



# Coronary artery calcium score scan at 100 kVp with tin filtration (Sn100 kVp) prior to coronary computed tomography angiography for overall radiation dose reduction: a prospective cohort study

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**Background:** Reducing radiation dose is a global concern in coronary computed tomography angiography (CCTA). We aimed to investigate whether a coronary artery calcium score (CACS) scan would lead to an overall reduction of radiation dose in CCTA examination and determine its necessity in routine CCTA imaging.

**Methods:** A total of 297 patients with suspected coronary heart disease were consecutively enrolled in this prospective cohort study between March 1, 2021, and September 1, 2021. All patients were scanned using a prospective electrocardiogram-triggered sequence acquisition mode on a dual-source computed tomography (CT) scanner. The first 1–150 patients (group A, n=150) were scanned with CACS using tin filtration with low voltage (Sn100 kVp) to guide the CCTA scanning range, whereas the subsequent 151–297 patients (group B, n=147) were scanned using a scout view for the CCTA range. Participant characteristics, number of scans, scan length, actual heart length, CT dose index (CTDIvol), dose-length product (DLP), effective dose (ED), and qualitative analysis were statistically analyzed between the groups.

**Results:** There was no significant difference in sex, age, height, weight, body mass index (BMI), or heart rate between the 2 groups. The number of scans and scan length (149 of 3 scans at 10.35 cm, 1 of 4 scans at 13.80 cm;  $P<0.001$ ), CTDIvol of CCTA (16.13 mGy;  $P<0.04$ ), DLP of CCTA (166.90 mGy\*cm;  $P<0.001$ ), ED of CCTA (4.34 mSv;  $P<0.001$ ), and overall ED (4.57 mSv;  $P<0.001$ ) of group A showed significant differences compared with group B (36 of 3 scans at 10.35 cm, 109 of 4 scans at 13.80 cm, 2 of 5 scans at 17.25 cm; CTDIvol of CCTA at 18.30 mGy; DLP of CCTA at 235.60 mGy\*cm; ED of CCTA at 6.13 mSv; overall ED at 6.13 mSv); meanwhile, actual heart length, qualitative analysis, and diagnostic CT reports were similar between the groups.

**Conclusions:** The CACS scan with Sn100 kVp prior to CCTA imaging on dual-source CT could reduce overall radiation dose.

**Keywords:** Tin filtration; radiation dose; coronary artery calcium score (CACS); coronary computed tomography angiography (CCTA)

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## Introduction

Reducing the radiation dose of coronary computed tomography angiography (CCTA), a widely used diagnostic modality for coronary artery disease (CAD), is a concern for medical centers throughout the globe (1,2). The radiation dose should be as low as reasonably achievable, as a higher radiation dose has been reported to possibly damage DNA with an effective dose (ED) of ionizing radiation over 6 mSv (3). The coronary artery calcium score (CACS) scan, with great clinical significance (4,5), is performed to assess the graded increased risk of future coronary events, heart failure, and mortality (6-8). In addition, CACS scans also have the potential to reduce radiation dose during subsequent cardiac imaging (9-11).

Previous studies have reported that the CACS scan may guide reduction of the scan length during CCTA scanning (10,11) and that the overall radiation dose can be determined by the ED of both the CACS and CCTA (10). However, tube voltage at 100 kVp with tin filtration (Sn100 kVp), which can lead to a significantly low radiation dose during the CACS scan, is feasible and highly accurate compared to the standard 120 kVp (9,12). Debates have emerged on the need for a CACS scan to be performed before CCTA imaging, and although the Society of Cardiovascular Computed Tomography (SCCT) guidelines (13) recommends the use of CACS, there is no consensus or guideline regarding this protocol. Therefore, we aimed to investigate whether the CACS scan can reduce the overall radiation dose in addition to reducing the scan length. If so, there will be additional benefits for patients (6), including exposure to a lower radiation dose, among others. We present the following article in accordance with the STROBE reporting checklist (available at <https://qims.amegroups.com/article/view/10.21037/qims-21-1129/rc>).

