantly higher mean CT-attenuation values and image noise levels at the measured anatomic locations than those of the 120 kV group (Fig. 3). However, there were no significant differences in CNR and SNR in the aorta, left atrium, left ventricle, and coronary arteries between the two groups.

Comparison of subjective image quality
All 52 patients were in sinus rhythm and a total of 806 coronary segments were evaluated. None of these coronary segments was considered non-diagnostic. Overall, the image quality of the coronary arteries was excellent in 746 (92.6%) and good in 60 (7.4%) of the 806 segments (Fig. 3). Specifically, the image quality was excellent in 363 segments (89.6%) and good in 42 segments (10.4%) for 100 kV group, while it was excellent in 383 segments (95.5%) and good in 18 segments (0.5%) in 120 kV group. The overall interobserver agreement in assessing image quality was almost perfect ($\kappa = 0.91$). In both groups, middle third of right coronary artery showed better image quality with systolic cardiac phase reconstructions (8/26 vs 4/26). There is no significant statistical difference between 2 groups in terms of subjective image quality evaluation.

DISCUSSION
Catheter coronary angiography and intravascular sonography allow direct evaluation of the coronary artery lumen and coronary arterial wall but these examinations are invasive and expensive [13, 14, 21]. With current widely installed 64-multidetector row CT, the performance of coronary CTA for the evaluation of the arterial wall and lumen approaches that of catheter angiography [1, 2]. Coronary CTA is increasingly being applied for assessing native, stented and bypassed coronary arteries because it is non-invasive, quick, and relatively less expensive than other modalities [1, 2, 12-14]. In the present study, all patients had atypical chest pain and an inconclusive or borderline positive treadmill ECG-stress test, compatible with an intermediate pre-test probability of coronary artery disease. Therefore, non-invasive assessment with CCT was considered a reasonable approach and appropriate for these patients.

The potential advantages of coronary CTA for the evaluation of coronary artery disease have to be weighed against the potential hazards associated with ionizing radiation [4-9]. The International Commission on Radiological Protection has estimated that the additional lifetime risk of fatal cancer is at approximately 1 in 2000 per 10mSv exposure.
for the whole population [11, 20]. Einstein et al. reported that the lifetime cancer risk estimates for standard cardiac scans varied from 1 in 143 for a 20-year-old woman to 1 in 3261 for an 80-year-old man and with the use of ECG-gated controlled tube current modulation, these risk estimates decreased to 1 in 219 and 1 in 5177, respectively [4]. Therefore, CTA examination parameters should be considered and set in accordance with the as-low-as-reasonably-achievable strategy without compromise of diagnostic image quality.

Radiation exposure in coronary CTA is influenced by various factors including heart rate, duration of exposure, tube current, tube voltage, pitch, scanning length, heart size and body size [5-10, 13-18]. Although higher heart rates with a shorter duration of exposure and higher pitch values may lead to reduction of radiation exposure, a low heart rate is important for obtaining optimal image quality in CTA [18, 22, 23]. Fortunately, with the use of an automatic modulation technique with ECG-gating, reduction of tube current during less contributive phases of the cardiac cycle can be attained. For patients with low and stable heart rates, coronary arteries may be best demonstrated in the end-diastolic phase. A narrowed ECG pulsing window with full tube current limited to the end-diastolic phase (70-80% of the R-R-interval) allows a reduction of tube output up to 80% outside the ECG pulsing window [5, 18, 24]. However, if the tube current is suboptimally decreased within this narrowed pulsing window, the accuracy of assessment of coronary arterial stenosis is hampered. Furthermore, the diagnostic accuracy of ECG-gating CTA also depends on the variation in heart rate during CT studies. Matt et al. reported 80 patients with a mean heart rate of 65.3 +/- 13.9 (SD) (bpm), and noted a wide range of heart rates from 35-99 bpm and a variability of 3.4 +/- 4.1 bpm with a range of 0.4-17.5 bpm causing 2.2% non-diagnosed coronary segments during coronary CTA [15].

Tsai et al. recommended retrospective ECG-gated cardiac CT to be served as a “one-stop shop” for the evaluation of cardiac structures and functions other than only coronary arteries evaluation [12]. However, much radiation from useless cardiac phases for final interpretation will be imposed to the patients without the use of a tube current modulation technique. Further dose reduction of comprehensive CCT could be achieved in our present study by using a lower kV setting, and a relatively wide ECG pulsing window of 40-80% of the R-R interval is used to avoid the possibility of non-diagnostic images owing to heart rate variation, and to ensure that the image quality was sufficient for evaluations of coronary arteries, cardiac structures and comprehensive CCT assessment. With this modification, generally, the image quality of the coronary arteries was excellent in 93% and good in 7% of the 806 segments assessed in our study and none was considered non-diagnostic.

In a recent study, Leschka et al. reported a 25% reduction in radiation dose when lowering tube voltage from 120kV to 100kV for cardiac dual-source CT [6]. Our study with wide ECG pulsing window achieved a further reduction in radiation dose of almost 38%. It might be caused by lower heart rates in their study population resulting in lower pitch values and thus higher radiation dose. Voros S.[25] reviewed radiation doses of comprehensive cardiac CT were between 15-25 mSv with 64-slice CT. In contrary to that, there was no obvious increase of dose even in 120kV group with wide ECG modulation pulsing window.

