Original Article

Low dose contrast media in step-and-shoot coronary angiography with third-generation dual-source computed tomography: feasibility of using 30 mL of contrast media in patients with body surface area <1.7 m^2

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Background: Reducing contrast media volume in coronary computed tomography angiography minimizes the risk of adverse events but may compromise diagnostic image quality. We aimed to evaluate coronary computed tomography angiography's diagnostic image quality while using 30 mL of contrast media in patients with a body surface area <1.7 m^2.

Methods: This prospective study included patients who underwent coronary computed tomography angiography from May 2018 to June 2019. The patients were divided into a low-dose group, who received 30 mL of contrast media, and a routine-dose group, who received contrast media based on body weight. Patient characteristics, coronary computed tomography angiography results, and quantitative and qualitative image results were assessed and compared.

Results: In total, 103 patients with a body surface area <1.7 m^2 were 53 in the low-dose group and 50 in the routine-dose group. Sex, age, body surface area, body weight, and heart rate were similar between the groups (P>0.05). A contrast media volume of 30±0 mL was used for the low-dose group, and 41.62±4.59 mL was used for the routine-dose group. The low-dose group's computed tomography values were significantly different from those of the routine-dose group (P<0.05). The radiologists demonstrated agreement regarding diagnostic image quality and accuracy (kappa =0.91 and 0.85, respectively).

Conclusions: Using 30 mL of contrast media for coronary computed tomography angiography in patients with a body surface area <1.7 m^2 provided a suitable diagnostic image quality for coronary artery disease diagnosis. Although radiation doses were similar between the groups, the decreased contrast media volume was likely beneficial for the patients.

Keywords: Contrast media; coronary angiography; body surface area; coronary artery disease; computed tomography angiography

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Introduction

Advances in computed tomography (CT) imaging have allowed coronary CT angiography (CCTA) to become a reliable, noninvasive method to assess coronary anatomy, coronary artery disease, and cardiac function (1). Iodinated contrast media (ICM) are extensively used and are indispensable in CCTA and other types of radiologic imaging (2). Optimal vascular attenuation during CCTA is important for obtaining an accurate estimation of the degree of stenosis (3); however, ICM may cause post-contrast acute kidney injury, which is an important consideration in patients at risk of acute hypersensitivity reactions that may occur within 1 hour of injection (2,4). Additionally, an appropriate volume of contrast media (CM) delivered at a specific injection flow rate (IFR) to maintain a constant dose during CT should be used to avoid CM waste and to save costs associated with the fast scan times afforded by modern CT equipment (5). Decreasing both the amount of CM and the injection rate would be advantageous for patients; therefore, the optimal dosage of ICM in CCTA imaging is a topic of ongoing interest (6,7).

The primary challenge related to reduced CM dosage is the effect on diagnostic image quality (DIQ). Lowering the CM dose while maintaining a constant injection duration lowers the IFR, decreasing the iodinated delivery rate (IDR), directly influencing the DIQ of CCTA images (5). Maintaining DIQ within a satisfactory range while using a relatively low dose of ICM has been the subject of many studies (3,8-17). Vascular attenuation during CCTA is influenced by several patient-specific factors, including body mass, blood volume, cardiac output, and factors related to the procedure, such as the administered CM concentration and injection rate (18). Both blood volume and cardiac output are closely correlated with body surface area (BSA) rather than body weight (10,19), and BSA-adapted CM administration protocols have been suggested accordingly (20); however, few studies have administered CM based on the BSA. As previous studies have shown that administration of 40mL of CM to patients with a BSA <1.7 m^2, based on a BSA-adapted protocol (19), showed suitable coronary contrast enhancement, we speculated that it might be possible further to decrease the CM volume to below 40 mL. Previous studies have suggested that 30 mL of CM can be used for prospective electrocardiogram (ECG)-triggered high-pitch CCTA (8,14,21), suggesting a low CM volume in high-pitch CCTA imaging may also be feasible. To date, there have been no investigations of low-volume CM administration in patients with a BSA <1.7 m^2 who undergo CCTA with the prospective ECG-triggered sequence acquisition scan mode [step-and-shoot (SAS), CCTA]. SAS acquisition has a longer scan time and allows for a higher heart rate (HR) than high-pitch scanning (22,23).

We hypothesized that 30 mL of CM would provide a sufficient DIQ for CCTA images in patients with a BSA <1.7 m^2. This study aimed to investigate the effects of 30 mL of CM on the DIQ of SAS CCTA images in patients with a BSA <1.7 m^2.

Methods

Patient population

A total of 103 patients were prospectively enrolled at our hospital from May 2018 to June 2019. This study was approved by the Ethics Committee of Huadong Hospital (No. 2019K005) and was conducted following the Declaration of Helsinki (1964). Written informed consent was obtained from all patients. The inclusion criteria were as follows: age 18 years or older, clinically suspected coronary heart disease in patients who had undergone CCTA, and a BSA <1.7 m^2. The exclusion criteria were as follows: cardiopulmonary insufficiency, renal insufficiency, allergy to CM, prior stent or coronary artery bypass graft, inability to complete breath-holding for 10 s, and a history of using medicine to control HR (*Figure 1*).

BSA was calculated according to the Stevenson formula: BSA (m^2) = 0.0061 × height (cm) + 0.0128 × weight (kg) — 0.1529 (24). The first 53 patients were enrolled in the low-dose (LD) group, and the next 50 participants were enrolled in the routine-dose (RD) group. The LD group received 30 mL of CM and 60 mL of saline at an IFR of 3.5 mL/s; the RD group was administered CM according to their weight (0.7 mL/kg) (11). The IFR of the CM for the RD group was calculated as the volume divided by 10 s, consistent with the IFR of saline. Beta-blockers and nitroglycerin were not administered before scanning.

