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# Prospective-triggered high-pitch spiral versus sequential dual-source CT coronary angiography: comparison of image quality and radiation dose

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► ***Original article***

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## ABSTRACT

***Background***: Prospectively electrocardiography (ECG)-triggered high-pitch spiral coronary computed tomography angiography (CCTA) is a unique scan mode for dual -source CT (DSCT). Our reports aim to compare image quality and radiation dose of CCTA using high-pitch spiral or sequential acquisition mode in patients with low and stable heart rates. ***Materials and Methods***: Patients with low and stable heart rates (HR) (HR ≤ 70 beats per minute [bpm]; heart rate variability [HRV] < 10 bpm) were randomly assigned to high-pitch spiral mode (group A; n = 80) or sequential acquisition mode (group B; n = 80). Image quality scores, image noise, effective radiation dose and influencing factors on image quality were assessed. ***Results:*** Mean image quality scores were 1.51 ± 0.32 and 1.70 ± 0.38 for groups A and B (P < 0.05), respectively. Image noises of the two groups were 19.05±4.70 Hu and 27.21±8.88 Hu (P < 0.05). Contrast media cost in group A was lower than group B (P < 0.05). No statistical difference was found in the rate of diagnostic patients between the two groups (P = 0.416). The estimated radiation dose of group A was 26.0% reduced compared with group B (0.74 ± 0.34 mSv vs. 1.00 ± 0.48 mSv, P < 0.05). ***Conclusion:*** In patients with regular and low heart rates, the prospectively high-pitch spiral acquisition mode can reduce radiation dose and contrast media cost while maintaining image quality compared with the prospectively sequential mode.

***Keywords:*** *Tomography, X-ray computed, coronary angiography, image quality, radiation dose.*

## INTRODUCTION

The recent rapid developments in multi-detector CT have made it an important tool in the assessment of coronary arterial stenosis [1, 2]. Retrospectively ECG-triggered CCTA is associated with high radiation exposure (8-18 mSv) [3]. As one of the most promising radiation saving techniques, prospective triggered sequential CCTA reduced the radiation dose to 1.5-2.5 mSv for 64-slice DSCT [3-6]. For 128-slice DSCT, prospectively ECG-triggered CCTA can be performed with a sequential or high-pitch spiral scan mode. A significant 75% reduction in the radiation dose was achieved with the sequential scan mode compared with the retrospectively ECG-triggered scan mode [7-9]. Prospectively ECG-triggered high-pitch spiral CCTA is a scan mode unique to DSCT. This method can acquire complete data in only one

heart beat with a remarkable reduction of radiation dose while maintaining similar image quality for patients with low and stable heart rates compared with retrospectively ECG-triggered CCTA [6-9]. However, to the best of our knowledge, little information is known about the superiority of prospectively ECG-triggered high-pitch spiral CCTA compared with sequential CCTA. The purpose of our study was to evaluate image quality and radiation dose of prospectively ECG-triggered high-pitch spiral or sequential CCTA in patients with low and stable heart rates using a 128-slice DSCT.

## MATERIALS AND METHODS

### *Study population*

We prospectively enrolled 170 consecutive patients with low (≤ 70 bpm) and stable (HRV, defined as the maximum HR minus the minimum HR, < 10 bpm) heart rates from April 2015 to February 2016. The patients were all suspected of coronary artery disease and underwent CCTA examination. Exclusion criteria were as follows: arrhythmia, renal insufficiency, unstable clinical condition, contraindications to beta-blockers and inability to follow breath-hold instructions. Six patients with arrhythmia and four with bypass grafts were excluded. A total of 160 patients were randomly assigned to the high-pitch group (group A, n = 80) or sequential group (group B, n = 80). In general, patients with negative CCTA or good response to medical treatment were not referred to conventional coronary angiography (CCA). Finally, 71 patients (group A, n=35; group B, n=36) underwent CCA within 4 weeks after CCTA. The study was approved by the local ethics committee, and written informed consent was obtained from all patients prior to examination.