## Methods

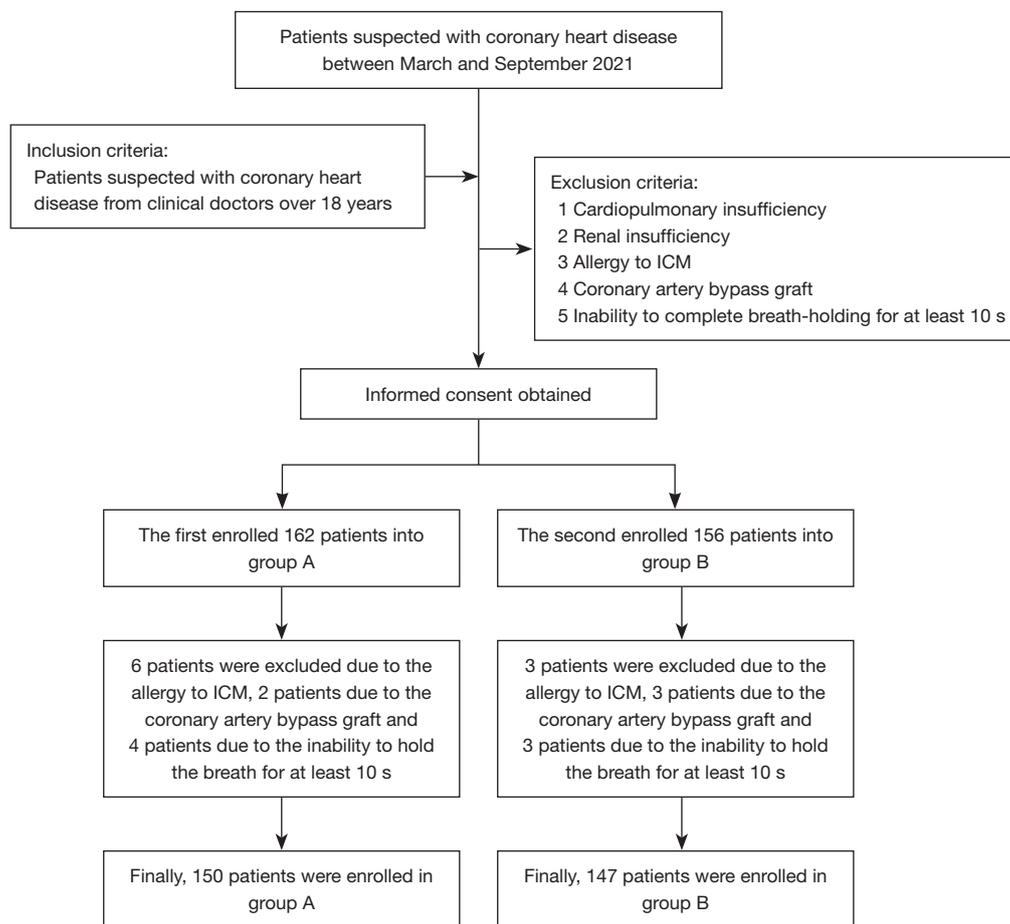
### Study population

This prospective cohort study was approved by the Ethics Committee of Huadong Hospital, and written informed consent was provided by all patients. The study was conducted in accordance with the Declaration of Helsinki

(as revised in 2013). We enrolled 297 consecutive patients [152 women, 145 men; mean age  $64.15 \pm 11.05$  years; age range 23 to 91 years; mean body mass index (BMI)  $24.09 \pm 3.27$  kg/m<sup>2</sup>; BMI range 15.99 to 34.38 kg/m<sup>2</sup>] between March 2021 and September 2021 with suspected CAD undergoing CCTA examination. The first 150 consecutive patients (group A, n=150) were scanned with CACS for guiding CCTA scanning range, whereas the remaining consecutive patients (151–297; group B, n=147) were not scanned with CACS to guide the CCTA range (Figure 1). The inclusion criteria were age over 18 years and the ability to control and hold breath. Patients were excluded if they had (I) allergies to iodine contrast agent, (II) severe renal insufficiency, (III) decompensated cardiac insufficiency, (IV) a history of medication use to control their heart rate, or (V) a coronary artery bypass graft.

