Impact of SSF on diagnostic performance of coronary CT angiography within one heart beat in patients with high heart rate using a 256-row detector CT

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Abstract

Objective: The aim of this study was to investigate the impact of a motion correction algorithm on diagnostic accuracy of coronary computed tomography angiography (CCTA) within one heart beat in patients with high heart rate (HR) using a 256-row detector CT.

Methods: Sixty-four consecutive patients with known or symptomatic suspected coronary artery disease and with HR⩾75bpm (mean HR 82.6±7.3 bpm) undergoing CCTA and invasive coronary angiography (ICA) within four weeks were prospectively enrolled. CCTA was performed with a 256-row detector CT (Revolution CT, GE Healthcare) using prospectively ECG-triggered volume scan in one heartbeat. All images were reconstructed using standard (STD) algorithm and a motion-correction algorithm reconstruction (Snapshot Freeze SSF; GE Healthcare) technique. The image quality of coronary artery segments was evaluated by two experienced radiologists using a four-point scale based on the 18-segment model. Diagnostic accuracy was compared between STD and SSF for significant lumen stenosis (⩾50%) of each segment with invasive coronary angiography as the reference standard for determining significant stenosis.

Results: The diagnostic sensitivity, specificity, positive predictive value and negative predictive value with STD and SSF were 93.7%, 85.1%, 50.2%, 98.8%, versus 91.9%, 95.8%, 77.9%, 98.7% on per-segment assessment; 98.7%, 74.0%, 62.9%, 99.2%, versus 96.2%, 94.4%, 77.9%, 98.7% on per-artery assessment; 100%, 14.3%, 70.5%, 100%, versus 100%, 85.7%, 93.5%, 100% on per-patient assessment, respectively. There was a significant difference in accuracy on per-patient level 71.9% versus 95.3%, on per-artery level was 81.6% versus 94.9%, and per-segment level was 86.3% versus 95.3%, respectively. The area under receiver operating characteristics curve (AUC) analysis also showed a significant improvement on diagnostic performance with the SSF technique versus with the STD algorithm on per-patient level ($p<0.001$), with corresponding AUC being 0.91 (95% confidence interval: 0.79–1.00) and 0.60 (95% confidence interval: 0.44–0.75). The mean effective dose was 2.0 mSv.

Conclusion: CCTA can be performed in patients with high heart rate within one heartbeat yielding low radiation dose. The use of SSF technique reconstruction for one heart beat CCTA achieves significant improvements in image quality and diagnostic value.

Keywords: heart rate, coronary CT angiography, diagnostic performance, motion, invasive coronary angiography

1. **Introduction**

Coronary computed tomography angiography (CCTA) has been widely utilized for the evaluation of coronary artery disease (CAD) asa non-invasive diagnostic tool [1-3]. However, insufficient temporal resolution of the most current CT scanners may result in suboptimal images due to motion artifacts, with about 12% of coronary artery segments regarded as “non-interpretable” in patient with high heart rate (HR) [4, 5]. During the past five years, attempts have been made to improve coronary artery image quality by using a software solution for vendor-specific motion correction algorithms (including the snapshot freeze-SSF, GE Healthcare). It has been reported that SSF technique can improve diagnostic accuracy using a 64-row detector CT scanner, but the effective dose of patients for CCTA was higher than 3.3 mSv [6-10]. The diagnostic performance of one heart beat CCTA using a 256-row detector CT with the use of SSF in patients with high HR has not been systematically studied. The purpose of this study was to determine the impact of the motion-correction technique, SSF on motion artifacts, image quality and diagnostic performance when compared to the images acquired with standard (STD) reconstruction. We hypothesized that the low dose one-beat CCTA with SSF can still achieve high image quality score and high diagnostic value in patients with high HR.

2. Materials and methods

2.1 Study population

We prospectively enrolled 64 consecutive patients with known or symptomatic suspected CAD, who underwent CCTA and invasive coronary angiography (ICA) within 4 weeks from December 2015 to July 2016. In this study, inclusion criteria were patients in sinus rhythm with HR higher than 75 beats per minute (bpm) during the CT scan, more than 18 years old, and estimated glomerular filtration rate⩾60 ml/min. Patients were excluded if they had known allergy to iodinated contrast agent, irregular HR, permanent or persistent atrial fibrillation, pregnancy, previous percutaneous coronary revascularization and/or coronary artery bypass graft surgery, unable to hold their breath for 10 seconds. Beta-blockers and nitroglycerin were not taken prior to the scan. All patients provided informed written consent. This study was approved by local institutional review board.