### *CT protocol and image reconstruction*

All imaging was performed using a 128-slice DSCT system (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany). CCTA data in group A were acquired in a prospectively ECG-triggered high-pitch mode in one heartbeat. The acquisition window was started at 60% R-R interval (figure 1). A prospectively ECG-triggered sequential mode was used for data acquisition in group B. The acquisition window was 70%-70% R-R interval. The entire heart was covered in three or four heart beats. Gantry rotation time was 0.28 s. Detector collimation was 2×64×0.6 mm. A z-axis flying focal spot was applied, resulting in an acquisition of 2×128-slice images per rotation. An automatic tube potential selection algorithm (CARE kV) was used. All patients received 0.5 mg nitroglycerin sublingually 3 minutes prior to scanning. Patients with an HR > 65 bpm received oral beta-blockers (50 mg metoprolol tartrate; AstraZeneca) one hour prior to examination to control heart rate.

The amount of Iohexol injection (Omnipaque 350, 350 mg I/mL; GE Healthcare) was applied according to the body weight (0.8 mL/kg for group A and 1 mL/kg for group B) of an individual patient with a flow rate of 4.0-4.5 mL/s (group A) or 4.5-5.0 mL/s (group B) followed by 40 mL of 20% blended contrast with saline with the same flow rate. A bolus tracking technique was used to trigger scanning with a threshold of 120 Hu at the root of the ascending aorta.

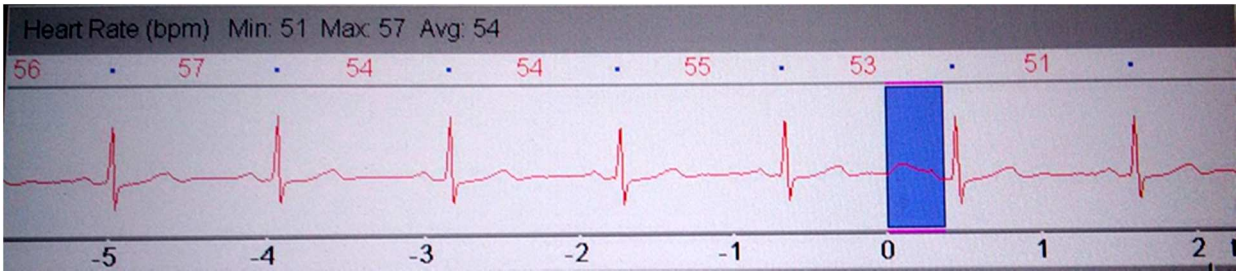


**Figure 1.** The ECG signal demonstrated a regular heart rate, and the data acquisition was exclusively performed in only one cardiac cycle.

All CCTA images were reconstructed with a slice thickness of 0.6 mm and an increment of 0.5 mm. An iterative reconstruction algorithm (sonogram-affirmed iterative reconstruction, SAFIRE, strength 3) was used with a medium-soft convolution kernel (I26f) and an additional sharp convolution kernel (I46) in patients with coronary calcium.

### *Image evaluation*

Reconstructed images were sent to an offline post-processing workstation (SOMATOM Definiton; SIEMENS, Forchheim, Germany) Syngo.Via, Siemens Forchheim, Germany). Two blinded observers with at least 5 years of experience in cardiac imaging assessed image quality independently on per-segment and per-patient bases. A 16-segment model of the American Heart Association was used to evaluate image quality with a 4-point scale as follows: 1 = excellent, no artifacts; 2 = good, minor artifacts; 3 = moderate, moderate artifacts, but still diagnostic; 4 = poor, severe artifacts, non-diagnostic (figure 2) (9, 10). Only segments with a diameter of ≥1.5 mm were evaluated. Discrepancy was resolved by consensus of the two observers. Furthermore, the objective image quality parameters were measured. Signal intensity was measured at the root of ascending aorta (AA), the proximal part of left main artery (LM), the right coronary artery (RCA), the left ascending artery (LAD), the left circumflex artery (LCX) and mediastinal fat. Image noise was defined as the corresponding standard deviation at the aortic root. The signal-to-noise ratio (SNR) was calculated by dividing the mean signal intensity by image noise. The contrast-to-noise ratio (CNR) was calculated by dividing contrast values (vessel attenuation – fat attenuation) by image noise. One cardiologist (5 years of experience in CCA) evaluated all coronary angiograms. All available segments were assessed and categorized (greater than 50% or not greater than 50%) using a validated quantitative coronary angiography (QCA) algorithm. The stenoses were classified as significant if the lumen diameter reduction was ≥50%.

