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Original article

The usefulness of low radiation dose subtraction coronary computed tomography angiography for patients with calcification using 320-row area detector CT

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ABSTRACT

Background: Although subtraction coronary computed tomography angiography (S-CCTA) has recently been developed to improve the diagnostic ability in patients with severe calcification, increase in radiation exposure remains a concern. The usefulness of S-CCTA using a low-radiation dose protocol was investigated.

Methods: S-CCTA in 320-row area detector CT was performed on 84 consecutive patients with suspected obstructive coronary artery disease with Agatston score ≥100. Reconstruction and radiation dose were changed according to the slow filling time (SF) (137.5 ms < SF ≤ 262.5 ms. Half reconstruction without reduction of the current, 262.5 ms < SF ≤ 275 ms: automatic patient motion correction with 50% reduction, SF ≥ 275 ms: full reconstruction with 70% reduction) at a tube voltage of 100 kV. The percentage of patients with non-diagnostic stenosis of calcified coronary artery lesions was calculated in conventional (C-) CCTA, and S-CCTA was calculated based on 84 patients (446 segments) bases. In 27 patients (137 segments) examined by invasive coronary angiography (ICA), the diagnostic ability was investigated regarding the ICA findings as reference standard.

Results: The percentage of non-diagnostic patients and segments on C-CCTA vs. S-CCTA was 40.5% vs. 9.5% and 16.4% vs. 2.9%, respectively. The Agatston score was 589.3 ± 655.3, and the total effective radiation dose (non-contrast scan and C-CCTA) was 2.7 ± 1.1 mSv. In the 27 patients, 137 segments area under the curve of S-CCTA (0.939, 95% CI: 0.895–0.983) for the ICA findings as reference standard was significantly higher than that of C-CCTA (0.785, 95% CI: 0.713–0.858) ($p < 0.0001$).

Conclusion: The diagnostic ability of S-CCTA performed following the low-radiation dose protocol for patients with calcification was superior to that of C-CCTA alone.

Introduction

Coronary computed tomography angiography (CCTA) has been widely used and established as a tool to make an early diagnosis of obstructive coronary artery disease (CAD) because of its high negative predictive value [1–3]. However, the positive predictive value is low compared with the negative predictive value, and coronary arteriosclerosis-associated calcification is one of the causes. Coronary arterial calcification leads to overestimation of the stenosis region due to beam hardening artifacts and difficulty in judging stenosis. High-degree calcification reduces the diagnostic ability of CCTA [4,5], which is markedly problematic clinically. Therefore, CCTA is not recommended in the guidelines for cases with an Agatston score ≥400 [6].

Subtraction CCTA (S-CCTA) has been developed, and improvement in diagnostic ability in patients with severe calcification has been reported [7–10]. We have also encountered patients difficult

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to diagnose depending on the position and expansion of calcification even though the Agatston score is not high. Therefore, improvement in diagnostic ability by performing S-CCTA in many patients is expected, but S-CCTA requires two acquisitions, for which an increase in the radiation dose and use is of concern [7–10]. We developed a protocol to achieve favorable image quality with low radiation dose by reducing the tube current using the successive approximation-applied reconstruction method and heart rate-based reconstruction method at a tube voltage of 100 kV [11]. In this study, the low-radiation dose protocol was applied to S-CCTA and its diagnostic ability was investigated in patients with an Agatston score ≥100.

Methods

Study population

Of patients with suspected obstructive CAD with coronary artery calcification judged as an Agatston score of 100 or higher between October 1, 2014 and December 1, 2015, 84 consecutive patients (age: 68.9 ± 8.9 years, 55 and 29 patients were male and female, respectively) meeting the following conditions were examined by S-CCTA, excluding patients with known CAD: (1) Ability to hold one's breath for 25 s, (2) body mass index ≥ 30, and (3) a heart rate of 61 bpm or lower with which one beat scan could be performed.

This study was approved by the Ethics Committee of our institution Anonymous use of the examination data for this study was orally explained to all patients and written consent was obtained before examination.