2.2 CCTA scanning protocols

Prospectively electrocardiography (ECG) triggered volume CCTA was performed in all patients in one heart-beat using a 256-row detector CT scanner (Revolution CT, GE Healthcare, Milwaukee, WI). Scanning parameters included 256×0.625 collimation, and detector coverage was 120 mm, 140 mm or 160 mm based on the scout image with a matrix size of 512×512 pixels and a reconstruction slice thickness and slice interval of 0.625 mm. Gantry rotation speed was 0.28 second per rotation and with automatically selected tube voltage of 100 kV or 120kV by kV assist and Smart-mA based on the scout image of the patients. The data acquisition window was set at 40%-55% of the R-R interval when HR was lower than 85 bpm, 30%-60% of the R-R interval when HR was higher than 85 bpm. Contrast medium (370 mg iodine/ml, Ultravist, Bayer Schering Pharma, Berlin, Germany) 50–60 ml was injected at 4.0-5.0 ml/s flow rate based on the body mass index and vein condition followed by 25 or 35 ml of saline by using a dual-head power injector. Coronary artery calcium scoring was not performed prior to the contrast-enhanced studies.

2.3 CCTA image reconstruction and analysis

To generate SSF reconstructions, CCTA datasets were reconstructed with 3-phase recon (left, target, right) on the console target phase with +/-~80 ms phases, and sent to AW 4.6 Advantage Workstation (GE Healthcare) for SSF processing. In this processing, vessel tracking is done on the target center phase volume and motion characterization and compensated from the neighboring left and right phases. All images were reconstructed using both standard (STD) algorithms and SSF technique with 50% of adaptive statistical iterative reconstruction-v (ASIR-V, GE Healthcare, Milwaukee, WI) on the target phase, which was with least motion artifacts. All images were sent to the institutional picture archiving and communication systems (PACS).

To assess the coronary segment image quality of STD and SSF, subjective analysis was performed by 2 independent readers (with 8 and 9 years of experience in cardiac CT imaging). STD and SSF reconstructions were analyzed in a random order to minimize any reader bias on the workstation. The use of curved multi-planar reformats (CPR) reconstructions and axial datasets were at the discretion of each reader. Image quality was evaluated using the 18-segment model based on the Society of Cardiovascular Computed Tomography guidelines [11]. All segments, if present, with longer than 15 mm and 1.5 mm or greater in diameter were evaluated. A four-point scale system was used to assess the image quality: 1, excellent image quality free of artifacts; 2, good image quality with minor artifacts, but fully evaluable; 3, adequate image quality with moderate artifacts, but acceptable for diagnosis; 4, non-diagnostic image quality with severe artifacts. Evaluable segments were assessed independently by the same two readers for the absence or presence of significant lumen stenosis, defined as a diameter narrowing ⩾50%. Image quality and stenosis was assessed on a per-segment, per-artery, and per-patient level both in the STD algorithm and SSF technology. If there was disagreement in the image quality score and stenosis rating between two readers, consensus agreement was reached during a joint reading session. Non-evaluable segments were considered as positive findings for diagnostic purposes.

2.4 Invasive coronary angiography

ICA images were evaluated by a single skilled observer (with 8 years of experience) blind to results of both STD algorithm and SSF technology reconstruction. At least two orthogonal views of each coronary artery were analyzed to determine stenosis, and additional views were used whenever it was necessary. The coronary angiogram was used as the reference standard to determine significant stenosis and independent of the CCTA results.

2.5 Radiation dose of CCTA

The effective radiation dose associated with the CT examination was based on the dose-length product (DLP), using the chest-specific conversion coefficient for the chest k =0.014(mSv×[mGy×cm]$^{-1}$) in adult [12].

2.6 Statistical analysis

Quantitative variables were described as mean and standard deviation. Categorical variables were expressed by frequencies or percentage if not otherwise noted. Kappa coefficient was used to test inter-observer agreement (kappa 0–0.2, slight agreement; 0.21–0.4, fair agreement; 0.41–0.6, moderate agreement; 0.61–0.8, substantial agreement; and 0.8–1, almost perfect agreement). Between the STD algorithm and SSF technology, image quality scores were compared using Wilcoxon matched pairs signed-ranks test. Comparison of the interpretability and diagnostic performance was performed with the pair-wise McNemar's test. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) in the two groups was calculated on per-segment, per-artery, per-patient, and in left anterior descending (LAD), left circumflex (LCX), and right coronary artery (RCA). The areas under curve (AUC) by receiver operating characteristic analyses were used to compare the diagnostic performance between these two image reconstruction techniques. P values of less than 0.05 were considered as statistically significant. The statistical analysis was performed using SPSS version 17.0 (SPSS, Chicago, IL, USA).