Image acquisition

A third-generation dual-source CT scanner (Somatom Force, Siemens Healthcare) was used for the CCTA scans. A prospective ECG-triggered sequence acquisition mode, SAS, was used to scan in a cranial-to-caudal direction. The automated anatomical tube current modulation technique with 320 mA (CARE Dose 4D^{TM}, Siemens Healthineers) and automatic tube voltage selection with 100 kV (ATVS,

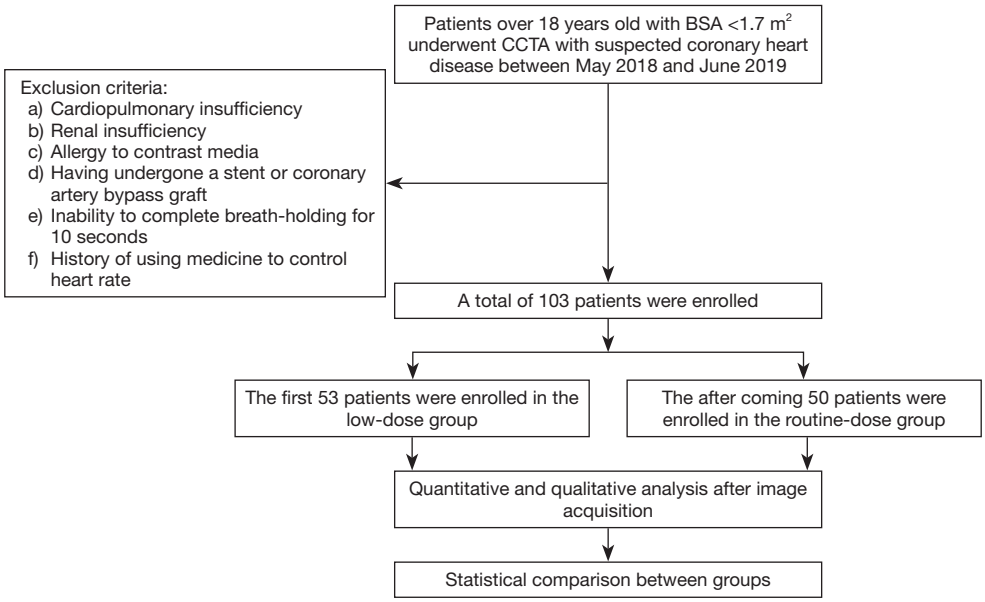

Figure 1 Flow diagram of the patients involved in this study. CCTA, coronary computed tomography angiography; CM, contrast media.

CAREkV^{TM}, Siemens Healthineers) were used. The exposure dose (ECG-pulsing) range was set at 30–80% for the R-R interval. The collimator was 2*(64-96)*0.6 mm, and the gantry rotation time was 0.25 s/rotation. The bolus tracking technique was used for threshold monitoring at the aortic root, with an enhancement threshold of 80 HU and a delay time of 7 s. The slice thickness and image reconstruction interval were both 0.75 mm, and the kernel used was Bv36. Pre-warmed CM [iobitridol, 350 mg iodine (mgI)/mL] was injected using an 18-G closed intravenous catheter system with an Ulrich high-pressure syringe. The IDR was defined as the iodine concentration of CM multiplied by the IFR when injected into the vessel (5).

Quantitative and qualitative analyses

The CT values and standard deviations (SDs) of the luminal segment of the aortic root (AO), proximal left main coronary artery (LMCA-P), middle left anterior descending artery (LAD-M), distal left anterior descending artery (LAD-D), middle left circumflex artery (LCX-M), distal left circumflex artery (LCX-D), proximal right coronary artery (RCA-P), middle right coronary artery (RCA-M), distal right coronary artery (RCA-D), and perivascular adipose tissues (PVAT) were separately measured. The SD of the AO was considered as image noise. The size of the region of interest (ROI) of the AO was set at 90 mm^2, and the others at 1 mm^2. The following equations were used: signal-to-noise ratio (SNR) = CT value of the ROI/noise; and contrast-to-noise ratio (CNR) = (CT value within the ROI – CT value of the PVAT)/SD of the PVAT.

A quality evaluation was performed by two radiologists (a radiologist with 8 years of experience performing cardiovascular diagnosis and a senior radiologist with more than 15 years of experience). Double-blinded scoring was performed using a scale from 1 to 5: 1, poor opacification insufficient for diagnosis; 2, suboptimal opacification with low diagnostic confidence; 3, acceptable opacification sufficient for diagnosis; 4, good opacification of proximal and distal segments; and 5, excellent opacification of proximal and distal segments. Scores for the RCA, LCA (including LMCA-P, LAD-M, and LAD-D), and LCX were integrated, and subjective scores of ≥3 points were considered sufficient DIQ standard.

Diagnostic accuracy

The presence of stenosis >50% in the three main coronary arteries (LAD, LCX, and RCA) was assessed by the two radiologists mentioned above on a per-segment, per-vessel, and per-patient level using the 16-segment American Heart Association classification. A final consensus read was performed to evaluate the consistency in interpretation between the two observers.

Radiation dose

CCTA radiation dose was recorded, while the radiation doses associated with the scout view, calcium score scan, and the automatic bolus tracking technique were omitted. The dose-length product (DLP) and volume CT dose index (CTDIvol) were automatically provided by the CT scanner. The effective dose was estimated by multiplying the DLP by a factor of 0.014 mSv/(mGy × cm) (8).

Statistical analysis

SPSS 22.0 statistical software (IBM, Armonk, NY) was used for analyses. Quantitative indexes were presented as mean ± SD or as a median (minimum, maximum). The independent samples t-test or Mann-Whitney U test was performed to analyze statistically significant differences between groups. Categorical data were presented as frequencies and percentages and were compared using the chi-squared test. Linear regression analysis was performed to correlate BSA and CT values of all coronary segments in each group. All statistical tests were two-sided, and P values <0.05 were considered statistically significant. Kappa statistics were used to evaluate the consistency of the observers. The kappa values were categorized as follows: <0.20, almost inconsistent; 0.21–0.40, slightly consistent; 0.41–0.60, medium consistency; 0.61–0.80, good consistency; and 0.81–1.00, almost perfect consistency (25).

Results

Patient characteristics are shown in *Table 1*. The volume (30 mL) and IFR (3.5 mL/s) of CM, volume (60 mL) and IFR (3.5 mL/s) of saline, and IDR (1.23 gI/s) of the LD group were significantly lower than those of the RD group (41.62±4.59 mL, 30 mL, 4.13±0.45 mL/s, and 1.45±0.16 gI/s, respectively; P<0.001).