Acquisition method

Devices and pretreatment

For the imaging device, Aquilion ONE ViSION Edition (Canon Medical Systems, Toshigi, Japan) was used. For the automatic contrast medium infection device, Dual Shot (Nemoto Kyorindo Co., Ltd., Tokyo, Japan) was used. For the image analysis device, ZIOSTATION (M900, Ziosoft Inc., Tokyo, Japan) was used. For the electrocardiography monitor, Model 7800 (Chronos Medical Device Inc., Tokyo, Japan) was used. In pretreatment, 20–40 mg of metoprolol was orally administered when the heart rate (HR) was more than 61 bpm on the examination day unless it was contra-indicated for the patient (severe aortic valve stenosis, bronchial asthma, systolic blood pressure <90 mmHg, high-degree atrioventricular block, or heart failure). When the heart rate was still more than 61 bpm after oral metoprolol administration, 12.5 mg of landiolol was intravenously injected to control the HR.

Image reconstruction method

Image reconstruction was acquired following the protocol of our institution reported previously [11].

Reportedly, the relationship of the RR and PQ intervals (PR-PQ) with the slow filling time (SF) is: SF = −362 + 0.742 (RR-PQ), r = 0.915 [12]. When RR-PQ is within a range of 600–1500 ms, −95% prediction is approximated to a straight line: SF = −443 + 0.742 (RR-PQ) [12]. As the gantry rotation speed was 275 ms/rot, SF was calculated using the above formula. When SF was: (1) 137.5 ms ≤ SF < 262.5 ms, half reconstruction was performed, (2) 262.5 ms ≤ SF < 275 ms, reconstruction was performed using automatic patient motion correction (APMC: The APMC function available for 320-ADCT adjusts weighting near 0° and 360° on the sinogram to reduce motion artifacts [13]), and (3) SF ≥275 ms, full reconstruction was performed. Full reconstruction, reconstruction using APMC, or half reconstruction was performed in the SF phase and end-systolic phase using the R+ absolute time method to generate images, and the images with the lowest level of motion artifacts were selected on the 4-chamber cardiac cine CT.

Low-radiation dose S-CCTA acquisition method

S-CCTA images were acquired applying the protocol of our institution reported previously [11].

Low-radiation dose S-CCTA was performed employing the single breath-holding method in which images were acquired twice during a single breath-holding (pre- and postcontrast scans) [7–10].

Fixing the injection time of contrast medium (Omnipaque 350 mg/mL I; Daiichi Sankyo Company, Tokyo, Japan), the 2-step injection method was employed in which contrast medium was injected into the cubital vein at an infusion rate of body weight × 0.06 mL/s for 12 s, followed by injection of 30 mL of saline at the same rate.

The acquisition conditions were: acquisition slice thickness, 0.5 mm × 320 rows; image slice thickness, 0.5 mm; and reconstruction interval, 0.25 mm. For the acquisition range, the minimum range including the entire coronary artery was set referring to the plain CT image for registration. The acquisition tube voltage was set at 100 kV. The tube current for reconstruction using APMC was set using the automatic exposure control (AEC) function based on the mean tube current calculated so as to adjust the standard deviation (SD) to 20, and the tube current was reduced by 50% for half reconstruction. For full reconstruction, it was set at 70% reduction from the tube current for half reconstruction. The gantry rotation speed was 275 ms/rot, the prospective CTA mode was used, and the X-ray exposure range was set at single rotation in the 75% phase of RR interval.

Adaptive iterative dose reduction using three-dimensional processing (AIDR3D: Canon Medical Systems) was used for all patients, with intensity at the standard setting.

On actual S-CCTA, the instruction to hold breath was announced one second after injection of contrast medium and the patients held their breath for approximately 25 s from 5 s after injection of contrast medium. The precontrast scan was performed from 9 s after contrast medium injection. Preparatory scanning was initiated 17 seconds after contrast medium injection, and R was triggered to perform the postcontrast scan when the CT value of the ascending aorta reached 200 HU.

S-CCTA images were processed using Canon software (^{sure} Subtraction). Calcification was removed by subtracting 3-dimensional data of the precontrast scan from the postcontrast scan [9–11]. The images prepared from the postcontrast scan were designated as conventional CCTA (C-CCTA).

The total effective radiation dose for non contrast scan and C-CCTA was calculated as the dose length product (DLP) × 0.014 [14].

Measurement of the Agatston score

The Agatston score was measured utilizing the registration image before C-CCTA following the method reported by Agatston et al. [15]. At a 120-kV tube voltage and 50-mA tube current, plain cardiac CT images were acquired including the aortic root over the apex targeting the mid-diastolic or end-systolic phase using 280 rows and prospective electrocardiography gating, and reconstructed at 3-mm slice thickness and 3-mm slice intervals. A calcified lesion was defined as ≥3 contiguous pixels with a peak attenuation ≥130 Hounsfield Unit (HU) using a software on ZIOSTATION. The Agatston score was calculated according to the method of Agatston et al. [15].