3. Results

3.1 Patient characteristics

All sixty-four enrolled patients underwent CCTA and ICA within 9.1 ± 6.2 days. There was a high prevalence of stenosis$\geqslant$50% on a per-patient level which was 67.2% (43/64). Clinical characteristics of this study population are shown in Table 1. Table 2 shows scanning and reconstruction parameters as well as the radiation dose.

3.2 Subjective assessment of image quality scores and interpretability

A total of 804 coronary segments were assessed using STD and SSF reconstructions. Three hundred forty-eight segments were missing due to anatomical variants or shorter than 15mm or <1.5 mm in diameter. Inter-observer agreement for image quality was associated with the STD and SSF group, with Kappa=0.704 and Kappa=0.776, respectively. In comparison with STD, the use of SSF was associated with an improvement in image quality scores and the interpretability on per-segment, per-artery and per-patient level, especially in RCA. However, there was no significant difference in the left main artery. Differences between the STD and SSF assessment in terms of image quality and interpretability are shown in Table 3.

3.3 CCTA diagnostic accuracy between STD and SSF

Between STD and SSF, the diagnostic accuracy on per-patient level was 71.9% versus 95.3% ($\chi 2$=8.21, p=0.04), on per-artery level was 81.6% versus 94.9% ($\chi 2$=21.82, p<0.001) and per-segment level was 86.3% versus 95.3% ($\chi 2$=38.56, p<0.001) analysis, respectively. The diagnostic performance of CCTA using STD algorithm and SSF technique reconstructions are shown in Tables 4 and 5. When compared to the STD, the use of SSF was also associated with an improvement in specificity, PPV, and NPV on per-segment level assessment, and in specificity, PPV on per-artery level and per-patient level assessment. However, there were no statistically significant differences in the sensitivity, and NPV on per-artery and per-patient level assessment between STD and SSF. In addition, a significant difference was found regarding the diagnostic performance on the per-segment, per-artery and per-patient levels between STD and SSF, with AUC being 0.89 versus 0.94, 0.86 versus 0.95 and 0.60 versus 0.91, respectively (Figure 1). The number of false positive was significantly decreased on per-segment, per-artery and per-patient level when using SSF technique.

There was only 3 left main artery stenosis ≥50% and no significant difference was found among STD, SSF and ICA. We assessed the diagnostic performance in the other three vessels. In comparison with the STD, the use of SSF technique reconstruction resulted in significant improvement of diagnostic performance in LAD, LCX and RCA (Table 5). The SSF group was also associated with an improvement in specificity in LAD, and improvement in specificity and PPV in LCX and RCA, with reduction of the number of false positives. The AUC showed a significantly improvement in the SSF group when compared with STD in LAD, LCX and RCA, with AUC being 0.77 versus 0.92, 0.77 versus 0.93 and, 0.81 versus 0.95, respectively (Figure 2). Figures 3 and 4 are two examples of CCTA examination in two patients with high HR using STD algorithm and SSF technique reconstruction, and coronary artery stenosis with ICA as the reference standard.

4. Discussion

Although SSF technique has been performed for several years, our study is the first report to document the impact of it on image quality, interpretability and diagnostic performance of one heart beat CCTA in patients with high HR using a latest 256-row detector CT scanner. Previous studies have showed that SSF as a vendor-specific for motion correction algorithm can improve image quality, interpretability [1, 2, 6-10, 13-19], and it also can improve diagnostic accuracy using a 64-row detector CT scanner [2, 6-10]. However, all of these studies were performed in patients with low HR and with resultant higher radiation dose. The current study is designed to fill the gap of addressing this limitation by using one heartbeat CCTA in patients with high heart rate.

With the development of detector rows and the reduction of gantry rotation time in the latest 256-row detector CT scanner, SSF technique can correct motion artifacts using single cardiac cycle information from adjacent phase to the target phase in patients with low and high HR within one heartbeat. The motion velocity and path of coronary arteries from adjacent cardiac phases are characterized and the information is used to calculate an optimal estimation of the vessel lumen at the target phase by SSF [7, 8]. SSF technique may play an important role in patients with high HR to improve temporal resolution based on software. In this study, we evaluated the impact of SSF technique on image quality, interpretability and diagnostic performance in patient with high HR, and our results are promising with satisfactory findings achieved.