### CT protocol and image reconstruction

All participants underwent CT using a new generation, dual-source CT scanner (Somatom Drive; Siemens Healthineers, Erlangen, Germany). A CACS scan was performed for group A to plan the scan range of CCTA using the following parameters: a tube voltage with Sn100 (Figure 2), an automated anatomical tube current modulation with 188 mA<sub>ref,qual</sub> (CARE Dose 4D; Siemens Healthineers), and a data acquisition window (R-R interval) set at 70%. For CCTA imaging of both groups, the collimation was 2×64×0.6 mm, and the rotation time was 0.28 seconds per rotation. A prospective electrocardiogram (ECG)-triggered sequence acquisition mode (step and shoot) was used, and scanning was performed from the cranium to the cauda. An automated anatomical tube current modulation technique with 380 mA<sub>ref,qual</sub> (CARE Dose 4D; Siemens Healthineers) and an attenuation-based tube voltage selection (ATVS) with 120 kV<sub>ref,qual</sub> (ATVS, CARE kV; Siemens Healthineers) were used, with the range of exposure dose (ECG pulsing) set at 30–80%. The bolus tracking technique was used for threshold monitoring at the aortic root for coronary arteries with an enhancement threshold of 80 Hounsfield units (HU) and a delay time of 7 seconds. Prewarmed contrast medium [CM; iobitridol, 350 mg iodine (mgI)/mL] was injected using an 18-G closed



**Figure 1** The flow diagram of patient enrollment. ICM, iodinated contrast media.

intravenous catheter system with an Ulrich high-pressure syringe. For CCTA, the CM was administered according to the patient's weight (0.8 mL/kg with a 13-s injection duration), and saline was administered at the same delivery rate with a 10-second injection duration.

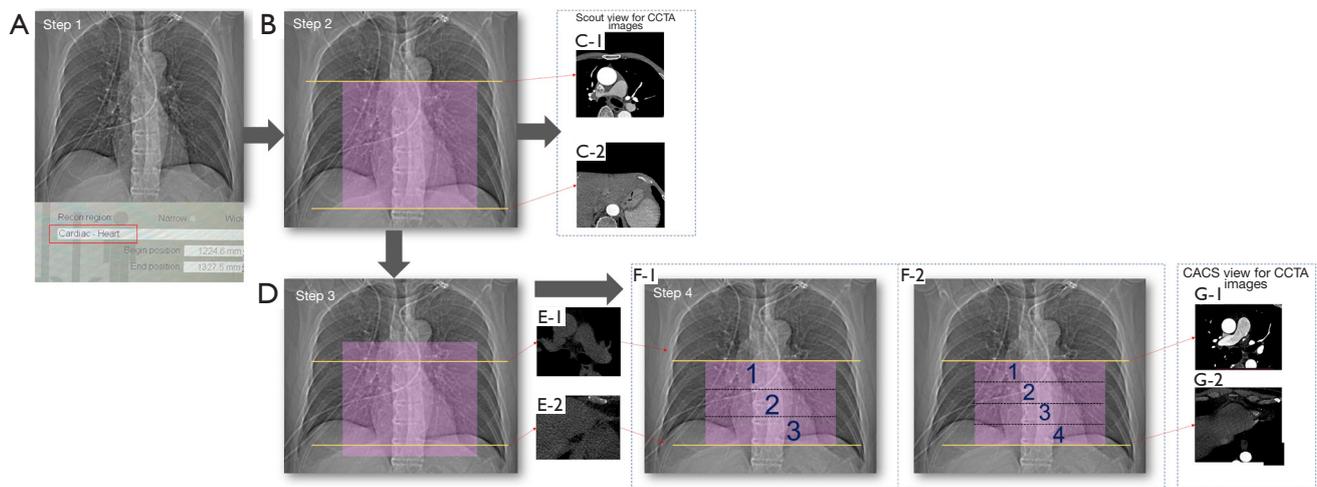
For the CACS scan, the images were reconstructed with a 3.0-mm slice thickness and image reconstruction interval using a medium sharp algorithm (B35f) with an advanced modeled iterative reconstruction (strength level 3) algorithm. For CCTA imaging, the slice thickness and image reconstruction interval with the Advanced Modeled Iterative Reconstruction (ADMIRE; strength level 4, Siemens Healthineers) algorithm for coronary arteries were 0.6 mm and 0.4 mm, respectively.