CT values of all measured vessel segments of the LD group were significantly different from those of the RD group (P<0.05). SNR values of the LMCA-P [12.71 (0.57, 64.46)], LAD-D [5.79 (1.59, 15.15)], and LCX-D [7.52 (1.55, 30.98)] were significantly lower in the LD group than in the RD group [21.31 (8.25, 57.80), 9.26 (2.96, 20.74), and 12.19 (4.20, 33.71), respectively]. Inter-rater reliability for the experienced radiologist showed almost perfect scoring consistency for quality (kappa =0.91), and the results of the senior radiologist were used for further analyses. Qualitative analysis of the RCA, LCA, and LCX showed significant differences between groups, but the images showed sufficient DIQ (*Table 2*).

To compare the diagnostic accuracy of stenosis between groups, four patients (five main coronary arteries) in the LD group and seven patients (seven main coronary arteries) in the RD group were assessed. As there was good inter-rater reliability between the two radiologists for image accuracy (kappa =0.85), the senior radiologist's results were used for further analyses.

Discussion

Despite recent reports that CM risk may be overstated (26), the updated guidelines recommend using the lowest CM dose (27). Previous studies have demonstrated that lower CM volumes and injection speeds reduce the incidence of acute hypersensitivity reactions to non-ionic ICM (4,28). The present study demonstrated that CM volume could be reduced to 30 mL in patients with a relatively low BSA while retaining 100% acceptable DIQ (*Figure 2*). This is consistent with the findings of previous studies worldwide (3,9-12,14-16,29-32), which have focused on optimizing CM dosage to achieve DIQ with CCTA. Feng *et al.* (15) demonstrated successful imaging using a total of 28 mL CM (370 mgI/mL) with an IFR of 3.5 mL/s in prospective high-pitch CCTA; therefore, the successful use of 30 mL CM for CCTA imaging should not be surprising. Furthermore, several studies (8,14,21) have demonstrated successful high-pitch CCTA with 30 mL of CM. The study by Feng *et al.* (15) involved patients with a body mass index (BMI) <26 kg/m^2 and achieved an IDR of 1.295 gI/s (370 mgI/mL × 3.5 mL/s). Jia *et al.* (8) achieved an IDR of 1.2 gI/s (300 mgI/mL × 4 mL/s), while Zhang *et al.* (21) conducted a study involving 44 patients and achieved an IDR of 1.48 gI/s (370 mgI/mL × 4 mL/s). Furthermore, Wang *et al.* (14) achieved an IDR of 1.85 gI/s (370 mgI/mL × 5 mL/s). Our study demonstrated the lowest IFR, 3.5 mL/s, and achieved the second-lowest IDR, 1.225 gI/s, without compromising the DIQ. Furthermore, our study is the first to demonstrate that 30 mL of CM for SAS CCTA can result in a satisfactory DIQ, which has not been reported previously for patients with a BSA <1.7 m^2. High-pitch CCTA is beneficial as it involves the lowest radiation exposure and has the fastest scan time compared to SAS acquisition; however, SAS acquisition can be performed for patients with a higher HR (<100 bpm) (23), whereas high-pitch CCTA strictly requires an HR of <75 bpm (22).

Yi *et al.* designed a study that included 30 patients with

Table 1 Baseline characteristics of patients with a BSA <1.7 m^2

Characteristic	Low-dose group (N=53)	Routine-dose group (N=50)	P
Sex, n (%)			
Male	8 (15.1%)	13 (26%)	0.170
Female	45 (84.9%)	37 (74%)	
Age (years), mean ± SD	64.18±10.82	64.62±11.33	0.844
Height (cm), mean ± SD	158.92±6.81	159.42±6.12	0.699
Weight (kg), mean ± SD	55.34±6.11	57.78±6.72	0.056
BMI (kg/m^2), n (%)			0.138
<20	10 (18.9%)	7 (14.0%)	
20–25	36 (67.9%)	35 (70%)	
25–30	7 (13.2%)	7 (14%)	
≥30	0 (0%)	1 (2%)	
BSA (m^2), mean ± SD	1.52±0.10	1.56±0.10	0.110
Heart rate (bpm), mean ± SD	69.47±10.78	72.24±10.63	0.421
<75	35 (66.0%)	29 (58%)	
≥75	18 (34.0%)	21 (42%)	
Contrast medium (mL), mean ± SD	30±0	41.62±4.59	<0.001*
Saline (mL), mean ± SD	60±0	30±0	NA
Flow rate (mL/s), mean ± SD	3.50±0	4.13±0.45	<0.001*
Iodine delivery rate (gI/s), mean ± SD	1.23±0	1.45±0.16	<0.001*
Tube voltage (kV)			0.306
70	27 (50.9%)	27 (54%)	0.240
80	21 (39.6%)	13 (26%)	
90	3 (5.7%)	4 (8%)	
100	1 (1.9%)	4 (8%)	
110	1 (1.9%)	0	
120	0	2 (4%)	
DLP (mGy × cm), mean ± SD	180.49±62.18	189.82±105.08	0.588
Effective dose (mSv), mean ± SD	2.53±0.87	2.66±1.47	0.588
CTDIvol (mGy), mean ± SD	18.90±7.08	19.70±11.59	0.671
CM injection time (s), mean ± SD	8.57±0	10±0	NA
Total injection time (s), mean ± SD	25.71±0	17.18±0.89	<0.001*

*, significant difference. BMI, body mass index; BSA, body surface area; CM, contrast media; CTDIvol, CT dose index volume; DLP, dose-length product; SD, standard deviation.