Our study is in agreement with other reports with regard to the usefulness of SSF in improving image quality and diagnostic value. SSF can improve image quality and interpretability in the three coronary arteries and on the per-segment, per-artery, per-patient assessment, according to previous studies by Leipsic [7] and Carrascosa [9] et al. When compared to the STD, there was higher significant improvement in image quality and interpretability with SSF technique reconstruction in the RCA than LAD and LCX. Because of the rapid velocity is in the RCA (mean, 35.8±2.8 mm/sec), and the velocities of RCA are higher than those of the LAD (mean, 20.2±2.3 mm/sec) and LCX (mean, 24.9±2.5 mm/sec) throughout the entire cardiac cycle [20]. Despite these differences, the AUC for RCA was only a small difference between STD and SSF compared to LAD and LCX. We also found that the improvement in interpretability of the LCX was not statistically significant, perhaps because some of the distal LCX arteries were small, thin and with more motion artifacts. Significant difference was defined between STD and SSF on per-artery level and per-segment level assessments, and also in the analysis of CAD in the LAD, LCX and RCA three vessels. These findings are similar to the results from Li [6] et al and Leipsic [7]. However, another report by Carrascosa [9] observed only mild differences regarding the diagnostic performance in patients with HR lower than 65 bpm. By using a quantitative pulsating coronary phantom, Cho [2] et al demonstrated that no difference in measurement error of the area or lumen when HR was 60 bpm. In contrast, the measurement errors for STD were substantially higher than those found for SSF when HR was reached to 80 and 100 bpm in their study. The mean HR was higher than 75 bpm in this study, and the diagnostic performance was improved by using SSF compared with STD, thus findings further confirm the clinical value of SSF in patients with high heart rates.

Despite the mean HR higher than 75 bpm, the effective dose is lower than previous reports [1, 6, 9, 10, 13, 14, 16, 19]. This is due to the use of one heart beat acquisition and prospectively ECG-gated CCTA was used in all patients. The effective dose of 2.0 mSv is much lower than that reported in Leipsic et al who was the first to report the use of motion correction algorithm in retrospectively ECG-gated CCTA. Our effective dose was also lower than the 2.4 mSv as reported in Andreini [16] et al that used the same SSF method in the prospectively ECG-triggered CCTA. Dose less than 1.0 mSv has been reported in some recent studies when using advanced dose-reduction strategies [21, 22], thus, further studies with use of more effective dose-reduction algorithms deserve to be investigated while still maintaining diagnostic images.

There are some limitations that need to be acknowledged in this study. First, this is a single center experience with inclusion of small sample size and the highest HR was 106 bpm. Further, we did not compare the differences with STD and SSF in patients with HR lower than 75 bpm. Patients with higher HR, irregular HR and atrial fibrillation were not enrolled in this study, thus further studies are needed to include more patients with consideration of above factors. Second, coronary artery calcium scoring was not assessed in this group of patients as we focused on the image quality, interpretability and diagnostic value of CCTA between STD and SSF algorithms. The presence of significant or heavy coronary artery calcification could lower the accuracy of luminal stenosis assessment, thus, further studies are necessary to determine if SSF still performs better than STD in the presence of coronary calcification.. Third, there was a high prevalence of CAD, which could affect the results and image analysis and interpretation. The current practice is to recommend CCTA in patients with low to intermediate pretest probability of CAD as these patients will benefit from this less invasive imaging modality. Therefore, future studies should be conducted to target on these patients with regard to diagnostic value and low radiation dose with use of the latest multi-slice CT scanners.

In conclusion, this study shows that CCTA using a 256-row detector CT scanner can be performed within one heart beat in patients with HR over 75 bpm yielding low radiation dose. The use of SSF technique reconstruction for one heart beat CCTA without heart rate-control achieves significant improvements in image quality and diagnostic value in patients with high heart rates.

Conflict of interest

All authors declared that there is no conflict of interest in this study.

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Figures and figure legends

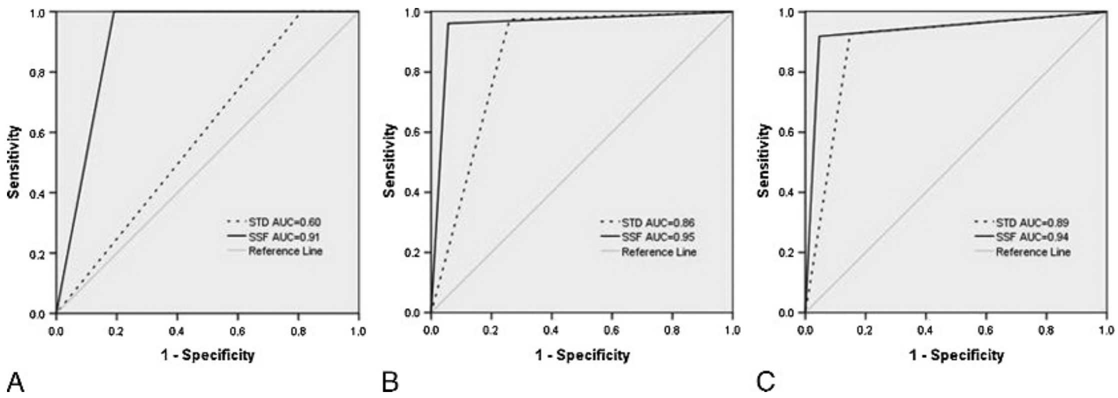

Fig.1. The area under receiver-operating characteristic curves for detection of lumen stenosis⩾50% of all 64 patients show with standard and snapshot freeze algorithm on per-patient (A), per-artery (B), per-segment (C) levels, respectively.

