Abstract. The present study included a total of 111 consecutive patients who had undergone coronary computed tomography (CT) angiography, using a first-generation dual-source CT with automatic tube potential selection and tube current modulation. Body weight (BW) and body mass index (BMI) were recorded prior to CT examinations. Image noise and attenuation of the proximal ascending aorta (AA) and descending aorta (DA) at the middle level of the left ventricle were measured. Correlations between BW, BMI and objective image quality were evaluated using linear regression. In addition, two subgroups based on BMI (BMI ≤25 and >25 kg/m²) were analyzed. Subjective image quality, image noise, the signal-to-noise ratio (SNR) and the contrast-to-noise ratio (CNR) were all compared between those. The image noise of the AA increased with the BW and BMI (BW: r=0.453, P<0.001; BMI: r=0.545, P<0.001). The CNR and SNR of the AA were inversely correlated with BW and BMI, respectively. The image noise of the DA and the CNR and SNR of the DA exhibited a similar association to those with the BW or BMI. The BMI >25 kg/m² group had a significant increase in image noise (33.1±6.9 vs. 27.8±4.0 HU, P<0.05) and a significant reduction in CNR and SNR, when compared with those in the BMI ≤25 kg/m² group (CNR: 18.9±4.3 vs. 16.1±3.7, P<0.05; SNR: 16.0±3.8 vs. 13.6±3.2, P<0.05). Patients with a BMI of ≤25 kg/m² had more coronary artery segments scored as excellent, compared with patients with a BMI of >25 kg/m² (P=0.02). In conclusion, this method is not able to achieve a consistent objective image quality across the entire patient population. The impact of BW and BMI on objective image quality was not completely eliminated. BMI-based adjustment of the tube potential may achieve a more consistent image quality compared to automatic tube potential selection, particularly in patients with a larger body habitus.

Introduction
Coronary CT angiography (CTA) has become an accurate and beneficial imaging modality for the non-invasive detection of coronary artery disease (CAD) (1,2). With the increasing number of coronary CTAs performed, concerns regarding the exposure of patients to ionizing radiation have also increased (3). Numerous techniques to reduce the radiation dose by using hardware and certain acquisition protocols have been developed (4-10).

An automatic software algorithm, known as automatic tube potential selection with tube current modulation (APSCM; Siemens Healthcare, Munich, Germany), has been developed and used in coronary CTA. Tube potentials and currents are selected according to patients' anatomy and attenuation information from the initial CT topogram (11,12). Based on the topographic image, the software calculates the total tissue attenuation along the z-axis of the patient, and calculates the tube current that would be required for each of the tube potential settings on the basis of the user-defined examination type, image quality and noise preferences. The system then determines the optimal combination of tube potential and tube current to produce the desired image quality at the lowest dose per patient (in terms of volume CT dose index), and these settings are used to scan the patient. Lower tube potentials tend to apply in APSCM. A previous study reported that the use of APSCM for coronary CTA significantly reduced the radiation dose, compared with that applied in the method of tube potential modulation according to the body mass index (BMI), while maintaining the subjective image quality (13). However, a low tube voltage is accompanied with a higher image noise due to the lower X-ray beam penetration capability, particularly in obese patients. A persistent question is whether, after automatically selecting the tube potential and current, a consistent image quality may be achieved among various individuals. Thus far, only few studies have investigated the
effect of this automatic software algorithm on the consistency of image quality (13).

The purpose of the present study was to investigate the influence of the body weight (BW) and BMI on the consistency of image quality in patients undergoing coronary CTA using the APSCM method.

Materials and methods

Patients. In February 2015, a total of 120 patients with suspected CAD who were referred to the Department of Radiology of the First Affiliated Hospital of Nanjing Medical University (Nanjing, China) for coronary CTA were enrolled in this prospective study. The indications were patients with chest pain suspected of having a low-to-intermediate risk of coronary lesions, which was in accordance with current guidelines and recommendations (2). Exclusion criteria were as follows: Impaired renal function (n=3), known hypersensitivity to iodinated contrast material (n=2) and patients with arrhythmias (n=4). A total of 111 patients (51 women and 60 men; mean age, 57.3±10.8 years, median age, 57 years; range, 32-84 years) with a mean BMI of 24.7±3.1 kg/m² (range, 17.9-36.9 kg/m²) were enrolled in the present study. The institutional Review Board of the First Affiliated Hospital of Nanjing Medical University (Nanjing, China) approved the present study and informed consent was obtained from all patients.

