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128-slice Dual-source Computed Tomography Coronary
Angiography in Patients with Atrial Fibrillation: Image Quality
and Radiation Dose of Prospectively Electrocardiogram-
triggered Sequential Scan Compared with Retrospectively
Electrocardiogram-gated Spiral Scan

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Objective To evaluate the image quality (IQ) and radiation dose of 128-slice dual-source computed tomography (DSCT) coronary angiography using prospectively electrocardiogram (ECG)-triggered sequential scan mode compared with ECG-gated spiral scan mode in a population with atrial fibrillation.

Methods Thirty-two patients with suspected coronary artery disease and permanent atrial fibrillation referred for a second-generation 128-slice DSCT coronary angiography were included in the prospective study. Of them, 17 patients (sequential group) were randomly selected to use a prospectively ECG-triggered sequential scan, while the other 15 patients (spiral group) used a retrospectively ECG-gated spiral scan. The IQ was assessed by two readers independently, using a four-point grading scale from excellent (grade 1) to non-assessable (grade 4), based on the American Heart Association 15-segment model. IQ of each segment and effective dose of each patient were compared between the two groups.

Results The mean heart rate (HR) of the sequential group was 96 ± 27 beats per minute (bpm) with a variation range of 73 ± 25 bpm, while the mean HR of the spiral group was 86 ± 22 bpm with a variation

range of 65 ± 24 bpm. Both of the mean HR ($t=1.91$, $P=0.243$) and HR variation range ($t=0.950$, $P=0.350$) had no significant difference between the two groups. In per-segment analysis, IQ of the sequential group vs. spiral group was rated as excellent (grade 1) in 190/244 (78%) vs. 177/217 (82%) by reader1 and 197/245 (80%) vs. 174/214 (81%) by reader2, as non-assessable (grade 4) in 4/244 (2%) vs. 2/217 (1%) by reader1 and 6/245 (2%) vs. 4/214 (2%) by reader2. Overall averaged IQ per-patient in the sequential and spiral group showed equally good (1.27 ± 0.19 vs. 1.25 ± 0.22 , $Z=-0.834$, $P=0.404$). The effective radiation dose of the sequential group reduced significantly compared with the spiral group (4.88 ± 1.77 mSv vs. 10.20 ± 3.64 mSv; $t=-5.372$, $P=0.000$).

Conclusion Compared with retrospectively ECG-gated spiral scan, prospectively ECG-triggered sequential DSCT coronary angiography provides similarly diagnostically valuable images in patients with atrial fibrillation and significantly reduces radiation dose.

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MULTI-detector computed tomography (MDCT) angiography of the coronary arteries has attained good sensitivity and a high negative predictive value in the detection of significant coronary stenosis, but arrhythmia remains a relative contraindication to CT coronary angiography,¹ because arrhythmia leads to inappropriate data sampling and results in severe motion artifacts. Image quality (IQ) and radiation dose-saving measure largely depend on low stable heart rates.

Atrial fibrillation (AF) is the most common type of arrhythmia and the incidence increases markedly with advancing age.² Coronary artery disease (CAD) is a cardiovascular condition associated with AF. Also AF patients may manifest symptoms mimicking CAD. Therefore, the demonstration of CAD is an important issue in the management of AF patients.

With the newly introduced dual-source CT (DSCT), the main improvement is the increase in temporal resolution. The higher temporal resolution is expected to decrease motion artifacts in patients with high heart rates (HR) as well as patients with arrhythmia. Most published experiences with coronary computed tomography angiography (CTA) of AF patients^{3, 4} used retrospectively electrocardiogram (ECG)-gated spiral scan to mitigate artifacts *via* ECG editing, which reported that DSCT coronary angiography is feasible in patients with AF and can be used to exclude CAD.

In recent years, the radiation dose associated with CT coronary angiography has raised more and more concerns. The prospectively ECG-triggered sequential scan protocol provides a new possibility to decrease dose. Previous studies have demonstrated that compared with traditional ECG-gated spiral scan, IQ can be maintained with significant dose reduction in patients with regular HR.^{5, 6} A few studies have reported successful trials using prospectively ECG-triggered sequential DSCT coronary angiography in patients with arrhythmia including AF.^{7, 8}

The purpose of our study was to evaluate the IQ and radiation dose of second generation 128-slice DSCT coronary angiography using prospectively ECG-triggered sequential scan mode compared with ECG-gated spiral scan mode in population with AF.

PATIENTS AND METHODS

Patients

This prospective study included a total of 32 consecutive patients clinically suspected for CAD with permanent AF over a period of 7 months, from September 1st, 2011 to March 31st, 2012. All patients were referred to a DSCT coronary angiography and randomly divided into two groups. One group (17 patients) used a prospectively ECG-triggered sequential scan mode (the sequential group), while the other group (15 patients) used a retrospectively ECG-gated spiral scan mode (the spiral group). During scanning, ECG was recorded simultaneously. We recorded the patient's mean HR, minimum and maximum HR during scan, and calculated the variation range of HR (maximum HR minus minimum HR).

The exclusion criteria were as follows: unstable clinical condition, previous allergy to iodinated contrast agents, elevated serum creatinine levels (>0.015 g/L, >132.6 $\mu\text{mol/L}$), previous bypass surgery or stenting, and failure to follow breath-hold commands. No AF patients were excluded on the basis of these criteria.

The study protocol was approved by the Institutional Ethics Committee of Peking Union Medical College Hospital. The written informed consent forms were signed by all patients.