Evaluation of the degree of stenosis

CCTA findings were evaluated in each segment based on agreement among 2 cardiologists (observer A and B) and one

radiological technologist (observer C) without clinical information of the patients following the modified American Heart Association classification [16]. The degree of stenosis was evaluated in the axial, curved multi planar reconstruction (MPR), and angiographic views. The percentage ratio of the stenotic lumen to the original vessel diameter of the lesion analogized by a presumed-to-be-healthy site distal and proximal to the stenosis was obtained and the degree of stenosis was expressed by subtracting this from 100. Obstructive CAD was defined as those with >50% diameter stenosis on CCTA. Segments in which the degree of stenosis could not be judged due to calcification were defined as non-diagnostic segments. Furthermore, when judgment was inconsistent among two cardiologists and one radiological technologist, the case was regarded as non-diagnostic patients and non-diagnostic segments. Coronary artery segments with a diameter >2.0 mm and calcification were evaluated.

Definition of stenotic judgment

C-CCTA. Non-diagnostic: Judgment of lumen is difficult due to calcification and blooming artifact.

Diagnostic: Calcification and blooming artifact are present, but the lumen can be confirmed.

S-CCTA. Non-diagnostic: The lumen cannot be confirmed.

Diagnostic: The lumen can be confirmed.

Invasive coronary angiography

Patients examined by invasive coronary angiography (ICA) within 3 months after CCTA were selected. Examination by ICA was decided based on the CCTA findings by the attending physician giving outpatient treatment. Judgments were made by two experienced cardiologists and one radiological technologist without information on the CT findings. Obstructive CAD was defined as luminal diameter stenosis >50% on visual evaluations, and it was compared between the calcified and calcification-subtracted segments.

Definition of risk factor

Hypertension was defined as 140/90 mmHg or higher, or being treated with oral antihypertensive drugs. Hyperlipidemia was defined as 220 mg/dL or higher total cholesterol, 140 mg/dL or higher low-density lipoprotein-cholesterol, 150 mm/dL or higher fasting triglycerides, 40 mg/dL or lower high-density lipoprotein-cholesterol, or being treated with lipid-lowering drugs. Diabetes was defined as 126 mg/dL or higher fasting blood glucose level, 200 mg/dL or higher casual blood glucose level, 6.5% (NGSP) or higher HbA1c, or being treated for diabetes. Patients with habitual cigarette smoking were defined as those smoking within 1 year before CT.

Statistical analysis

Statistical analyses were performed using Statview J-5.0 for Windows (HULINKS, Inc., Tokyo, Japan) and MedCalc Version 12.2.1 (MedCalc Software bvba, Mariakerke, Belgium). Continuous variables were expressed as means ± standard deviation (SD), or median (minimum – maximum) and categorical variables were presented as percentages.

In analyses of the patients and segments, the percentages of non-diagnostic patients, and segments on C-CCTA and S-CCTA acquired employing the half, APMC, and full reconstruction methods were calculated, and Agatston score and the HR, total effective radiation dose (non-contrast scan and C-CCTA: mSv) under each condition were calculated and analyzed using Kruskal–Wallis test. They were also divided into five categories based on Agatston score: 100–399, 400–699, 700–999, 1000–1999, and 2000-, and the percentages of non-diagnostic patients on C-CCTA and S-CCTA were calculated in each category.

Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were calculated per-segment for both C-CCTA and S-CCTA, whereby ICA served as the standard of reference. A positive finding was defined as the presence of a significant stenosis in ≥1 segment. If ≥1 non-diagnostic segment due to severe calcification was observed on CCTA, the segment was defined as having significant stenosis. Furthermore, inter-observer agreement was assessed between observer A, B, and C and the values of the kappa coefficient.

In addition, the area under the curve (AUC) was determined from the receiver operating characteristic curve (ROC) on C-CCTA and S-CCTA, using ICA as the reference standard, and diagnostic ability was compared considering $p < 0.05$ as significant.

Table 1
Patient characteristics and scanning data.