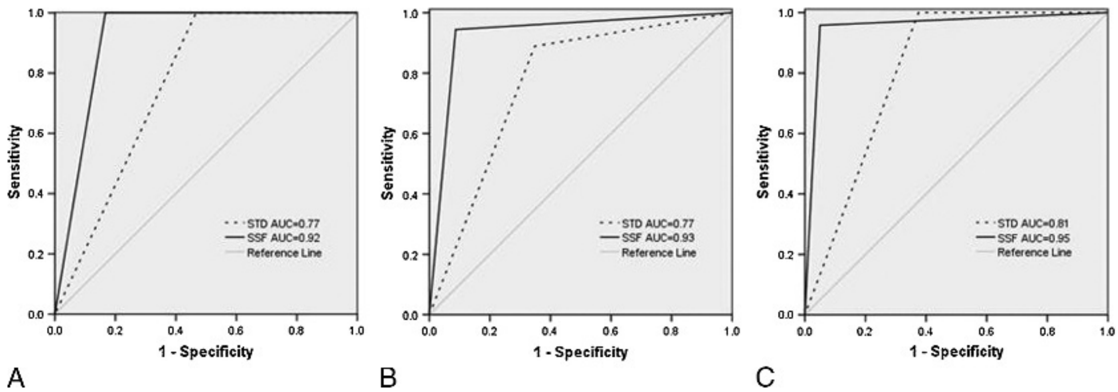

Fig.2. The area under receiver-operating characteristic curves for detection of lumen stenosis⩾50% of all 64 patients show with standard and snapshot freeze algorithm on the left anterior descending coronary artery (D), left circumflex coronary artery (E), right coronary artery (F).