Table 2 Comparison of quantitative and qualitative analyses using CCTA

	Low-dose group (N=53)	Routine-dose group (N=50)	P
CT values (HU)			
AO	550.24±115.46	631.19±114.41	0.001*
LMCA-P	524.06±111.15	596.98±110.74	0.001*
LAD-M	318.22±113.6	473.19±93.58	<0.001*
LAD-D	195.48±79.26	332.93±94.65	<0.001*
LCX-M	437.32±98.09	511.75±97.18	<0.001*
LCX-D	262.63±89.29	350.92±86.08	<0.001*
RCA-P	506.13±119.93	585.31±114.38	0.001*
RCA-M	423.4±106.1	515.01±119.64	<0.001*
RCA-D	370.04±111.74	455.84±122.64	<0.001*
PVAT	−130.43±21.27	−125.13±31.89	0.327
SNR values			
AO	22.36 (14.38, 50.29)	21.17 (13.69, 38.25)	0.328
LMCA-P	46.03 (13.71, 145.01)	46.53 (13.86, 86.72)	0.926
LAD-M	12.71 (0.57, 64.46)	21.31 (8.25, 57.80)	<0.001*
LAD-D	5.79 (1.59, 15.15)	9.26 (2.96, 20.74)	<0.001*
LCX-M	22.15 (3.79, 73.24)	24.60 (7.25, 64.44)	0.370
LCX-D	7.52 (1.55, 30.98)	12.19 (4.20, 33.71)	<0.001*
RCA-P	37.63 (10.00, 126.92)	45.69 (15.35, 109.84)	0.090
RCA-M	28.50 (6.99, 83.67)	29.74 (4.44, 76.72)	0.719
RCA-D	15.16 (3.75, 48.21)	19.01 (3.34, 74.70)	0.101
CNR values			
AO	75.66 (19.86, 232.22)	69.47 (19.95, 177.15)	0.248
LMCA-P	75.54 (17.65, 232.80)	66.42 (18.60, 176.51)	0.233
LAD-M	51.38 (15.19, 188.05)	55.00 (15.93, 129.92)	0.539
LAD-D	37.37 (10.46, 173.87)	41.78 (12.86, 119.91)	0.356
LCX-M	64.57 (19.66, 193.97)	58.50 (15.07, 138.95)	0.352
LCX-D	43.53 (14.66, 113.25)	43.65 (10.47, 116.50)	0.978
RCA-P	73.79 (18.99, 189.31)	65.09 (19.31, 176.58)	0.240
RCA-M	63.50 (17.49, 157.53)	58.19 (16.63, 155.09)	0.399
RCA-D	56.86 (16.78, 154.02)	51.89 (15.97, 120.18)	0.362
Qualitative score (5-point scale), median (IQR)			
QIA-RCA	5 (5, 5)	5 (4.5, 5)	<0.001*
QIA-LCA	5 (4, 5)	4 (4, 4.5)	0.003*
QIA-LCX	5 (4, 5)	4.25 (4, 4.5)	<0.001*
Meeting diagnostic quality	53 (100%)	50 (100%)	0.299

*, the asterisk represents a significant difference. AO, aortic root; CCTA, coronary CT angiography; CNR, contrast-to-noise ratio; CT, computed tomography; IQR, interquartile range; LAD-D, distal left anterior descending; LAD-M, middle left anterior descending; LCA, left coronary artery; LCX, left circumflex; LCX-D, distal left circumflex; LCX-M, middle left circumflex; LMCA-P, proximal left main coronary artery; PVAT, perivascular adipose tissue; QIA, quality image assessment; RCA, right coronary artery; RCA-D, distal coronary right artery; RCA-M, middle right coronary artery; RCA-P, proximal right coronary artery; SNR, signal-to-noise ratio.

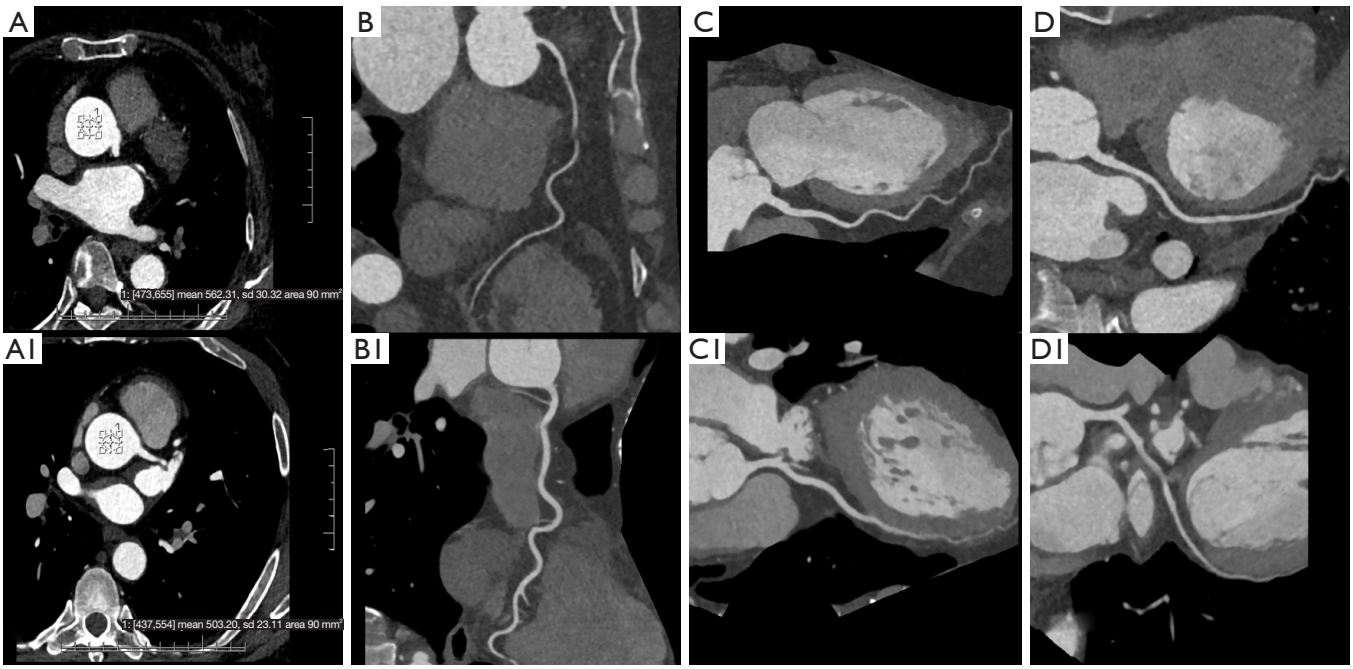

Figure 2 (A-D) A 67-year-old female patient with chest pain and a body surface area (BSA) of 1.60 m^2, body mass index (BMI) of 28.51 kg/m^2, 30 mL of contrast media (CM), and a flow rate of 3.5 mL/s. (A) The computed tomography (CT) value of the opening of the coronary sinus was 562 HU. Curved planar reconstruction images of the right coronary artery (B), left anterior descending artery (C), and left circumflex artery (D) are shown. (A1-D1) A 43-year-old male patient with chest pain with a BSA of 1.68 m^2, BMI of 28.89 kg/m^2, 59.5 mL of CM, and a flow rate of 5.5 mL/s. (A1) The CT value of the opening of the coronary sinus was 503 HU. Curved planar reconstruction images of the right coronary artery (B1), left anterior descending artery (C1), and left circumflex artery (D1) are shown.

a limited BMI (20–25 kg/m^2) using 36 mL of CM with an IDR of 1.11 gI/s (370 mgI/mL ×3 mL/s) (9). Qu *et al.* demonstrated a shortened injection duration with 36.2 mL of CM and an IFR of 4.5±0.71 mL/s (12). Furthermore, Andreini *et al.* performed CCTA with an ultra-low CM concentration (80 mL bolus) and an IDR of 1.35 gI/s (iodixanol, 270 mgI/mL ×5 mL/s) (16). Therefore, our study demonstrated the lowest CM dose compared to recent studies involving SAS acquisition.