### Image analysis

Qualitative analysis was performed by 2 independent

radiologists (one with 8 years of experience in chest imaging and the other with over 15 years of experience in chest imaging) using a 5-point Likert scale: 1= poor opacification, insufficient for diagnosis; 2= suboptimal opacification, 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 (14).

Each CCTA imaging was diagnosed within 48 hours by both independent radiologists (usually a junior radiologist with 1–5 years of experience in chest diagnosis and another senior radiologist with over 10 years of experience in chest diagnosis) who did not participate in this study. The CT reports of all participants were analyzed in 2 categories: (I) there was a definitive diagnosis for diagnostic CT reports; and (II) there was motion artifact, other artifacts affected the diagnosis, or the image quality could not be diagnosed for nondiagnostic CT reports.



**Figure 2** The original flowchart for accurately planning the scan range. (A) Step 1 performed to acquire the scout view with the cardiac-heart recon region selected (red frame). (B) Step 2 performed to plan the scan range (pink area) of groups with CACS view or groups with scout view. The scan range was generated using the CT scanner automatically. (C) C1–2 show the first slice (C1) and the last slice (C2) of groups with the scout view for CCTA images. (D) Step 3 performed to plan the scan range of CCTA images with scanned CACS images. The above the line on the top with red arrow pointing to E1 is the actual first slice of planned CCTA imaging, and the line on the bottom pointing to E2 is the actual last slice of planned CCTA imaging. Step 4 presents the actual scan range that could be scanned after the scan range of CCTA imaging was planned by a CACS scan, with 3 (F1) or 4 scans (F2), after which the CCTA images of the actual first (G1) and last slice (G2) could be observed. CACS, coronary artery calcium score; CT, computed tomography; CCTA, coronary computed tomography angiography.

### Actual heart length

The actual heart length was calculated as follows: the table position on the image of the termination of the coronary arteries minus the table position on the image of the origin of the coronary arteries, plus the thickness of the image (0.6 mm).

### Radiation dose

The radiation dose of calcium score and CCTA were recorded using the dose-length product (DLP) and volume CT dose index (CTDIvol), which were automatically provided by the CT scanner. Radiations associated with the scout view and the automatic bolus tracking technique were excluded. The ED was estimated by multiplying the DLP by a conversion factor of 0.026 (3) for coronary arteries.

### Statistical analyses

The SPSS 26.0 software (IBM Corp., Armonk, NY, USA) was used for statistical analysis. The Levene test was used to verify the homogeneity of variance, while the Shapiro–Wilk

test was used for normal distribution. Measurement data that conformed to the normal distribution are expressed in the form of mean  $\pm$  SD, whereas data that did not conform to the normal distribution are described as median and interquartile range [expressed as M (P<sub>25</sub>, P<sub>75</sub>)]. The count data are expressed as frequencies and percentages. If the variances of the basic patient data and radiation parameters of the 2 groups of data were homogeneous, an independent sample *t*-test was performed, and if the variances were not uniform, the Wilcoxon rank-sum test was performed. Count data and subjective image scores were tested using the chi-squared test. The kappa test was used to determine the consistency between the subjective scores of different physicians. A *k* value between 0.21 and 0.40 indicated poor consistency, that between 0.41 and 0.60 indicated moderate consistency, and that between 0.61 and 0.80 indicated good consistency. The statistical significance level was set at *P*<0.05.

### Results

All participants in group A (with CACS) finished CCTA

**Table 1** Patient characteristics

Characteristics	Group A (N=150)	Group B (N=147)	P value
Male/female	66/84	79/68	0.093
Age (years) (P <sub>25</sub> , P <sub>75</sub> )	64.0 (57.0, 71.0)	66.0 (59.0, 72.0)	0.259
Height (cm) (P <sub>25</sub> , P <sub>75</sub> )	1.64 (1.58, 1.70)	1.65 (1.59, 1.72)	0.136
Weight (kg) (P <sub>25</sub> , P <sub>75</sub> )	62.25 (57.1, 73.0)	69.0 (58.0, 75.0)	0.111
BMI, mean ± standard deviation	23.95±3.13	24.23±3.41	0.455
HR (bpm) [P <sub>25</sub> , P <sub>75</sub> ]	70 [64, 80]	72 [65, 81]	0.467

BMI, body mass index; HR, heart rate; bpm, beats per minute.

imaging successfully with no rescans required, whereas 2 patients in group B (without CACS) were scanned twice because their coronary arteries had not been included in the scan range at the first scan. There were no significant differences in gender, age, height, weight, BMI, and heart rate between the 2 groups (*Table 1*).