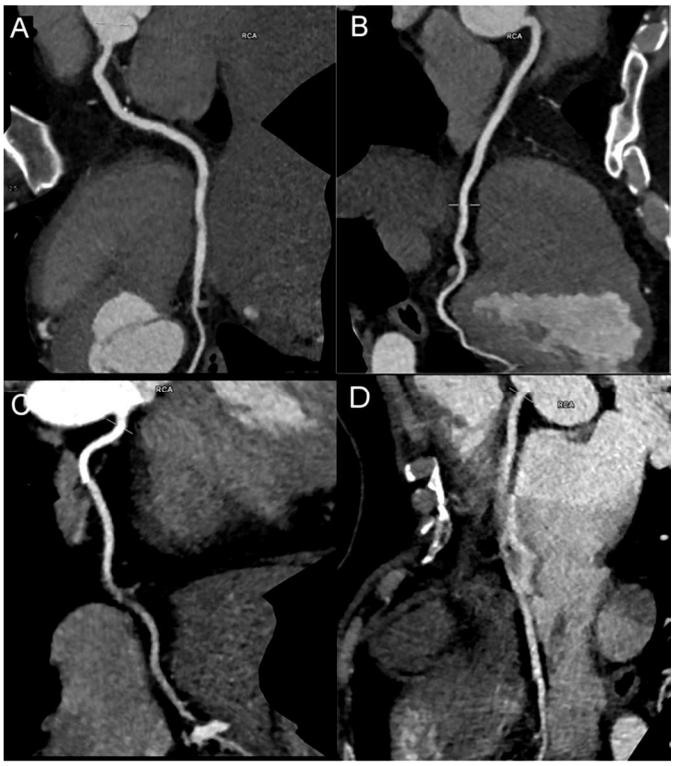


**Figure 2.** Subjective image quality was evaluated using a 4-point scale: 1 = excellent, no artifacts (A); 2 = good, minor artifacts (B); 3 = moderate, moderate artifacts but still diagnostic (C); 4 = poor, severe artifacts, non-diagnostic (D).

***Radiation dose estimation***

The study investigators obtained the parameters relevant to radiation dose, including volume CT dose index (CTDIvol) and dose-length product (DLP) from the scan protocol generated by the CT system after each coronary CTA study. The estimated radiation dose (ED) was calculated by multiplying the DLP by the conversion coefficient (0.014 mSv · mGy-1 · cm-1) at the chest (11). This weighting factor is considered to be derived from the most self-consistent and reliable dataset.

***Statistical analysis***

All statistical analyses were performed with using SPSS software version 17.0 (SPSS Inc. Chicago, USA). Quantitative variables were expressed as the means ± standard deviations, and categorical variables were expressed as frequencies and percentages. The Student's t-test, Mann-Whitney U test, Chi-square test and Fisher's exact test were performed to analyze the differences in patient characteristics, image acquisition parameters, objective image quality parameters, and estimated radiation dose. The inter-observer agreement between the two observers was evaluated with kappa analysis (κ > 0.75, excellent agreement; κ = 0.4-0.75, good agreement). Mean image quality grade between groups A and B was assessed using the Mann-Whitney U test. The rates of diagnostic segments and patients were compared using the Chi-square test. Statistical significance was defined as a P-value of < 0.05.