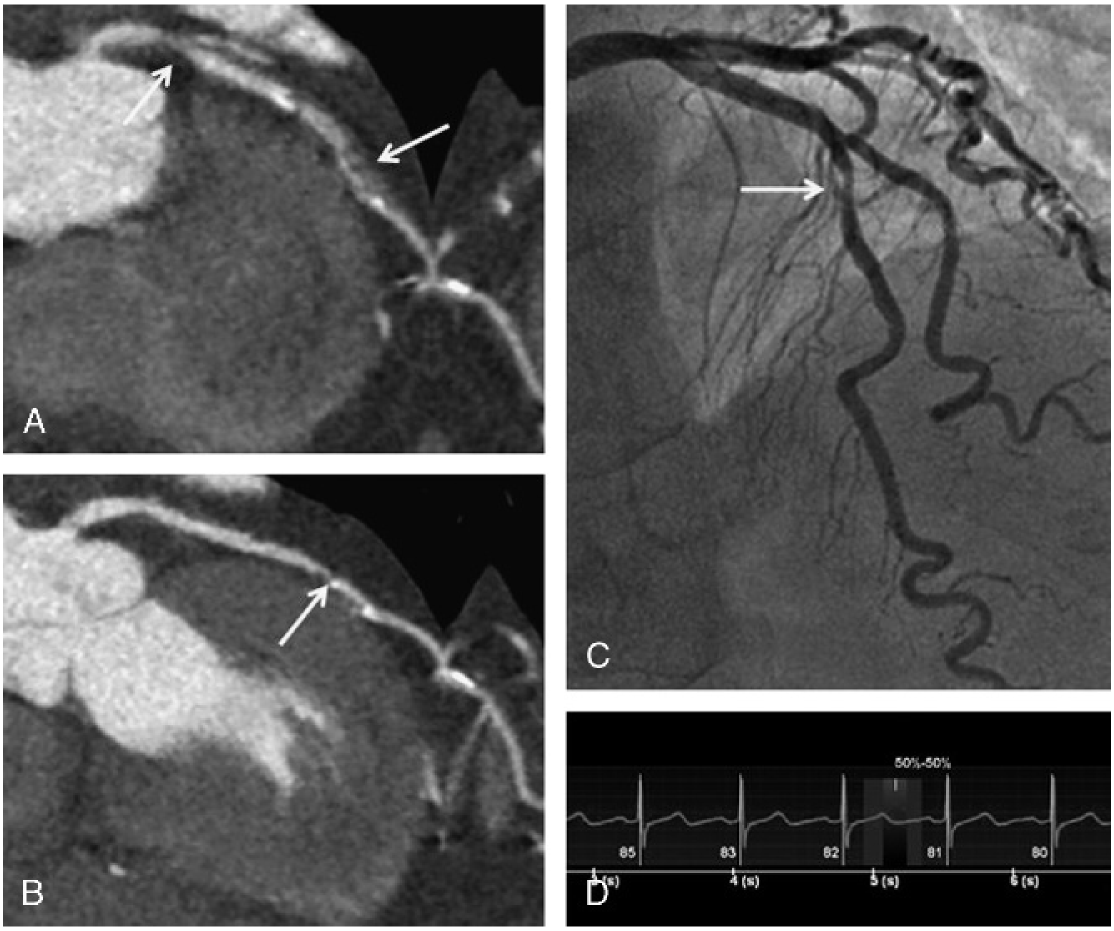

Fig.3. A 65-year-old man with a body mass index of 23.04 kg/m^2 was suspected coronary artery disease. The effective dose from coronary CT angiography was 0.76 mSv. Curved multiplanar reformatted image (A) with standard algorithm shows significant stenosis *(arrow)* at proximal and mid segment of left anterior descending branch. Image (B) with snapshot freeze technique shows no stenosis at proximal segment and a significant stenosis *(arrow)* at mid segment of left anterior descending branch. Invasive coronary angiography (C) shows a significant stenosis *(arrow)* at mid segment of left anterior descending branch. The ECG report (D) shows that the heart rate was 81 bpm and heart rate variability was 7 bpm during the scan and the reconstruction phase was 50% R-R interval.