Recently, prospectively ECG-gated coronary CTA, especially BMI-adapted, with radiation exposure at a narrowed predefined cardiac phase has been studied and the radiation dose may be further reduced to 1-3.2 mSv in patients with heart rates <63 bpm [7-10]. However, the prospectively ECG-gated method offers information only on the coronary arteries and is suitable for patients with slow and stable heart rates. It also has inherent limitations, including inconsistent contrast agent filling due to the time delay during table movement, more stair-step artifacts, and lack of functional assessment and evaluation of the cardiac valves [7-10]. Thus, the 100 kV protocol with retrospective wide ECG-gating window reduces radiation dose and allows greater flexibility in choosing the optimal cardiac phase for coronary visualization. On the other hand, combining the 100 kV protocol with prospective ECG-gating, would be the most effective approach to minimize radiation exposure (>86% reduction) if coronary arteries evaluation is the only interest [26].

In addition to descriptions relevant to congenital or acquired coronary artery disorders, CCT has increasingly been integrated in clinical practice as a comprehensive tool for assessing the pericardium, cardiac chamber and valves, cardiac functional evaluation as well as details of the aorta, pulmonary arteries and veins [12-14]. Although there are many reports of low radiation exposure using prospectively or retrospectively ECG-gated coronary CTA, the present study is the first thorough assessment of this dose-saving strategy on various cardiac image quality parameters of low tube voltage CCT in patients with normal BMI.

BMI is an important factor influencing the image quality of CT studies. A high BMI unfavorably affects image quality with poorer vessel opacification [27] and a higher tube voltage is needed to maintain a certain image quality. However, the radiation dose increases with the square of the tube voltage. Thus, adaptation of tube voltage to BMI has been suggested [6, 9, 28]. Abada et al. reported that the combined effects of low tube voltage (80 kV) and ECG-gated tube current modulation can reduce radiation exposure up to 88% in slim patients without impairing image quality, but the 80 kV setting is probably suboptimal for patients with a normal BMI [29]. Moreover, for obese patients with a high BMI, the 100 kV voltage setting results in a low CNR, and high image noise levels [30].

In the present study, we found that for patients with a normal BMI, a tube voltage of 100 kV coupled with an appropriately selected 40-80% pulsing window for tube
current modulation, which may compensate for impairment of image quality due to reduced tube voltage, seemed to be an optimal dose-saving strategy for comprehensive CCT. Our results demonstrated that the 100 kV and 120 kV groups showed no significant differences with respect to age, sex, BMI, heart rate, heart rate variability and image quality scores of the coronary arteries. The image quality scores were excellent in 89.6% and good in 10.4% of the coronary segments in the 100 kV group while the effective radiation dose (mean ± SD, 7.6 ± 0.7 vs 12.3 ± 1.5 mSv) was significantly lower than that in the 120 kV group. In addition, no coronary segment was considered non-diagnostic. Although our results attained an averaged 38.2% dose reduction, which was slightly less than those in prior reports [3-8], the present study encompassed assessment of other CCT image quality parameters. Compatible with prior reports, the mean CT-attenuation values in the aorta, left atrium, coronary arteries and left ventricle in the 100 kV group were higher than in the 120 kV group, which has been ascribed to an increase in the photoelectric effect and a decrease in Compton scattering [31]. Low kV could enhance the presence of non-calcified coronary plaques in our study (Fig. 4), but accuracy and plaque detection of low kV coronary CTA compared with invasive coronary angiography need to be further investigated. Moreover, our study revealed that even when there was a higher image noise level, the CNR and SNR in the aorta, left atrium and left ventricle, as well as the coronary arteries showed no statistically significant differences between two groups. This confirmed that comprehensive CCT with low tube voltage and a modified ECG-gated pulsing window is clinically feasible in patients with a normal BMI.

Our study has a number of limitations. First, radiation exposure was estimated and not measured. In addition, we used an arbitrary BMI threshold of 18-24 kg/m² for inclusion of patients in our study and the image quality may differ in patients with higher BMI. Also, we only evaluated image quality and not diagnostic accuracy, e.g., for the detection of coronary artery stenoses. It is not known whether sensitivity and specificity for stenosis detection would differ for scanning protocols using tube voltages of 120 kV and 100 kV. Finally, the sample size (n=52) in this study is moderate.

In conclusion, although the image noise level was higher than that in the 120 kV group, the 100 kV protocol significantly reduced the radiation dose of CCT in patients with a normal BMI while the coronary artery quality scores, CNR, SNR, and mean CT-attenuation values were not negatively affected. This imaging protocol represents a good compromise between radiation and image quality.

ACKNOWLEDGEMENT

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Figure 4. Cardiac CT angiography with low tube voltage (100 kV) reveals non-calcified plaques (white arrow) at the middle third of left anterior descending artery causing significant stenosis (A); catheter coronary angiography confirms the lesion and stenosis (white arrow) (B).
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