The diagnostic performance of CTCA for the diagnosis of significant coronary artery disease compared with the reference standard was determined using sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) and their 95% confidence intervals.

## RESULTS

The patient characteristics and scan parameters are summarized in table 1. Significant differences in image noise, contrast agent cost, kV ratio and CNR ($P$ < 0.05) were noted. The estimated radiation dose of group A was 26.0% reduced compared with group B (0.74 ± 0.34 mSv vs. 1.00 ± 0.48 mSv, $P$ < 0.001). No significant differences in mean HR, HRV, and other patient characteristics and scan parameters were noted ($P$ > 0.05).

Image quality scores of coronary artery segments in the two groups are summarized in table 2. In group A, a total of 980 segments were included in the analysis, of which 99.4% (974/980) segments were diagnostic (figure 3). In group B, 978 segments were evaluated, of which 98.9% (967/978) was diagnostic. No significant difference was observed in the rate of diagnostic segments between groups A and B (P = 0.222). Mean image quality scores were 1.51 ± 0.32 and 1.70 ± 0.38 for groups A and B, respectively. A statistical difference in image quality scores was noted between groups A and B (P < 0.001). On a per-patient basis, the rates of diagnostic patients were 92.5% (74/80) and 88.8% (71/80) for groups A and B, respectively. No statistical difference was observed regarding the rate of diagnostic patients between the two groups (P = 0.416). On a per-segment basis, the rates of diagnostic segments between the two groups were 98.7% (312/316) and 98.7% (306/310), 100% (412/412) and 99.3% (415/418), 100% (250/250) and 98.4% (246/250) in RCA, LAD (including LM) and LCX, respectively. No statistical difference was found in the rate of diagnostic segments in RCA and LAD (P=0.551, P=0.085). A statistical difference in the diagnostic segments in LCX (P=0.045) was noted between the two groups.

There was excellent agreement of image quality grading between the two reviewers (κ= 0.530). Six segments had non-diagnostic images due to motion artifacts (4/6), poor cooperation in breath holding (1/6) and blurring artifacts (1/6) in group A, and these events all occurred in RCA. In group B, there were eleven non-diagnostic segments caused by severe stair-step artifacts (8/11) and blurring artifacts (3/11). Four segments occurred in RCA, 3 in LAD and an additional 4 in LCX.

Using CCA findings as the reference standard, a total of 35 (413 segments) and 36 (425 segments) patients were confirmed in the

high-pitch and sequential acquisition group, respectively. The diagnostic accuracy, sensitivity, specificity, PPV and NPV on per-segment and per-vessel bases are presented in table 3. In the 71 patients, 258 segments stenoses with ≥50% lumen diameter reduction were detected by CCA, whereas 260 were observed by DSCT. Of the coronary segments, 10 were classified as false-positive by DSCT: 6 were invaluable and thus estimated as having significant stenosis but did not exhibit significant stenosis on CCA, and 4 segments were evaluated as false-positive given that the degree of lumen reduction was overestimated. Eight segments were classified as false negative due to the non-diagnostic image. The diagnostic accuracy values of the high-pitch group and sequential group were 97.8% (404/413) and 97.9% (416/425), respectively. No significant difference in the diagnostic accuracy was noted between the two groups (p=0.951).