Scan protocol. All examinations were performed using a first-generation Dual Source CT Scanner (Somatom Definition; Siemens Healthcare). All CT scans were completed in a retrospective electrocardiogram-triggered manner. Scanning parameters were as follows: Detector collimation, 2x32x0.6 mm; slice collimation, 2x64x0.6 mm by means of a z-flying focal spot; gantry rotation time, 330 msec; heart-rate adapted pitch, 0.20-0.42. β-receptor antagonists were administered when the heart rate was >90 bpm. APSCM, a commercially available automated software algorithm (Care kV and CAREDose 4D; Siemens Healthcare), was applied for the selection of tube parameters. The Care kV type setting was maintained in the ‘angiography’ position for all patients indicating a robust performance for CTA. A slice thickness of 0.75 mm with an increment of 0.5 mm and medium soft-tissue conformity between the two radiologists regarding the image assessment, consensus was reached by discussion.

Statistical analysis. Statistical analysis was performed using commercially available statistical software (SPSS v.13.0; SPSS, Inc., Chicago, IL, USA). Continuous variables are presented as the mean ± standard deviation. A simple linear regression model was used to investigate the influences of BW and BMI on the image noise, CNR and SNR. All patients were divided into two subgroups based on their BMI (BMI ≥25 or >25 kg/m²). Averages of the image noise, CNR and SNR of each of the two subgroups were compared using an independent Samples t-test. Nonparametric data were evaluated with the Mann-Whitney-U test. The inter-observer variability for subjective image quality scoring was determined by using linear weighted Cohen's kappa statistics. P<0.05 was considered to indicate a statistically significant difference.

Results

Patient characteristics and scan parameters. A total of 111 patients (60 male, 51 female; age range, 32-84 years; mean age, 57.3 years; BMI range 17.9-36.9, mean BMI 24.7 kg/m²) received CT examinations. One patient was selected 120 kV using APSCM. Patient characteristics and coronary CTA parameters are summarized in Table 1.

Objective image quality. Correlations between BW and the image noise, SNR and CNR. A moderate positive correlation was identified for the BW against Noise_{AA} (r=0.453, P<0.001) and Noise_{DA} (r=0.473, P<0.001). In addition, a weakly positive correlation was noted between BW and the image noise of
Objective image quality was substantially improved before IR was used. Although the subjective image quality was further compared in the two subgroups with different BMIs. Among the 777 segments of the smaller BMI group, 585 segments (75.29%) were scored as 4, with excellent subjective image quality. Among the 638 segments in the larger BMI group, 453 segments (71.00%) were scored as 4. Patients with a BMI of ≥25 kg/m² had more coronary artery segments scored as excellent compared with patients with a BMI of >25 kg/m² (P=0.02; Table IV).

**Discussion**

The present study indicated that the application of APSCM in coronary CTA maintains a subjective image quality, but that it cannot achieve uniform image quality among various individuals. The image noise, SNR and CNR were still correlated with the BW and BMI. Although the larger BMI group demonstrated a comparable subjective image quality to that in the smaller BMI group, the objective image quality was degraded.

APSCM assigns the optimal tube current and tube potential automatically for each patient depending on the type of study performed, the body region that is being imaged, and the patient's body habitus. It was considered that certain basic patient-specific information, including the BW and BMI, should be contributing factors in the selection of scanning parameters. In several studies, a lower tube potential (80 or 100 kV) was automatically selected for >90% patients in the APSCM group. In addition, 80 kV was selected in a small part of the cohort (11,12). In the present study, 100 kV was selected for all of the patients except one, although the BMI ranged from 17.9-36.9 kg/m². Patients with a BMI of ≥25 kg/m² accounted for ~55% of this consecutive cohort. The objective image quality, including image noise, SNR and CNR, was not consistent between individuals. The results indicated that low tube potentials tended to be more frequently selected with APSCM for radiation dose reduction. In general, the radiation dose is proportional to the tube current and the square of the tube potential. Consequently, lowering the tube voltage is one of the most effective dose reduction techniques. For coronary CTA scans, a low tube voltage increases the attenuation of iodinated contrast agents, which maintains the contrast between the vessel lumen and surrounding structures.