N = 84 (446 vessels)	
Characteristics	Value
Age (mean SD, years)	68.6 ± 8.9
BMI (kg/m^2)	23.8 ± 3.0
Coronary risk factor	
Family history (%)	16.7
Hypertension (%)	59.5
Dyslipidemia (%)	71.4
Diabetes mellitus	32.1
Smoking (%)	19.0
Agatston score	589.3 ± 655.3
Scanning data	
Tube current (mA)	398.1 ± 157.2
Total DLP (mGy cm)	192.7 ± 79.7
Total dose (mSv)	2.7 ± 1.1

BMI, body mass index; DLP, dose length product.

Results

Patient characteristics and scanning data

Fifty-five (65.5%) and 29 patients were male and female, respectively. The mean Agatston score was 589 ± 655.3. The scanning data were: tube current (mA), 398.1 ± 157.2; total DLP (mGy cm), 192.7 ± 79.7; and total effective radiation dose (mSv), 2.7 ± 1.1 (Table 1).

Analysis of non-diagnostic rate and the total effective radiation dose on patient-based and segment-based by reconstruction method

The percentage of non-diagnostic patients on C-CCTA was 40.5% (34/84). By the reconstruction method, the percentage was 43.1% (*N* = 19/44) on half reconstruction (half), 46.7% (*N* = 7/15) on APMC, and 32.0% (*N* = 8/25) on full reconstruction. The percentage of non-diagnostic patients on S-CCTA was 9.5% (8/84), revealing that the percentage of non-diagnostic patients decreased. The percentage by the reconstruction method also decreased: 9.1% (4/44) on half reconstruction, 13.3% (2/15) on APMC, and 8.0% (2/25) on full reconstruction.

On segment-based analysis, the percentage of non-diagnostic segments was 16.4% (73/446) on C-CCTA, and that by the reconstruction method was 21.0% (50/238) on half reconstruction, 12.5% (11/88) on APMC, and 10.0% (12/120) on full reconstruction.

Table 2
Analysis of non-diagnostic rate and the total effective dose on patient-based and segment-based by reconstruction method.

	Half	APMC	Full	*p*-value
Patients base (%) (*N* = 84)				
Conventional CCTA non-diagnosable (%)	43.1 (*N* = 19/44)	46.7 (*N* = 7/15)	32.0 (*N* = 8/25)	N.S.
Subtraction CCTA non-diagnosable (%)	9.1 (*N* = 4/44)	13.3 (*N* = 2/15)	8.0 (*N* = 2/25)	N.S.
Total	44	15	25	
Segment base (%) (*N* = 446)				
Conventional CCTA non-diagnosable (%)	21.0 (*N* = 50/238)	12.5 (*N* = 11/88)	10.0 (*N* = 12/120)	0.0139
Subtraction CCTA non-diagnosable (%)	2.5 (*N* = 6/238)	2.3 (*N* = 2/88)	4.2 (*N* = 5/120)	N.S.
Total	238	88	120	
Agatston score	381.0 (105.4–3225.8)	210.9 (103.2–1253.0)	240.4 (100.1–2973.3)	N.S.
HR (bpm)	54 (48–63)	54 (47–57)	48 (40–60)	0.0001
Total dose (mSv)	3.6 (1.5–4.9)	2.0 (1.5–4.4)	1.2 (0.8–5.0)	0.0001

APMC, automatic patient motion correction; CCTA, coronary computed tomography angiography; HR, heart rate; bpm, beats per minute.

The percentage of non-diagnostic segments on S-CCTA was 2.9% (13/446) and percentages by the reconstruction method were 2.5% (6/238), 2.3% (2/88), and 4.2% (5/120) on half, APMC, and full reconstruction, respectively, demonstrating decreases in the amounts of non-diagnostic segments. The total effective radiation dose was 1.2 (0.8–5.0) mSv at full reconstruction (Table 2).

Comparison of non-diagnostic patients divided in Agatston score between C-CCTA and S-CCTA

The percentages of non-diagnostic patients with an Agatston score of 100–399, 400–699, 700–999, 1000–2000, and 2000- on C-CCTA were 29.4% (15/51), 36.4% (4/11), 66.7% (4/6), 69.2% (9/13), and 66.7% (2/3), respectively, showing that non-diagnostic patients accounted for more than 60% in patients with an Agatston score of 700 or higher. On S-CCTA, these were 3.9% (2/51), 9.1% (1/11), 16.7% (1/6), 23.1% (3/13), and 33.3% (1/3), respectively, showing that non-diagnostic patients increased as the Agatston score increased as observed on C-CCTA, but more than 77.3% of patients were readable on S-CCTA even though the Agatston score was more than 700 (Fig. 1A).