Injection protocols for CCTA involve titration of CM dose based on individual patient characteristics, including adjustments related to patient BSA and blood volume (10,29,30,33). Pazhenkottil *et al.* adapted a BSA protocol and demonstrated that a significantly lower amount of CM might help prevent contrast-induced nephropathy and its consequences (18,19); however, CM remained in the right heart chambers of patients with a BSA <1.7 m^2 when using 40 mL, indicating that CM volume could possibly be reduced even further. In the present study, the CM volume of 40 mL was only reduced by 25% to 30 mL (19); however, this was a great challenge during SAS CCTA imaging, which requires a longer acquisition time compared to high-pitch helical scanning (14,15,17,22). Furthermore, 10 mL of CM with an IFR of 3.5 mL/s was sufficient to maintain vessel enhancement within 3 s, but only if the acquisition time was 3 s longer than that reported in the study by Pazhenkottil *et al.* (19), whose 40 mL dosage for patients with a BSA <1.7 m^2 was unsuccessful. The present study postulated that a further reduction in CM to less than 30 mL could be investigated with decreasing BSA.

HR is another factor that influences both acquisition time and CCTA enhancement (23,33,34). When HR decreases during SAS acquisition—especially when it is <60 bpm—the acquisition time required for the end-diastole phase is longer, increasing the total exposure time (35,36). This makes it difficult to maintain the target blood vessel enhancement with a CM volume of 30 mL. In the study by Pazhenkottil *et al.*, the mean HR of patients who underwent the examination was 56±7 bpm, with a maximum of 74 bpm (19). The higher temporal resolution of the

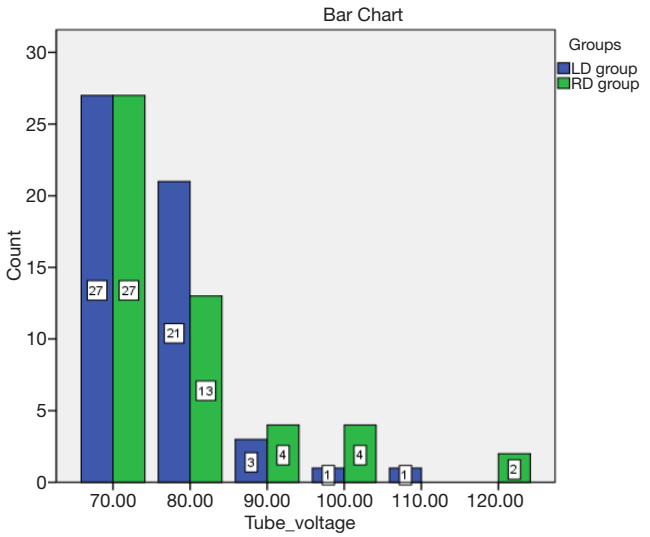

Figure 3 Distribution of tube voltages of all patients in both groups. LD, low dose; RD, regular dose.

third-generation dual-source CT used in our study (8) allowed for examining patients with an 18.8% higher average HR (69.47±10.78 bpm), with 34% of HRs in the LD group higher than 75 bpm. Zhu *et al.* reported that an increased HR resulted in increased cardiac output, leading to decreased CM attenuation in the coronary arteries, which was consistent with Tang *et al.* (37,38) findings. Therefore, BSA-based injection protocols' ability to provide an appropriate enhancement in higher HR patients is of clinical interest. Our study included 18 patients (34.0%) in the LD group and 21 patients (38.9%) in the RD group with an HR >75 bpm; as the differences between groups were not significant between groups, we assume that this method was successful for patients with an HR >75 bpm.

The body weight-adjusted protocol of the RD group has been used for the LD group in other studies (39-42). All CT values of measured vessel segments in our LD group were lower than those in the RD group, which may be explained by the significantly lower IDR (1.23 gI/s) of the LD group compared with the RD group (1.45 gI/s) and the fact that IDR is the main determinant of vessel contrast enhancement in CCTA (29). Our study demonstrated that the IDR associated with satisfactory DIQ in both groups was lower than 1.5–2.0 gI/s, which is usually recommended for CCTA (29). The SNR and CNR values showed similar image quality between groups, except for the SNR values of the LAD-M, LAD-D, and LCX-D, thus explaining why the CCTA images were reported to have equal DIQ even though the CT values were better in the RD group. The excellent inter-rater reliability for diagnosis of stenosis >50% may also explain why the LD group had comparable diagnostic accuracy compared to the RD group. Using a lower tube voltage (<80 kVp) may have also improved image quality because of the lower average energy closer to the K-edge of iodine (33.2 keV) (5,13). The distribution of tube voltages (*Figure 3*) showed that >80% of patients in the LD group were scanned using 80 kV with a lower IDR (1.23 gI/s), resulting in better CT, SNR, and CNR values than those reported by Feng *et al.*, who used 28 mL with an IDR of 1.295 gI/s and 70 kV (15). The inverse correlation between CT values and BSA in the LD group showed that CT values of most measured segments decreased when the BSA increased, whereas the RD group had homogeneous CT values (*Figure 4*), indicating that patients with a BSA <1.7 m^2 could still benefit from a personalized protocol based on 30 mL of CM; the smaller the BSA, the lower the volume required (≤30 mL). The inverse correlation between CNR and BSA in the RD group may explain the higher qualitative score of the LD group, as the CNR of the LD group did not decrease with increased BSA.

There were several possible limitations of our patient population. Patients who had undergone a coronary artery bypass graft were excluded because they underwent CCTA with a larger scanning range (usually twice that of patients without a bypass). Patients who were unable to hold their breath for 10 s were also excluded because breathing artifacts worsen the DIQ. Patients who had a history of pharmaceutical HR control were excluded because the present study aimed to investigate SAS acquisition, which allows for higher HR.