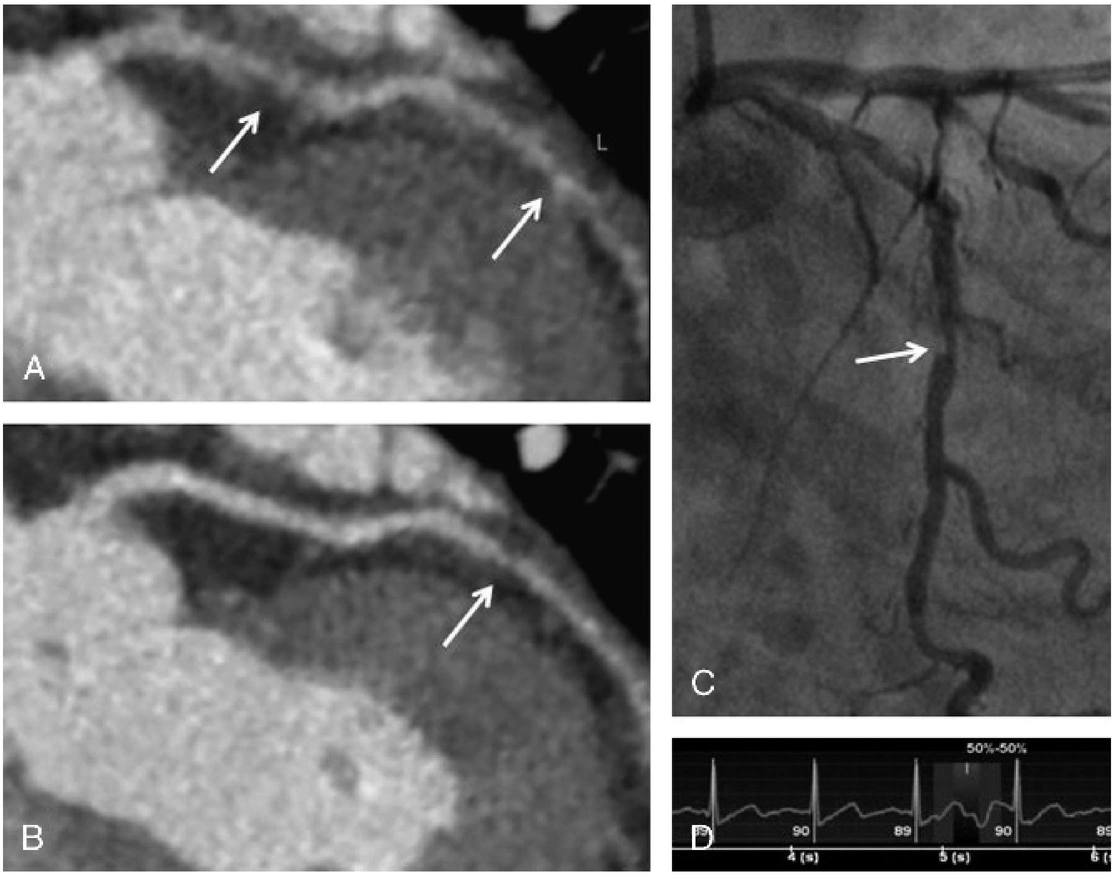

Fig.4. A 59-year-old man with a body mass index (BMI) of 26.49 kg/m^2 was suspected coronary artery disease. The effective dose from coronary computed tomography angiography was 2.26 mSv. Curved multiplanar reformatted image (A) with standard algorithm was non-interpretability *(arrow)* at left circumflex, and shows a stenosis at proximal segment. Image (B) using snapshot freeze technique shows a stenosis at distal segment *(arrow)* of left circumflex. Invasive coronary angiography (C) shows a significant stenosis *(arrow)* at distal segment of left circumflex. The ECG report (D) shows that the heart rate was 92 beat per minute and heart rate variability was 4 bpm during the scan and the reconstruction phase was 50% R-R interval.

TABLE 1. Patient Characteristics

Patients Characteristics	n = 64
Male	42 (65.6)
Age, y	59.5 (9.2, 34–76)
Body mass index, kg/m^2	25.8 (3.4, 16.8–34.4)
HR during the scan, beats per minute	82.5 (7.3, 75–106)
HR variability, beats per minute	8.4 (4.8, 2–23)
Hypertension	44 (68.8)
Dyslipidemia	11 (17.2)
Smoking	25 (39.1)
Diabetes mellitus	22 (34.4)
Family history of coronary artery disease	8 (12.5)

Values are presented as mean(SD, range) or n (%).

TABLE 2. Scanning, Reconstruction Parameters, and Radiation Dose

Scanning and Radiation Dose	n = 64
kV (100 kV/120 kV)	34 (53.1)/30 (46.9)
mA	521.6 (86.3, 334–599)
Scan length (120 mm/140 mm)	2 (3.1)/62 (96.9)
Target phases %	47.8(8.2)
CTDIvol mGy	10.3 (5.1, 1.9–22.8)
DLP mGy	143.7 (71.3, 26.5–318.7)
Effective dose mSv	2.0 (0.9, 0.37–4.4)

Values are presented as mean(SD, range) or n (%).

CTDI indicates computed tomography volume dose index; DLP, dose-length product.

TABLE 3. The Image Quality Scores of Segment, Artery, and Interpretability Between Standard and Snapshot Freeze Group

Image Quality and Interpretability	Standard	Snapshot Freeze	*P*
Segment score			
1	41.9 (337/804)	71.4 (574/804)	<0.001
2	42.0 (338/804)	22.8 (183/804)	<0.001
3	8.5 (68/804)	4.43 (35/804)	0.001
4	7.6 (61/804)	1.5 (12/804)	<0.001
Artery mean score			
RCA	1.73 (0.71)	1.33 (0.58)	<0.001
LM	1.15 (0.40)	1.14 (0.39)	0.829
LAD	1.72 (0.71)	1.29 (0.58)	<0.001
LCX	1.97 (0.82)	1.47 (0.73)	<0.001
Interpretability on every artery			
RCA	68.8 (44/64)	96.9 (62/64)	<0.001
LM	98.4 (63/64)	100 (64/64)	1.000
LAD	81.3 (52/64)	96.9 (62/64)	0.005
LCX	82.8 (53/64)	92.2 (59/64)	0.109
Interpretability			
Per-segment	92.4 (743/804)	98.5 (792/804)	<0.001
Per-artery	84.8 (217/256)	97.3 (249/256)	<0.001
Per-patient	68.8 (44/64)	92.2 (59/64)	0.001

Values are presented as % (n/N) or mean (SD).
LM indicates left main artery.