Diagnostic accuracy of C-CCTA and S-CCTA and inter-observer agreement

The diagnostic abilities of C-CCT and S-CCTA were investigated involving a total of 137 segments regarding the findings on ICA as the reference standard. The patient characteristics and scanning data are shown in Table 3A.

On C-CCTA, significant stenosis was detected in 59 segments and 36 of these were non-diagnosable. Significant stenosis was actually present in 36 segments on ICA, but 18 of these were non-diagnosable on C-CCTA.

On S-CCTA, significant stenosis was detected in 46 segments and 5 of these were non-diagnosable. Significant stenosis was actually present in 41 segments on ICA, but 4 of these were non-diagnosable on S-CCTA.

The sensitivity and specificity of C-CCTA were 81.81% and 75.26%, respectively. The positive (PPV) and negative (NPV) predictive values were 61.01% and 89.74%, respectively, and the accuracy was 77.37%. The sensitivity and specificity of S-CCTA were 93.18% and 94.62%, respectively, PPV and NPV were 89.13% and 96.70%, respectively, and the accuracy was 94.16%, revealing that all items improved (Table 3B). Inter-observer kappa score was the highest in observer A and B on C-CCTA (0.875), S-CCTA (0.956).

The diagnostic ability was compared between C-CCTA and S-CCTA using ROC analysis regarding the ICA findings as the reference standard. AUC of C-CCTA and S-CCTA calculated on ROC analysis were 0.785 (95% CI: 0.713–0.858) and 0.939 (95% CI: 0.895–0.983), respectively, showing that the diagnostic ability of S-CCTA was significantly superior ($p < 0.0001$) (Fig. 1B).

A representative case of C-CCAT, S-CCTA, and ICA is shown in Fig. 2.

Discussion

We investigated the usefulness of S-CCTA employing the low-radiation dose protocol for patients with an Agatston score of 100 or higher with suspected CAD. On patient-based analysis, the

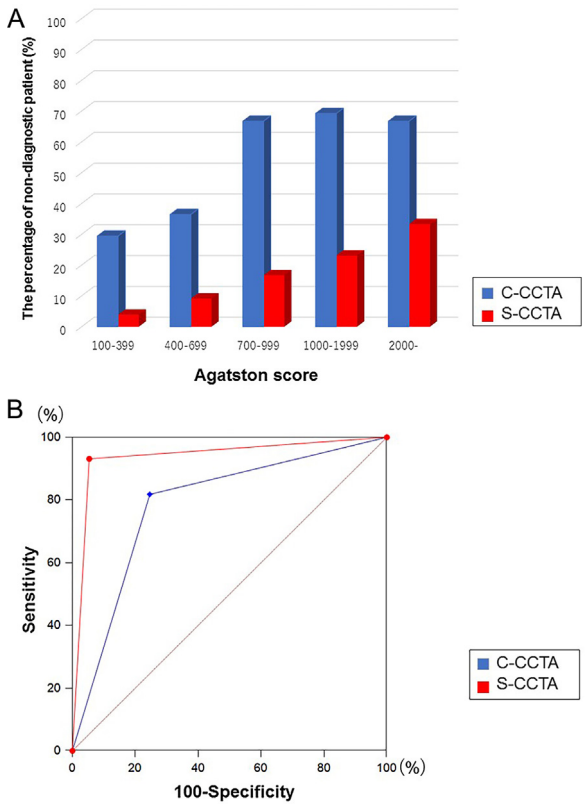

Fig. 1. (A) Comparison of non-diagnostic patients divided in Agatston score between C-CCTA and S-CCTA. Blue bar: C-CCTA, Red bar: S-CCTA. (B) Comparison of diagnosability between C-CCTA and S-CCTA. AUCs of the ROC curves were prepared using C-CCTA and S-CCTA. 0.785 (95% CI: 0.713–0.858) vs. 0.939 (95% CI: 0.895–0.983) ($p < 0.0001$). Blue line: C-CCTA; red line: S-CCTA. C-CCTA, conventional-coronary CT angiography; S-CCTA, subtraction-coronary CT angiography; ROC curve, receiver operating characteristic curve; AUC, area under the curve; CI, confidence interval.

Table 3A
Patient characteristics and scanning data.