Several other limitations existed in this study. As a single-center study, the sample size was small; a larger, multi-center study would provide stronger evidence for these results. The radiation doses for both groups in this study were slightly higher than normal because the range of exposure (ECG-pulsing) was set at 30–80% for the R-R interval; therefore, future research should reduce the exposure time without affecting the conclusions of this study. Furthermore, grouping patients with a BSA <1.7 m^2 might not have been sufficiently personalized, and stratification based on BSA could be used in the future to explore the possibility of further contrast dose adjustment through both delivery rate and volume changes. More studies are required to establish whether a BSA-adjusted method might reduce the incidence of contrast-induced adverse events. Finally, the contrast dose associated with a

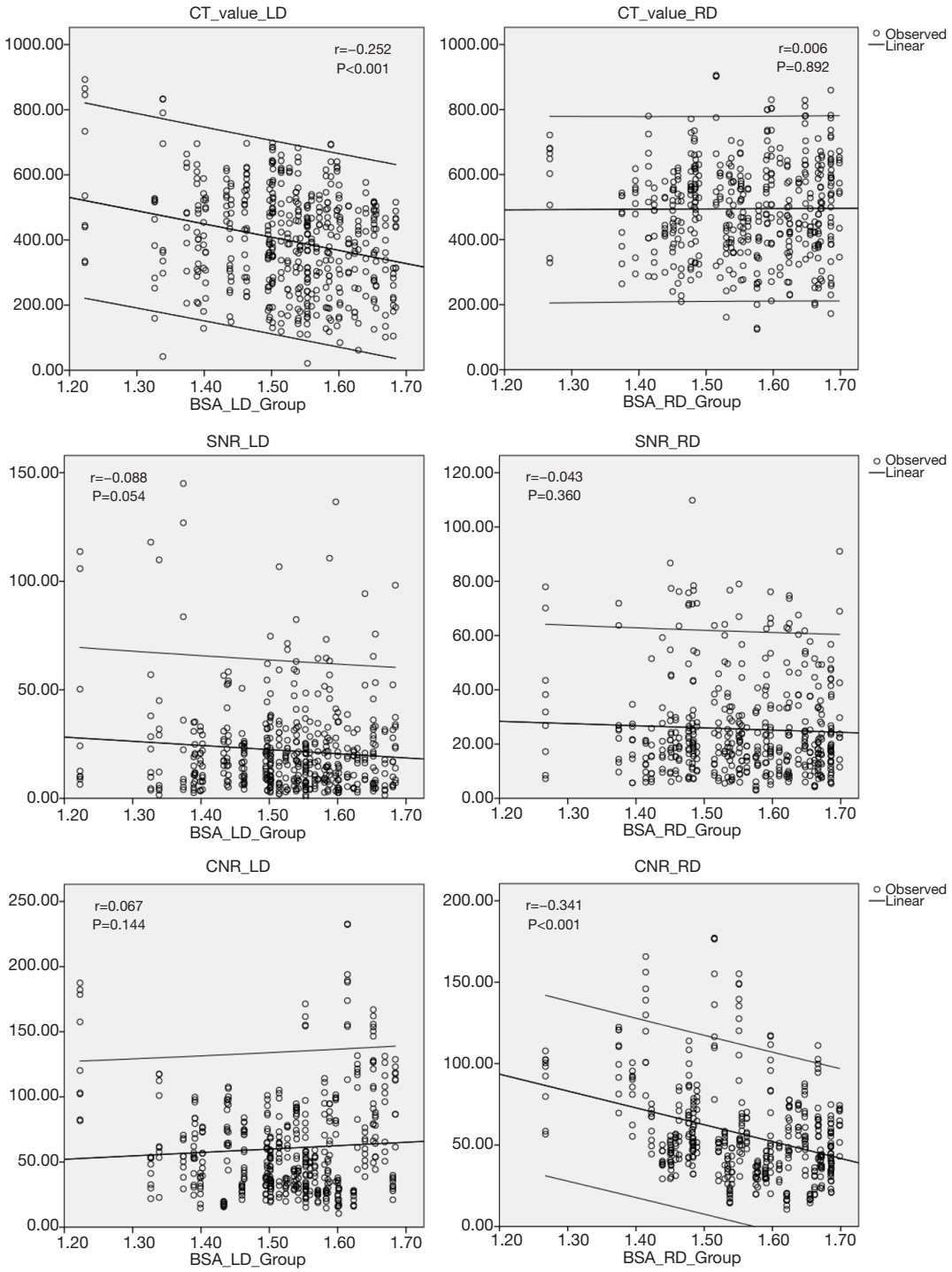

Figure 4 Correlations among computed tomography (CT), signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) values and body surface area (BSA) for the two groups. LD, low dose; RD, regular dose.

reduced ICM dose and/or injection speed requires further investigation (43,44).

Conclusions

In conclusion, using a CM volume of 30 mL for patients with a BSA <1.7 m^2 was appropriate for SAS CCTA with a third-generation dual-source CT and showed suitable DIQ for diagnosis.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/qims-20-500). The authors have no conflicts of interest to declare.