In group A, there were 115 (76.7%) participants scanned at 90 kV, 22 (14.7%) scanned at 100 kV, 8 (5.3%) scanned at 110 kV, and 5 (3.3%) scanned at 120 kV; meanwhile in group B, 84 (57.1%) patients were scanned at 90 kV, 45 (30.6%) were scanned at 100 kV, 12 (8.2%) were scanned at 110 kV, and 6 (4.1%) were scanned at 120 kV; this showed a significant difference ( $P < 0.001$ ) between the groups. In group A, 149 patients underwent 3 scans of CCTA, and 1 patient underwent 4 scans of CCTA; meanwhile, in group B, 36 patients underwent 3 scans of CCTA, 109 patients underwent 4 scans of CCTA, and 2 patients underwent 5 scans of CCTA; this also showed a significant difference ( $P < 0.001$ ) between groups. However, the actual heart lengths were similar between groups. The CTDIvol of CCTA (16.13;  $P < 0.04$ ), DLP of CCTA (166.90;  $P < 0.001$ ), ED of CCTA ( $4.34 \times 0.026$ ;  $P < 0.001$ ), and overall ED ( $4.57 \times 0.026$ ;  $P < 0.001$ ) of group A showed significant differences compared to group B (36 of 3 scans at 10.35 cm, 109 of 4 scans at 13.80 cm, 2 of 5 scans at 17.25 cm; CTDIvol of CCTA at 18.30 mGy; DLP of CCTA at 235.60 mGy\*cm; ED of CCTA at 6.13 mSv; overall ED at 6.13 mSv), whereas the qualitative analysis and diagnostic CT reports were similar. The details are shown in *Table 2*.

## Discussion

Our study used a CACS scan with Sn100 kVp to plan the scan range of CCTA for overall examination of radiation dose reduction, and our results demonstrated the

following: (I) A CACS scan with Sn100 kVp could reduce the radiation dose of the CCTA scan by approximately 29.7% due to accurate scan length, which is consistent with previous studies (10,11,15). However, our study also found a significant difference in CTDIvol between the 2 groups, which had not been previously reported with the ATVS algorithm. Leschka *et al.* (11). did not report the relationship between scan length and tube voltage in detail, whereas our previous study (10) showed that similar CTDIvol was not associated with scan length either on force CT or revolution CT, indicating that the tube voltage selection may change due to the increased scan length (*Figure 3*). Our study demonstrated that the ED of CCTA could be raised by increased CTDIvol and scan length with the new dual-source CT (Somatom Drive). More importantly, 2 patients were rescanned because some of their coronary arteries had not been included in the first scan, indicating that the CACS scan could reduce the risk of rescans, leading to a lower radiation dose. (II) A CACS scan with tin-filtered 100 kV could reduce the overall ED by approximately 25.5%, with a conversion factor of 0.026. A previous study stated that the ED of CACS scan was the main factor in presenting the main power in terms of overall dose reduction (10), as the overall dose increase with CACS scan only reduces the scan length of CCTA imaging and has no added benefits for patients. The present study showed that a CACS scan with Sn100 kVp contributed to the sufficiently low radiation dose of the CACS scan, and it has also been reported that a CACS scan with Sn100 kVp does not reduce the image quality or accuracy (9,12,16).

Drive CT is an upgraded CT based on the second-generation dual-source CT, which has the same detector width (38.4 mm) and gantry speed (0.28 s per rotation); the number of scans of the step-and-shoot acquisition is used to cover the scan length of each CCTA imaging