**Table 1.** Patient characteristics and scan parameters

| | Group A (*n* = 80) | Group B (*n* = 80) | *P*-value |
|---|---|---|---|
| **Age (years)** | 11.46±59.58 | 10.99±60.52 | 0.593 |
| **Male** | (%60.0)48 | (%47.5)38 | 0.113 |
| **BMI (kg/m$^2$)** | 3.09±24.46 | 2.30±24.36 | 0.817 |
| **Mean heart rate (bpm)** | 5.24±58.50 | 5.67±59.69 | 0.171 |
| **HRV (bpm)** | 7.51 ± 5.04 | 3.91±6.92 | 0.114 |
| **Beta blocker usage** | (%60.0) 50 | (%61.2) 48 | 0.746 |
| **Contrast agent (mL)** | 8.27±54.03 | 9.10±66.36 | 0.001 > |
| **Tube voltage (kV)** | | | 0.001 > |
| **80** | 15 | 47 | |
| **100** | 55 | 31 | |
| **120** | 10 | 2 | |
| **CTDIvol (mGy)** | 1.48±3.04 | 2.61±5.85 | 0.001 > |
| **DLP (mGy · cm)** | 24.17±52.99 | 34.45±71.74 | 0.001 > |
| **ED (mSv)** | 0.34 ± 0.74 | 0.48 ± 1.00 | 0.001 > |
| **Signal intensity (Hu)** | | | |
| **AA** | 129.02±455.06 | 125.97±572.82 | 0.001 > |
| **RCA** | 135.53±452.15 | 146.96±575.90 | 0.001 > |
| **LM** | 128.08±450.20 | 132.71±573.66 | 0.001 > |
| **LAD** | 118.03±419.44 | 124.48±546.35 | 0.001 > |
| **LCX** | 120.39±415.68 | 119.28±530.95 | 0.001 > |
| **Image noise (Hu)** | 4.70±19.05 | 8.88±27.21 | 0.001 > |
| **SNR (Hu)** **RCA** | 7.83±24.53 | 6.98±22.62 | 0.105 |
| **LM** | 7.44±24.43 | 6.73±22.55 | 0.094 |
| **LAD** | 7.20±22.85 | 6.05±21.42 | 0.178 |
| **LCX** | 7.58±22.66 | 6.25±20.92 | 0.114 |
| **CNR (Hu)** **RCA** | 8.45±29.99 | 7.92±26.99 | 0.021 |
| **LM** | 8.12±29.89 | 7.78±26.91 | 0.019 |
| **LAD** | 7.90±28.31 | 7.10±25.79 | 0.036 |
| **LCX** | 8.26±28.12 | 7.30±25.28 | 0.022 |

**Table 2.** Image quality scores of the two groups

| Image quality | Group A (*n* = 980) | Group B (*n* = 978) |
|---|---|---|
| 1 | (%56.9) 557 | (%43.1) 421 |
| 2 | (%36.9) 362 | (%45.5)445 |
| 3 | (%5.6)55 | (%10.3) 101 |
| 4 | (%0.6)6 | (%1.1)11 |

A four-point grading scale was used with grading defined as follows: 1, excellent; 2, good; 3, moderate, diagnostic; 4, poor image quality, non-diagnostic.