The present study demonstrated that the objective image quality with a reduced radiation dose was comparable to that with IR at 120 kV. The objective image quality was substantially improved before IR was used. Although the subjective image quality was further compared in the two subgroups with different BMIs. Among the 777 segments of the smaller BMI group, 585 segments (75.29%) were scored as 4, with excellent subjective image quality. Among the 638 segments in the larger BMI group, 453 segments (71.00%) were scored as 4. Patients with a BMI of ≥25 kg/m² had more coronary artery segments scored as excellent compared with patients with a BMI of >25 kg/m² (P=0.02; Table IV).

### Table I. Patient characteristics and coronary CTA parameters.

| Characteristic         | Value                          |
|------------------------|--------------------------------|
| Age (years)            | 57.3±10.8                      |
| Male sex               | 60 (54.0)                      |
| Height (cm)            | 163±9                          |
| Body weight (kg)       | 67.9±11.3                      |
| BMI (kg/m²)            | 24.7±3.1                       |
| Heart rate (beats/min) | 71.3±10.2                      |
| Tube potential (kV)    | 100:110 (99.1); 120:1 (0.9)    |
| Tube current time (mAs)| 228 (180-315)                  |
| CTDI (mGy)             | 25.7±4.8                       |
| DLP (mGy x cm)         | 370.7±71.7                     |

Values are expressed as the mean ± standard deviation, median (range) or n (%). BMI, body mass index; CTDI, computed tomography dose index; DLP, dose length product.

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and decreased CNR and SNR were observed in the APSCM group, compared with the standard dose coronary CTA.

In the subgroup analyses performed in the present study, it was also determined that the image noise in the BMI...
A previous study suggested that a higher tube current may be selected to overcome the increased image noise (21). However, a low kV cannot be used in all patients, as the tube current has limitations, and in patients with a high BMI and/or BW, the proper tube current cannot be emitted in a low-kV setting. In the present study, the objective image quality deteriorated in heavier patients. Numerous studies have indicated that advanced modeled iterative reconstruction may be used to decrease image noise (22,23). IR entails fewer assumptions regarding noise distribution with an image, and operates with an iterative process of mathematical and statistical modeling to reduce image noise. When image noise is increased in the low-kV potential, IR is an effective method to compensate for image impairment. According to our experience, the use of APS SCM combined with IR for coronary CTA allows for a reduction in radiation dose whilst maintaining the image quality. However, in the present study, only the FBP algorithm with the first-generation Dual Source CT Scanner was used.

The optimal image noise, SNR and CNR for diagnostic accuracy in coronary CTA were not fully determined in the present study. Different levels of image noise have been reported with distinct protocols. Shen et al (24) maintained the image noise at the target value of 35 HU using the noise-based tube current reduction method with IR; the SNR of the image was ~12. According to the subjective 4-point scale evaluation, all images were accepted for diagnosis in their study. In another study, an image with a higher image noise and SNR (image noise, 40 HU; SNR, 14) in the APS SCM group was also accepted as being of diagnostic image quality (12). In the present study, the image noise of the AA was 33.1±6.9 and 27.8±4.0 HU in the BMI >25 kg/m² and BMI ≤25 kg/m² subgroups, respectively, while the subjective image quality was not significantly different between these two subgroups. One possible explanation was that the subjective image quality was affected by several factors, including heart rate, image noise, contrast attenuation and calcification on the vessel walls. Subjective image quality was assessed according to the physicians’ experience and knowledge in coronary CTA. The absolute CNR and SNR are sufficiently high in coronary CTA, and thus, increased image noise does not affect the subjective judgment of images from the larger BMI subgroup. One possible explanation was that the subjective image quality was affected by several factors, including heart rate, image noise, contrast attenuation and calcification on the vessel walls.