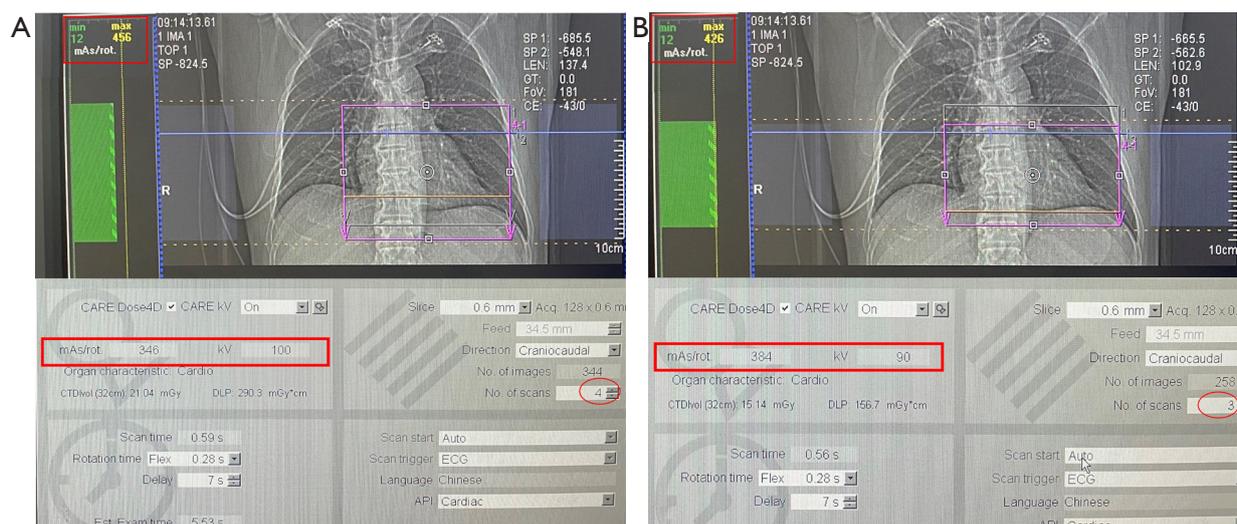
**Table 2** Comparison of radiation parameters and qualitative analysis

Parameters	Group A (N=150)	Group B (N=147)	P value
Tube voltage (kV)			0.004
70	0	0	
80	0	0	
90	115 (76.7%)	84 (57.1%)	
100	22 (14.7%)	45 (30.6%)	
110	8 (5.3%)	12 (8.2%)	
120	5 (3.3%)	6 (4.1%)	
Number of scans (scanning length)			<0.001
3 (10.35 cm)	149	36	
4 (13.80 cm)	1	109	
5 (17.25 cm)	0	2	
Actual heart length (cm)			0.169
<10.35	149	143	
10.35–13.80	1	4	
13.80–17.25	0	0	
CTDI <sub>vol</sub> -CACS (P <sub>25</sub> , P <sub>75</sub> )	0.60 (0.49, 0.82)	N/A	N/A
DLP-CACS (P <sub>25</sub> , P <sub>75</sub> )	8.00 (6.58, 10.73)	N/A	N/A
ED-CACS ×0.026 (mSv) (P <sub>25</sub> , P <sub>75</sub> )	0.21 (0.17, 0.28)	N/A	N/A
CTDI <sub>vol</sub> -CCTA (P <sub>25</sub> , P <sub>75</sub> )	16.13 (12.33, 21.86)	18.30 (12.94, 26.20)	0.040
DLP-CCTA (P <sub>25</sub> , P <sub>75</sub> )	166.90 (129.35, 226.23)	235.60 (169.40, 336.50)	<0.001
ED-CCTA ×0.026 (mSv) (P <sub>25</sub> , P <sub>75</sub> )	4.34 (3.37, 5.88)	6.13 (4.40, 8.75)	<0.001
ED-whole examination ×0.026 (mSv) (P <sub>25</sub> , P <sub>75</sub> )	4.57 (3.54, 6.18)	6.13 (4.40, 8.75)	<0.001
Qualitative analysis			
LAD	4.0 (3.0, 4.0)	4.0 (3.75, 4.0)	0.375
LCX	4.0 (3.0, 4.0)	4.0 (3.0, 4.0)	0.131
RCA	4.0 (4.0, 4.0)	4.0 (4.0, 4.0)	0.551
Diagnostic CT reports	145	141	0.733
Non-diagnostic CT reports	5	6	

The median and interquartile range, expressed as P<sub>25</sub>, P<sub>75</sub>. CTDI<sub>vol</sub>-CACS, volume CT dose index in coronary artery calcium score scan; CTDI<sub>vol</sub>-CCTA, volume CT dose index in coronary computed tomography angiography; DLP-CACS, dose-length product in coronary artery calcium score scan; DLP-CCTA, dose-length product in coronary computed tomography angiography; DLP-whole-examination, dose-length product in whole examination; ED-CACS, effective dose in coronary artery calcium score scan; ED-CCTA, effective dose in computed tomography angiography; D-whole examination, effective dose in whole examination; kV, kilovolt; mSv, millisievert; LAD, left anterior descending; LCX, left circumflex artery; RCA, right coronary artery.