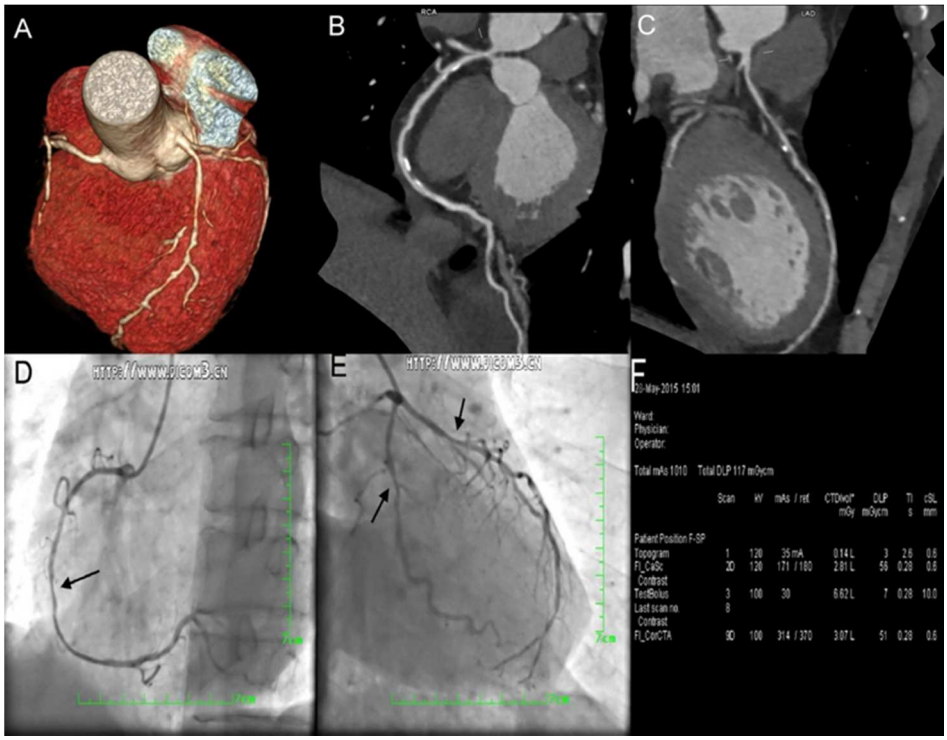


**Figure 3.** High-pitch spiral CCTA of a 65-year-old man exhibited excellent volume rendering images (A) and curve mulitplanar reformation imaged of RCA (B) and LAD (C). Mixed plaques and soft plaques were observed in the right coronary artery and left anterior descending artery. The lesion was confirmed by CCA (D and E). The dose-length product was 51 mGy.cm (F), and the estimated effective dose was 0.71 mSv.

**Table 3.** Diagnostic performance of high-pitch mode and sequential mode on 128-slice DSCT angiography.

| | TP | NP | FN | TN | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) |
|---|---|---|---|---|---|---|---|---|
| **Per-segment analysis** | | | | | | | | |
| **Group A** | 120 | 6 | 2 | 284 | （99.5-93.0）97.6 | （99.2-95.6）97.9 | （98.2-89.9）95.2 | （99.8-97.0）99.0 |
| **Group B** | 130 | 4 | 5 | 286 | （99.6-91.6）96.3 | （99.6-96.5）98.6 | （99.2-92.5）97.0 | （99.4-96.0）98.3 |
| **Per-vessel analysis** | | | | | | | | |
| **Group A** | 50 | 2 | 2 | 85 | （99.5-86.8）96.2 | （99.7-91.9）97.7 | （99.5-86.8）96.2 | （99.7-91.9）97.7 |
| **Group B** | 51 | 2 | 3 | 89 | （98.8-84.6）94.4 | （99.7-92.3）97.8 | （99.5-87.0）96.2 | （99.3-90.8）96.7 |

## DISCUSSION

The recent development of new-generation dual-source CT systems allowed a high-pitch spiral acquisition protocol with a very high-pitch value of 3.4 [1-8]. In our study, the high-pitch mode acquired better diagnostic performance at a low radiation dose and contrast agent cost compared with sequential mode. The high-pitch mode can be applied as the first-line protocol for patients with low and stable heart rates.

The high-pitch spiral mode and sequential mode with diastolic reconstruction have been used successfully in patients with heart rates less than 70 bpm [9-13]. During late diastole, most of left ventricular filling has already occurred, and the myocardium is relaxed. Thus, late diastole is relatively quiescent compared with other phases of the cardiac cycle, making it optimal for image acquisition due to reduced coronary motion. However, the duration of late diastole decreases with increasing heart rate. For patients with heart rates greater than 80 bpm, late diastole becomes negligible in length, and diastolic coronary motion increases significantly [14, 15]. Our results were consistent with previous studies. The heart rates in the two groups were less than 70 bpm, and image quality scores were good to excellent.