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References

1. Leipsic J, Abbara S, Achenbach S, Cury R, Earls JP, Mancini GJ, Nieman K, Pontone G, Raff GL. SCCT guidelines for the interpretation and reporting of coronary CT angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee. J Cardiovasc Comput Tomogr 2014;8:342-58.
2. Timal RJ, Kooiman J, Sijpkens YWJ, de Vries JPM, Verberk-Jonkers IJAM, Brulez HFH, van Buren M, van der Molen AJ, Cannegieter SC, Putter H, van den Hout WB, Jukema JW, Rabelink TJ, Huisman MV. Effect of no prehydration vs sodium bicarbonate prehydration prior to contrast-enhanced computed tomography in the prevention of postcontrast acute kidney injury in adults with chronic kidney disease: the Kompas randomized clinical trial. JAMA Intern Med 2020;180:533-541.
3. Zhu X, Yu Y, Xu D, Zhang H, Tang L. Coronary angiography using second-generation dual source computed tomography: feasibility of low dose and low flow rate to achieve appropriate individual contrast enhancement using a test bolus-based contrast medium protocol-A CONSORT compliant article. Medicine (Baltimore) 2018;97:e11425.
4. Park HJ, Son JH, Kim TB, Kang MK, Han K, Kim EH, Kim AY, Park SH. Relationship between lower dose and injection speed of iodinated contrast material for CT and acute hypersensitivity reactions: an observational study. Radiology 2019;293:565-72.
5. Faggioni L, Gabelloni M. Iodine concentration and optimization in computed tomography angiography: current issues. Invest Radiol 2016;51:816-22.
6. Nijssen EC, Rennenberg RJ, Nelemans PJ, Essers BA, Janssen MM, Vermeeren MA, Ommen VV, Wildberger JE. Prophylactic hydration to protect renal function from intravascular iodinated contrast material in patients at high risk of contrast-induced nephropathy (AMACING): a prospective, randomised, phase 3, controlled, open-label, non-inferiority trial. Lancet 2017;389:1312-22.
7. Kooiman J, Sijpkens YW, van Buren M, Groeneveld JH, Ramai SR, van der Molen AJ, Aarts NJ, van Rooden CJ, Cannegieter SC, Putter H, Rabelink TJ, Huisman MV. Randomised trial of no hydration vs. sodium bicarbonate hydration in patients with chronic kidney disease undergoing acute computed tomography-pulmonary angiography. J Thromb Haemost 2014;12:1658-66.
8. Jia CF, Zhong J, Meng XY, Sun XX, Yang ZQ, Zou YJ, Wang XY, Pan S, Yin D, Wang ZQ. Image quality and diagnostic value of ultra low-voltage, ultra low-contrast coronary CT angiography. Eur Radiol 2019;29:3678-85.
9. Yi Y, Zhao XM, Wu RZ, Wang Y, Vembar M, Jin ZY, Wang YN. Low dose and low contrast medium coronary

CT angiography using dual-layer spectral detector CT. Int Heart J 2019;60:608-17.
10. Yu Y, Yin W, Liao K, Liu T, Wang X, Sun K, Lu B. Individualized contrast agents injection protocol tailored to body surface area in coronary computed tomography angiography. Acta Radiol 2019;60:1430-7.
11. Tang Z. Application of double low dose combined low flow injection in coronary dual-source coronary computed tomography angiography. Echocardiography 2018;35:1442-7.
12. Qu TT, Li JY, Jiao XJ, Zhang XL, Song ZF, Guo YX, Guo JX. Contrast dose reduction with shortened injection durations in coronary CT angiography on 16-cm Wide-detector CT scanner. Br J Radiol 2018;91:20180580.
13. Kim SY, Cho JY, Lee J, Hwang SI, Moon MH, Lee EJ, Hong SS, Kim CK, Kim KA, Park SB, Sung DJ, Kim Y, Kim YM, Jung SI, Rha SE, Kim DW, Lee H, Shim Y, Hwang I, Woo S, Choi HJ. Low-tube-voltage CT urography using low-concentration-iodine contrast media and iterative reconstruction: a multi-institutional randomized controlled trial for comparison with conventional CT urography. Korean J Radiol 2018;19:1119-29.
14. Wang W, Zhao YE, Qi L, Li X, Zhou CS, Zhang LJ, Lu GM. Prospectively ECG-triggered high-pitch coronary CT angiography at 70 kVp with 30mL contrast agent: an intraindividual comparison with sequential scanning at 120 kVp with 60mL contrast agent. Eur J Radiol 2017;90:97-105.
15. Feng R, Tong J, Liu X, Zhao Y, Zhang L. High-pitch coronary CT angiography at 70 kVp adopting a protocol of low injection speed and low volume of contrast medium. Korean J Radiol 2017;18:763-72.
16. Andreini D, Mushtaq S, Conte E, Segurini C, Guglielmo M, Petullà M, Volpato V, Annoni A, Baggiano A, Formenti A, Bartorelli AL, Fiorentini C, Pepi M. Coronary CT angiography with 80 kV tube voltage and low iodine concentration contrast agent in patients with low body weight. J Cardiovasc Comput Tomogr 2016;10:322-326.
17. Lu GM, Luo S, Meinel FG, McQuiston AD, Zhou CS, Kong X, Zhao YE, Zheng L, Schoepf UJ, Zhang LJ. High-pitch computed tomography pulmonary angiography with iterative reconstruction at 80 kVp and 20 mL contrast agent volume. Eur Radiol 2014;24:3260-8.
18. van der Wall EE, van Velzen JE, de Graaf FR, Boogers MM, Schuijf JD, Bax JJ. Increased accuracy in computed tomography coronary angiography; a new body surface area adapted protocol. Int J Cardiovasc Imaging 2010;26:601-4.
19. Pazhenkottil AP, Husmann L, Buechel RR, Herzog BA, Nkoulou R, Burger IA, Vetterli A, Valenta I, Ghadri JR, von Schulthess P, Kaufmann PA. Validation of a new contrast material protocol adapted to body surface area for optimized low-dose CT coronary angiography with prospective ECG-triggering. Int J Cardiovasc Imaging 2010;26:591-7.
20. Herzog BA, Husmann L, Valenta I, Tay FM, Burkhard N, Gaemperli O, Wyss CA, Landmesser U, Kaufmann PA. Determinants of vessel contrast in BMI-adapted low dose CT coronary angiography with prospective ECG-triggering. Int J Cardiovasc Imaging 2009;25:625-30.
21. Zhang LJ, Wang Y, Schoepf UJ, Meinel FG, Bayer RR 2nd, Qi L, Cao J, Zhou CS, Zhao YE, Li X, Gong JB, Jin Z, Lu GM. Image quality, radiation dose, and diagnostic accuracy of prospectively ECG-triggered high-pitch coronary CT angiography at 70 kVp in a clinical setting: comparison with invasive coronary angiography. Eur Radiol 2016;26:797-806.
22. Gordic S, Husarik DB, Desbiolles L, Leschka S, Frauenfelder T, Alkadhi H. High-pitch coronary CT angiography with third generation dual-source CT: limits of heart rate. Int J Cardiovasc Imaging 2014;30:1173-9.
23. Brodoefel H, Burgstahler C, Tsiflikas I, Reimann A, Schroeder S, Claussen CD, Heuschmid M, Kopp AF. Dual-source CT: effect of heart rate, heart rate variability, and calcification on image quality and diagnostic accuracy. Radiology 2008;247:346-55.
24. Stevenson PH. Height-weight-surface formula for the estimation of surface area in Chinese subjects. Chinese J Physiol 1937;12:327-34.
25. Yin WH, Lu B, Li N, Han L, Hou ZH, Wu RZ, Wu YJ, Niu HX, Jiang SL, Krazinski AW, Ebersberger U, Meinel FG, Schoepf UJ. Iterative reconstruction to preserve image quality and diagnostic accuracy at reduced radiation dose in coronary CT angiography: an intraindividual comparison. JACC Cardiovasc Imaging 2013;6:1239-49.
26. McDonald RJ, McDonald JS, Newhouse JH, Davenport MS. Controversies in contrast material-induced acute kidney injury: closing in on the truth? Radiology 2015;277:627-32.
27. Nyman U, Ahlkvist J, Aspelin P, Brismar T, Frid A, Hellström M, Liss P, Sterner G, Leander P; Contrast Media Committee of the Swedish Society of Uroradiology and in collaboration with the Swedish Society of Nephrology (GS) and the Swedish Society of Diabetology (AF). Preventing contrast medium-induced acute kidney