TABLE 4. Diagnostic Performance Between Standard and Snapshot Freeze on 3 Levels

Level	Standard, % (n/N)	Snapshot Freeze, % (n/N)	*P*
Per-segment (n = 804)			
Sensitivity, % (n/N)	93.7 (104/111)	91.9 (102/111)	0.604
(95% CI), %	(87.4–97.4)	(85.2–96.2)	
Specificity, % (n/N)	85.1 (590/693)	95.8 (664/693)	<0.001
(95% CI), %	(82.3–87.7)	(94.1–97.2)	
PPV, % (n/N)	50.2 (104/207)	77.9 (102/131)	<0.001
(95% CI), %	(43.2–57.3)	(69.8–84.7)	
NPV, % (n/N)	98.8 (590/597)	98.7 (664/673)	0.001
(95% CI), %	(97.6–99.5)	(97.5–99.4)	
AUC (ROC)	0.89	0.94	0.205
(95% CI)	(0.86–0.92)	(0.91–0.97)	
Per-artery (n = 256)			
Sensitivity, % (n/N)	98.7 (78/79)	96.2 (76/79)	0.620
(95% CI), %	(93.2–100.0)	(89.3–99.2)	
Specificity, % (n/N)	74.0 (131/177)	94.4 (167/177)	<0.001
(95% CI), %	(66.9–80.3)	(89.9–97.3)	
PPV, % (n/N)	62.9 (78/124)	88.4 (76/86)	<0.001
(95% CI), %	(53.8–71.4)	(79.7–94.3)	
NPV, % (n/N)	99.2 (131/132)	98.2 (167/170)	0.634
(95% CI), %	(95.9–100.0)	(94.9–99.6)	
AUC (ROC)	0.86	0.95	0.030
(95% CI)	(0.81–0.90)	(0.92–0.98)	
Per-patient (n = 64)			
Sensitivity, % (n/N)	100.0 (43/43)	100.0 (43/43)	1.000
(95% CI), %	(91.8–100.0)	(91.8–100.0)	
Specificity, % (n/N)	14.3 (3/21)	85.7 (18/21)	<0.001
(95% CI), %	(3.1–36.3)	(63.7- 97.0)	
PPV, % (n/N)	70.5 (43/61)	93.5 (43/46)	0.002
(95% CI), %	(54.3–78.4)	(82.1–98.6)	
NPV, % (n/N)	100.0 (3/3)	100.0 (18/18)	1.000
(95% CI), %	(29.2–100.0)	(81.5–100.0)	
AUC (ROC)	0.60	0.91	<0.001
(95% CI)	(0.44–0.75)	(0.79–1.00)	

AUC (ROC) indicates area under the receiver operating characteristic curve.

TABLE 5. Diagnostic Performance Between Standard and Snapshot Freeze on 3 Arteries

Artery	Standard, % (n/N)	Snapshot Freeze, % (n/N)	*P*
LAD (n = 64)			
Accuracy	75.4 (49/65)	89.2 (58/65)	
Sensitivity, % (n/N)	100.0 (34/34)	100.0 (34/34)	1.000
(95% CI), %	(89.7–100.0)	(89.7–100.0)	
Specificity, % (n/N)	53.3 (16/30)	83.3 (25/30)	0.012
(95% CI), %	(34.3–71.7)	(65.3–94.4)	
PPV, % (n/N)	70.8 (34/48)	87.2 (34/39)	0.066
(95% CI), %	(55.9–83.1)	(72.6–95.7)	
NPV, % (n/N)	100.0 (16/16)	100.0 (25/25)	1.000
(95% CI), %	(79.4–100.0)	(86.3–100.0)	
AUC (ROC)	0.77	0.92	0.003
(95% CI)	(0.64–0.89)	(0. 84–1.00)	
LCX (n = 64)			
Sensitivity, % (n/N)	94.4 (17/18)	94.4 (17/18)	1.000
(95% CI), %	(72.7–99.9)	(72.7–99.9)	
Specificity, % (n/N)	65.2 (30/46)	91.3 (42/46)	0.002
(95% CI), %	(49.8–78.7)	(79.2–97.6)	
PPV, % (n/N)	51.5 (17/33)	81.0 (17/21)	0.029
(95% CI), %	(33.5–69.2)	(62.3–91.6)	
NPV, % (n/N)	96.7 (30/31)	97.7 (42/43)	1.000
(95% CI), %	(83.3–99.2)	(86.2–99.7)	
AUC (ROC)	0.77	0.93	0.002
(95% CI)	(0.65–0.89)	(0.84–1.00)	
RCA (n = 64)			
Sensitivity, % (n/N)	100.0 (24/24)	95.8 (23/24)	1.000
(95% CI), %	(85.8–100.0)	(78.9–99.9)	
Specificity, % (n/N)	62.5 (25/40)	95.0 (38/40)	<0.001
(95% CI), %	(45.8–77.3)	(83.1–99.4)	
PPV, % (n/N)	61.5 (24/39)	92.0 (23/25)	0.007
(95% CI), %	(44.6–76.6)	(74.8–97.8)	
NPV, % (n/N)	100.0 (25/25)	97.4 (38/39)	1.000
(95% CI), %	(86.3–100.0)	(84.8–99.6)	
AUC (ROC)	0.81	0.95	0.002
(95% CI)	(0.71–0.92)	(0.00–1.00)	

AUC (ROC) indicates area under the receiver operating characteristic curve; CI, confidence interval.