$N = 27$ (137 vessels)	
Characteristics	Value
Age (mean SD, years)	69.0 ± 65.7
BMI (kg/m^2)	23.7 ± 3.1
Coronary risk factor	
Family history (%)	16.0
Hypertension (%)	65.4
Dyslipidemia (%)	69.2
Diabetes mellitus (%)	34.6
Smoking (%)	19.2
Agatston score	631.2 ± 532.1
Scanning data	
Tube current (mA)	405.4 ± 159.4
Total DLP (mGy cm)	193.0 ± 87.9
Total dose (mSv)	1.4 ± 0.6
HR	52.3 ± 4.0
Half/APMC/Full	15/4/7

BMI, body mass index; DLP, dose length product; HR, heart rate.

Table 3B
Diagnostic accuracy of C-CCTA and S-CCTA and inter-observer agreement.

	ICA		Total
	Stenosis (+)	Stenosis (−)	
Conventional CCTA			
Stenosis (+) (non-diagnosable)	36 (18)	23 (18)	59 (36)
Stenosis (−)	8	70	78
Total	44	93	137
Subtraction CCTA			
Stenosis (+) (non-diagnosable)	41 (4)	5 (1)	46 (5)
Stenosis (−)	3	88	91
Total	44	93	137

	Conventional CCTA	Subtraction CCTA
Sensitivity	81.81	93.18
Specificity	75.26	94.62
Positive Predictive Value	61.01	89.13
Negative predictive value	89.74	96.70
Accuracy	77.37	94.16
Inter observer kappa score		
A and B	0.875	0.956
A and C	0.643	0.803
B and C	0.586	0.743

ICA, coronary angiography; C-CCTA, conventional coronary computed tomography angiography; S-CCT, subtraction coronary computed tomography.

percentages of non-diagnostic patients on C-CCTA and S-CCTA were demonstrating a decrease on S-CCTA, and those on the segment-based analysis were also showing a decrease. Non-diagnostic segments also decreased on S-CCTA in both patient- and segment-base analyses by the reconstruction method. When the effectiveness was investigated in 27 patients (137 segments) examined by ICA regarding the ICA findings as the reference standard, S-CCTA was superior to C-CCTA in sensitivity, specificity, NPV, PPV, and accuracy. Furthermore, AUC of S-CCTA was high (0.939, 95% CI: 0.895–0.983), whereas that of C-CCTA was 0.785 (95% CI: 0.713–0.858), demonstrating that the diagnostic ability of S-CCTA was also significantly superior to that of C-CCTA. This result was superior in comparison with diagnostic ability of C-CCTA and S-CCTA reported previously [7–10].

The guidelines do not recommend CCTA for patients with an Agatston score of 400 or higher [6]. The amount of non-diagnostic patients increased as the Agatston score increased on C-CCTA and S-CCTA, but 29.4% were non-diagnosable on C-CCTA in patients with a relatively low Agatston score of 100–399, which is within the range recommended by the guidelines. For example, the Agatston score is high when only calcification is present in each coronary artery in an eccentric pattern, but the image is readable in some patients. In contrast, when calcification is localized in a coronary artery, some patients are non-diagnosable even though the Agatston score is low. Therefore, it is considered that the degree of coronary artery calcification cannot be judged based on the Agatston score alone [17]. In the present study, the percentage of non-diagnostic patients decreased to 3.9% on S-CCTA even though the Agatston score was 100–399, suggesting that S-CCTA may contribute to improvement of the diagnostic ability for patients with coronary artery calcification regardless of the Agatston score.

However, S-CCTA requires two acquisitions, and an increase in exposure is a major issue. We investigated patients with calcification and an Agatston score of 100 or higher following the low-radiation dose protocol in which the tube voltage was reduced to 100 kV and the tube current was reduced employing the heart rate-based reconstruction method. The total effective radiation dose was low (2.7 ± 1.1 mSv) and the percentage of non-diagnostic patients decreased on S-CCTA compared with that on C-CCTA in all Agatston score categories. By the reconstruction method, the total effective radiation dose was low on full reconstruction. On patient-based analysis by the reconstruction method, the percentage of non-diagnostic patients on S-CCTA was not significantly different among the half reconstruction, APMC, and full reconstruction. No change in the percentage was also noted on segment-based analysis. For acquisition at a low tube voltage [18], noise enhancement due to an influence of beam hardening and dose reduction is of concern, and it may influence the diagnosis on S-CCTA [19,20]. The diagnoses were sufficiently accurate in the present study, and the reasons for this are considered as follows: signal to noise ratio was improved by collecting many projection data employing APMC and full reconstruction for reconstruction and by applying AIDR3D, which is an iterative reconstruction method, to all patients. Furthermore, radiation dose reduction has been achieved with next-generation adaptive iterative reconstruction procedures [21–24]. Adaptive iterative reconstruction procedures could help further reduce the radiation dose.