injury: side-by-side comparison of Swedish-ESUR guidelines. Eur Radiol 2018;28:5384-95.
28. Li X, Liu H, Zhao L, Liu J, Cai L, Liu L, Zhang W. Clinical observation of adverse drug reactions to non-ionic iodinated contrast media in population with underlying diseases and risk factors. Br J Radiol 2017;90:20160729.
29. Tan SK, Ng KH, Yeong CH, Raja Aman RRA, Sani FM, Abdul Aziz YF, Sun Z. Personalized administration of contrast medium with high delivery rate in low tube voltage coronary computed tomography angiography. Quant Imaging Med Surg 2019;9:552-64.
30. Eijsvoogel NG, Hendriks BMF, Willigers JL, Martens B, Carati LF, Horehledova B, Kietselaer BLJH, Crijns HJGM, Wildberger JE, Das M. Personalization of injection protocols to the individual patient's blood volume and automated tube voltage selection (ATVS) in coronary CTA. PLoS One 2018;13:e0203682.
31. Lell MM, Fleischmann U, Pietsch H, Korporaal JG, Haberland U, Mahnken AH, Flohr TG, Uder M, Jost G. Relationship between low tube voltage (70 kV) and the iodine delivery rate (IDR) in CT angiography: an experimental in-vivo study. PLoS One 2017;12:e0173592.
32. Achenbach S, Paul JF, Laurent F, Becker HC, Rengo M, Caudron J, Leschka S, Vignaux O, Knobloch G, Benea G, Schlosser T, Andreu J, Cabeza B, Jacquier A, Souto M, Revel D, Qanadli SD, Cademartiri F; X-ACT Study Group. Comparative assessment of image quality for coronary CT angiography with iobitridol and two contrast agents with higher iodine concentrations: iopromide and iomeprol. A multicentre randomized double-blind trial. Eur Radiol 2017;27:821-830.
33. Bae KT, Seeck BA, Hildebolt CF, Tao C, Zhu F, Kanematsu M, Woodard PK. Contrast enhancement in cardiovascular MDCT: effect of body weight, height, body surface area, body mass index, and obesity. AJR Am J Roentgenol 2008;190:777-84.
34. Husmann L, Alkadhi H, Boehm T, Leschka S, Schepis T, Koepfli P, Desbiolles L, Marincek B, Kaufmann PA, Wildermuth S. Influence of cardiac hemodynamic parameters on coronary artery opacification with 64-slice computed tomography. Eur Radiol 2006;16:1111-6.
35. Paul JF, Amato A, Rohnean A. Low-dose coronary-CT angiography using step and shoot at any heart rate: comparison of image quality at systole for high heart rate and diastole for low heart rate with a 128-slice dual-source machine. Int J Cardiovasc Imaging 2013;29:651-7.
36. Earls JP. How to use a prospective gated technique for cardiac CT. J Cardiovasc Comput Tomogr 2009;3:45-51.
37. Zhu X, Chen W, Li M, Xu Y, Xu H, Zhu Y, Wang D, Tang L. Contrast material injection protocol with the flow rate adjusted to the heart rate for dual source CT coronary angiography. Int J Cardiovasc Imaging 2012;28:1557-65.
38. Tang L, Zhu X, Xu Y, Yu T, Xu H, Tang J, Dogra V, Wang D. Factors influencing delay time and coronary arterial density during coronary angiography with DSCT. Acta Radiol 2011;52:59-63.
39. Hosch W, Hofmann NP, Mueller D, Iwan J, Gitsioudis G, Siebert S, Giannitsis E, Kauczor HU, Katus HA, Korosoglou G. Body mass index-adapted prospective coronary computed tomography angiography. Determining the lowest limit for diagnostic purposes. Eur J Radiol 2013;82:e232-9.
40. Hosch W, Stiller W, Mueller D, Gitsioudis G, Welzel J, Dadrich M, Buss SJ, Giannitsis E, Kauczor HU, Katus HA, Korosoglou G. Reduction of radiation exposure and improvement of image quality with BMI-adapted prospective cardiac computed tomography and iterative reconstruction. Eur J Radiol 2012;81:3568-76.
41. Tatsugami F, Matsuki M, Nakai G, Inada Y, Kanazawa S, Takeda Y, Morita H, Takada H, Yoshikawa S, Fukumura K, Narumi Y. Body size-adapted dose of contrast material and scanning protocol in 320-detector row CT coronary angiography. J Comput Assist Tomogr 2011;35:475-9.
42. Husmann L, Herzog BA, Burkhard N, Valenta I, Burger IA, Gaemperli O, Kaufmann PA. Low-dose coronary CT angiography with prospective ECG triggering: validation of a contrast material protocol adapted to body mass index. AJR Am J Roentgenol 2009;193:802-6.
43. Brockow K. Reduced iodinated contrast media dose and injection speed for CT: how much does this decrease the risk of a hypersensitivity reactions? Quant Imaging Med Surg 2020;10:537-40.
44. Böhm IB. Lower dose and lower injection speed of iodinated contrast media: a new strategy to reduce the incidence rate of immediate hypersensitivity reactions. Quant Imaging Med Surg 2020;10:883-5.

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