The most challenging issue in CCTA is non-diagnostic imaging. The high-pitch spiral mode of DSCT enables data acquisition for one heart beat with continuous and fast table movement [16, 17]. In high-pitch mode, non-diagnostic images are mainly attributed to motion artifact, predominantly affecting the mid to distal RCA. Minimal motion artifacts occur in a phase of the cardiac cycle with the least coronary artery motion [6]. For sequential CCTA, stair-step artifacts are the main reason for non-diagnostic images. Coronary CT angiography performed on wide detector offers a large z-coverage that reduces the scan blocks [17-19]. Stair-step artifacts typically do not occur in high-pitch mode given the high speed of data acquisition within a single cardiac cycle. In our study, four segments had non-diagnostic images due to motion artifacts (4/6) in group A, and all segments occurred in RCA. In group B, eight non-diagnostic segments were caused by severe stair-step artifacts (8/11): 3 segments occurred in RCA, 3 in LAD and 2 in LCX. The high-pitch mode has an advantage in the manifestation of LCX.

Numerous factors affect CCTA radiation dose, including scan length, scan speed and tube voltage. The main improvement of DSCT using high-pitch mode was the increased thread pitch from 0.2-0.4 to 3.4. Thus, the total scan time and the radiation dose were subsequently significantly reduced. An automatic tube voltage selection technique was used in the two groups. The technique was based on modulating the tube voltage and maintaining constant image noise from patient to patient and over the entire scan. The reference voltage was adjusted automatically according to the anatomy of the patient's body and organs [2]. This technique was used to reduce radiation exposure while preserving diagnostic image quality in our study. Group A used a higher tube voltage, and there was no additional radiation exposure. Our results suggested that radiation exposure could be significantly reduced with the high-pitch protocol. Two main reasons explain this finding. First, the sequential technique requires an overlap of approximately 10% of block images due to the cone-beam geometry. However, this overlap is not required for the high-pitch spiral mode. Second, the sequential scan technique requires "beam on" time for each block, whereas the high-pitch mode requires the extra "beam on" only once. Thus, the cumulative "beam on" time is reduced for the high-pitch spiral technique [8].

From a clinical perspective, reducing the amount of iodine as much as possible is helpful to avoid the risk of contrast-induced nephropathy [20-22]. However, a lower iodine concentration will lead to reduced vascular attenuation, which may result in degraded image quality and thus affect diagnostic accuracy. In our study, we reduced the contrast agent cost in group A, which only required one cardiac cycle. Group A had a lower mean attenuation. This finding may be explained by the reduced contrast media cost and 80 kV ratio in group A. The high-pitch mode achieved

significant reductions in image noise and radiation dose and improvements in image quality and CNR. CCTA is becoming the first-line diagnostic examination in patients with low-to-intermediate risk of coronary heart disease [23]. High-pitch mode provides high diagnostic accuracy for the detection of coronary artery stenoses in patients with low and stable heart rates [23-25]. Our results were in contrast with the results reported by Neefjes *et al.* [23].

The strength of CCTA is its high negative predictive value. As a first-line test, CCTA should be as safe and non-invasive as possible because the vast majority of patients do not have significant CAD. The introduction of radiation-lowering techniques has boosted the implementation of CCTA in routine clinical settings [23-25]. Achembach *et al*. reported that the high-pitch mode provided high diagnostic accuracy for the detection of coronary artery stenoses with a sensitivity of 100% and a negative predictive value of 100% in patients with low and stable heart rates [25]. Our results were consistent with previously reported work, but most of patients did not need to undergo conventional coronary angiography. Thus, we will collect more materials and perform more studies in the future.

### *Study limitations*

There are several limitations. First, we excluded patients with high and irregular heart rates. Second, the image quality grading may have been influenced by a subjectivity bias. Third, image diagnostic accuracy was compared with conventional CCA in part patients. Finally, we used a 128-slice DSCT, and the results cannot be generalized to other CT systems.

## CONCLUSION

Our study suggested that the prospectively ECG-triggered high-pitch spiral acquisition CCTA reduces radiation doses and contrast agent costs while improving image quality compared with prospectively ECG-triggered sequential mode.

***Conflicts of interest*:** *Declared none.*

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