Limitations

There are several limitations to this study. Firstly, this was a single-center retrospective study and the number of patients was small. Secondly, the ratio of non-diagnostic patients was high on C-CCTA. When the judgment was inconsistent among two cardiologists and one radiological technologist, the case was regarded as non-diagnostic patient and segment. The strict judgment criteria may have been one cause of the high ratio of non-diagnostic patients. The influence of low voltage-induced beam hardening was unable to be ruled out. Thirdly, ICA was performed based on the C-CCTA findings, but not all indicated patients were examined by ICA, and its application was entrusted to the attending physicians, giving a selection bias to some extent. Finally, the temporal resolution is one big problem about the technique of APMC and full reconstruction. The deterioration of temporal resolution could have the risk of leading to exaggeration of misregistration artifact on S-CCTA.

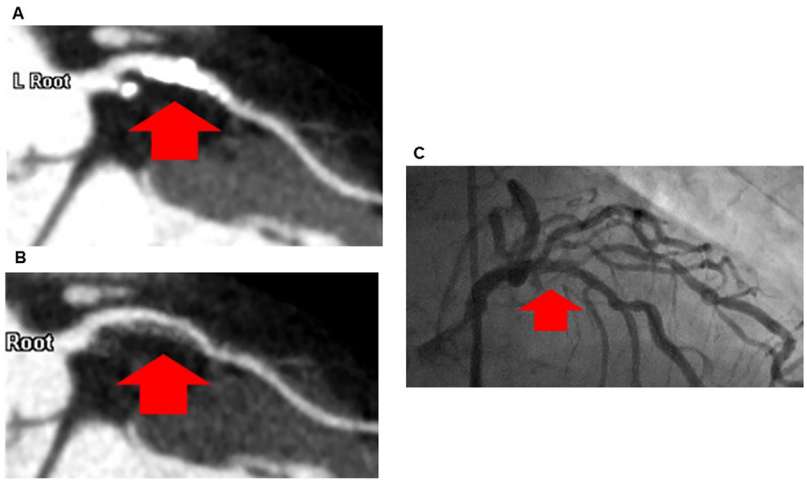

Fig. 2. 78-year-old female who underwent C-CCTA, S-CCTA, and ICA. Agatston score was 1409.6. DLP was 60.4 mGy cm (0.8456 mSv). (A) Curved MPR image of the LAD by using C-CCTA (arrow). (B) Curved MPR image of the LAD by using S-CCTA (arrow). (C) ICA of the LAD (arrow). C-CCTA, conventional coronary computed tomography angiography; S-CCTA, subtraction coronary computed tomography angiography; ICA, invasive coronary angiography; DLP, dose length product; MPR, multiplanar reformatted; LAD, left anterior descending artery.

Conclusion

The diagnostic ability of S-CCTA performed following the low-radiation dose protocol for patients with calcification was superior to that of C-CCTA alone. Patients with calcification difficult to diagnose are present at a specific rate even though the Agatston score is not high, for which this method may be clinically useful.

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Conflicts of interest

Dr. Daida has received research funds from Kyowa Hakko Kirin Company Ltd., Philips Electronics Japan, Ltd., Astellas Pharma Inc., ABBOTT JAPAN Co., Ltd., Sanofi K.K., Eisai Co., Ltd., Shionogi & Co., Ltd., Daiichi-Sankyo Company, Ltd., Dainippon Sumitomo Pharma Co., Ltd., Takeda Pharmaceutical Co., Ltd., Nippon Boehringer Ingelheim Co., Ltd., Bayer Yakuhin, Ltd., Pfizer Co., Ltd., Philips Electronics Japan, Ltd., Canon Medical Systems, FUJIFILM Corporation, Bristol-Myers Squibb Company, Boston Scientific Japan K.K., SANWA KAGAKU KENKYUSHO Co., Ltd., MSD.K.K., and endowed department from ResMed Japan K.K. Philips Electronics Japan, Ltd., Fukuda Denshi Co., Ltd. Canon Medical Systems are unrelated to this project. The other authors declare that there is no conflict of interest.

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