The present study had several limitations. First, the diagnostic accuracy was not evaluated, as only a small number of patients underwent invasive coronary angiography. Furthermore, instead of IR, only the FBP algorithm was applied due to the scanner's limitation. As is known, more advanced iterative techniques further improve the image quality with substantially decreased noise. However, these techniques are currently not available on the current scanner.

### Table II. Statistical results on objective image quality.

| Variable     | Value       | BW r      | P-value | BMI r      | P-value |
|--------------|-------------|-----------|---------|------------|---------|
| Noise of AA  | 30.2±6.1    | 0.453     | <0.001  | 0.545      | <0.001  |
| CNR of AA    | 17.6±4.3    | 0.360     | <0.001  | 0.357      | <0.001  |
| SNR of AA    | 14.9±3.7    | 0.362     | <0.001  | 0.352      | <0.001  |
| Noise of DA  | 32.5±7.0    | 0.473     | <0.001  | 0.566      | <0.001  |
| CNR of DA    | 15.8±4.0    | 0.439     | <0.001  | 0.434      | <0.001  |
| SNR of DA    | 13.3±3.4    | 0.446     | <0.001  | 0.432      | <0.001  |

Values are expressed as the mean ± standard deviation. BMI, body mass index; CNR, contrast-to-noise ratio; SNR, signal-to-noise ratio; DA, descending aorta; AA, ascending aorta.

### Table III. Noise, CNR and SNR of DA and AA in the two subgroups.

| Variable     | BMI ≤25 kg/m² | BMI >25 kg/m² | P-value |
|--------------|---------------|---------------|---------|
| Noise of AA  | 27.8±4.0      | 33.1±6.9      | <0.001  |
| CNR of AA    | 18.9±4.3      | 16.1±3.7      | <0.001  |
| SNR of AA    | 16.0±3.8      | 13.6±3.2      | <0.050  |
| Noise of DA  | 29.8±6.5      | 35.9±6.1      | <0.001  |
| CNR of DA    | 17.2±4.1      | 14.2±3.3      | <0.001  |
| SNR of DA    | 14.4±3.5      | 11.9±2.8      | <0.001  |

Values are expressed as the mean ± standard deviation. BMI, body mass index; CNR, contrast-to-noise ratio; SNR, signal-to-noise ratio; DA, descending aorta; AA, ascending aorta.

### Table IV. Subjective image quality between the two subgroups.

| Image quality score | BMI ≤25 kg/m² | BMI >25 kg/m² | P-value |
|---------------------|---------------|---------------|---------|
| 1-3                 | 192 (24.7)    | 185 (29.0)    | 0.02    |
| 4                   | 585 (75.3)    | 453 (71.0)    |         |

Values are expressed as n (segments) (%). BMI, body mass index.
image noise. In addition, the objective image quality was evaluated for coronary arteries and aorta; however, the objective image quality of coronary arteries was slightly or not linearly correlated with the BW and BMI. It appears that the objective image quality of the aorta is better than that of parameters of coronary arteries due to the deviation arising from measurement. Finally, the software was only applied in a relatively small number of patients, and 100 kV was selected in the majority of them. Therefore, the objective parameters cannot be entirely matched to all possible determinants in different individuals.

In conclusion, the APSCM method in coronary CTA is not able to achieve consistent objective image quality across the entire patient population. The impact of the BW and BMI on objective image quality was not completely eliminated by APSCM. Greater image noise, and reduced CNR and SNR were recorded in patients with larger BMIs. Clinically, BMI-based adjustment of the tube potential may achieve a better, consistent image quality compared to automatic tube potential selection, particularly in patients with a larger body habitus. Combined with IR, this may resolve the inconsistency in objective image quality of coronary CTA among various individuals to a certain extent.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

XPW analyzed the patient data and drafted the manuscript. XMZ conceived and designed the study. XPW wrote the manuscript. YSZ interpreted the patient data. WYL and WWH evaluated the coronary scores. XHY contributed to data analysis. YX helped perform the analysis with constructive discussion. LJT helped interpret the results and played an important role in revising manuscript.

The final version of the manuscript has been read and approved by all authors, and each author believes that the manuscript represents honest work.

Ethical approval and consent to participate

The institutional Review Board of the First Affiliated Hospital of Nanjing Medical University (Nanjing, China) approved the present study and informed consent was obtained from all patients.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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