(Figure 2). In the present study, only 1 patient in group A finished the CCTA imaging with 4 scans, whereas the other 149 underwent 3 scans, which comprised the actual

heart length coverage (149<10.35 cm and 1 between 10.35 and 13.80 cm); however, in group B, most of the patients [109] underwent 4 scans, and 2 patients underwent 5 scans,



**Figure 3** Original schematic diagram of automatic tube voltage changing. (A,B) show the possibility of tube voltage change, and (A,B) present the same patient before starting the CCTA imaging, with the scout view for CCTA imaging planning (A). The scan range (pink frame) is selected to be 4 scans using the CT scanner automatically [red oval frame in (A)], and the tube voltage is selected with 100 kV (red rectangle frame in B). If a CACS scan is used to plan the scan range, 3 scans are applied (red oval frame in B) when the tube voltage is selected with 90 kV (red rectangle frame in B). Moreover, the red rectangle frame in both figures at the top left corner and the max mAs/rot differs from the different tube voltage. CACS, coronary artery calcium score; CT, computed tomography; CCTA, coronary computed tomography angiography.

while the actual heart length coverage of 143 patients was <10.35 cm and 10.35–13.80 cm for 4 patients (Table 2). The similar actual heart length (all <13.80 cm) of both groups ( $P=0.169$ ) indicated that the number of scans required to cover the scan length of CCTA used in group A through CACS scan was more accurate than that in group B, as the overused number of scans led to higher ED in group B. In addition, through the tube voltage distribution, the accurate scan length in group A led to a lower tube voltage than in group B (Figure 3).

The CACS has great clinical benefits for patients (6). The only instance of CACS being mentioned in the SCCT guidelines suggests that CACS may be performed before CCTA scanning to detect and quantify coronary artery calcification (13). However, to date, the guidelines have not stipulated when to perform the scan, and it remains controversial whether it is a part of the entire CCTA examination just before CCTA scanning (at the same time) or an isolated scan. Our results indicated that CACS with Sn100 kVp could be added to the CCTA examination as a necessary component, either because of the accurate calculation of calcification or the low radiation dose, both of which will be beneficial to patients.

This study had some limitations. First, ATVS with 120 kV<sub>ref,qual</sub> may be higher than usual setting like 100 kV<sub>ref,qual</sub>, which may lead to lower ED of both CCTA scanning and overall radiation dose. We speculate that a further reduction in radiation dose could be achieved with a lower tube voltage or narrow range of exposure (30–80%) dose; however, the narrow range could also lead to a possible unsatisfactory image quality of CCTA imaging. Second, in our study, tube voltage below 90 kV in both groups did not appear; thus, we will try to investigate this issue in the future. Third, the accuracy of calcium score by using Sn100 kVp was not evaluated in our study; however, a previous study had already proven the accuracy of calcium score by using Sn100 kVp compared with conventional 120 kVp (9,12,16). Finally, this was a single-center study, which may limit the generalizability of the results. Large, multicenter prospective studies may be designed to generalize these results in the future.

In conclusion, CACS scan with Sn100 kVp prior to CCTA imaging on dual-source CT could reduce the overall radiation dose of the CCTA examination, which would be of great value in the clinical setting, with additional clinical information.

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## Footnote

*Reporting Checklist:* The authors have completed the STROBE reporting checklist. Available at <https://qims.amegroups.com/article/view/10.21037/qims-21-1129/rc>

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at <https://qims.amegroups.com/article/view/10.21037/qims-21-1129/coif>). The authors have no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This prospective cohort study was approved by the Ethics Committee of Huadong Hospital, and written informed consent was provided by all participants. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

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