CT coronary angiography: scan protocol and reconstruction

All coronary CTA was performed with a second-generation dual-source 128-slice CT scanner (Somatom Definition

Flash; Siemens, Forchheim, Germany). With two 64-detectors of 0.6 mm row width, the scanner acquired 128 overlapping 0.6 mm slices with a flying focus along the z-axis (z-sharp technology, Siemens). The scanner's gantry rotation time is 280 ms, the temporal resolution equals 75 ms in mono-segment reconstruction.

In both of the groups, we set tube voltage as 100 kV and used a prospective automatically electrocardiographic tube current modulation (ECG-pulsing, Siemens) technique (pulsing from 60%-75% R-R interval if HR<70 bpm, 35%-75% R-R interval if 70 bpm<HR<90 bpm, 35%-50% R-R interval if HR>90 bpm; scan from 30%-80% R-R interval in sequential scan mode). In retrospectively ECG-gated spiral scans, we also used an automatically exposure control system (CAREDose4D, Siemens) and set the reference current as 360 mAs/rot. On the basis of pre-scan ECG, the pitch was adapted automatically to the HR, ranging from 0.20 to 0.43. In prospectively ECG-triggered sequential scan protocol, we did not use CAREdose4D. The tube current was set as 320 mAs/rot. Feed was 34.5 mm. In all of the prospective scan group patients, we used an advanced arrhythmia rejection/compensation mode (Adaptive Cardio Sequence, Siemens), which compensated gradual changes in HR, by immediately repeating the scan position in the case of an ectopic or widely irregular HR.

The scan was performed in a craniocaudal direction for a single breath hold. Sublingual nitroglycerin was given to all patients within 2 minutes before scanning. The patients did not receive any additional drugs for HR regulation prior to the CT examination.

The CTA was triggered automatically by the arrival of the main contrast material-enhanced bolus (automatic bolus tracking), which was performed in the ascending aorta with an additional scan delay of 5 seconds. And 60-65 mL nonionic contrast medium (370 mgI/mL) was injected at a flow rate of 5 mL/s, which was followed by a 50 mL saline chaser bolus (5 mL/s) to washout contrast from the superior vena cava and right ventricle.

The datasets were reconstructed manually in multiple cardiac phases at an absolute delay determined from the R wave with intervals of 50-ms from the delay of 200 ms to 600 ms. Axial images with a slice thickness of 0.75 mm and slice increment of 0.5 mm were reconstructed using a medium soft-tissue convolution kernels (B26f) and a mono-segment reconstruction algorithm. The reconstruction phase with the fewest motion artifacts was chosen for each segment and used for further analysis.

CT coronary angiography IQ assessment

For image post-processing, a MMWP workstation (Siemens) was utilized. For the evaluation of coronary artery stenosis, original transverse images, multi-planar reformations, curved multi-planar reformations, maximum intensity projections, and volume-rendered images were used.

Two experienced readers reviewed the CT coronary angiograms and evaluated the IQ independently, blinded to each other's results. For each segment, the images with fewest artifacts from the reconstructions of multi-phases were chosen. Both readers were unaware of the patients' group and any previous examination results.

The segmental evaluation of the coronary arteries was performed according to the American Heart Association 15-segment classification. All segments were included for the assessment. If a coronary artery segment was not present because of coronary anatomy, it was not recorded. IQ was evaluated qualitatively for each coronary artery segment by using a 4-point Likert scale as published previously:⁹ 1=excellent IQ, with no motion artifacts or step artifacts; 2=good IQ, with insignificant steps or mild blurring; 3=moderate IQ, with significant steps, but sufficiently clear delineation of the individual segments of the vessel, or moderate blurring with a representation of the lumen that satisfies the requirements for making a diagnosis; 4=poor IQ, not enough for diagnostic purposes because of severe step artifacts or blurring.

Every coronary artery segment with a score of at least grade 3 was considered to be of "diagnostic" quality; a segment with quality grade 4 was not assessable.

We got the overall averaged IQ per-patient by calculating the average segment IQ-score of both readers.

Patient dose evaluation

The dose-length product (DLP) was obtained from the patient protocol of the scanner. The effective radiation dose of the CTA was estimated by a method proposed by the Fleischner society. The effective dose was derived from the DLP by means of a conversion factor of 0.014 mSv/mGy·cm for the chest.¹⁰

Statistical analysis

Continuous data were presented as means±SD. All statistical analysis was performed with statistical software (SPSS, version 16.0 for Windows). Independent samples *t* test was used to compare the difference in mean HR, variation of HR, DLP and effective dose between the two groups. Non-parametric independent samples *Mann-Whitney* test was used in per-segment IQ score comparison. *P* value <0.05 was considered statistically significant.

For the assessment of IQ, inter-rater agreement was

determined by calculating Cohen's *kappa* statistics (κ): $\kappa=0$ indicated poor agreement, $\kappa=0.01-0.20$ indicated slight agreement, $\kappa=0.21-0.40$ indicated fair agreement, $\kappa=0.41-0.60$ indicated moderate agreement, $\kappa=0.61-0.80$ indicated good agreement, and $\kappa=0.81-1.00$ indicated excellent agreement.¹¹

RESULTS

The general information of the two group patients is shown in Table 1. All the patients successfully underwent the DSCT coronary angiography with no related adverse reaction. Both of the mean HR and HR variation range had

no significant differences between the two groups (all $P>0.05$, Table 1).

In all of the CT angiography images, the reconstructions were done with absolute intervals in milliseconds. For most of the patients (12/17 of the sequential group, 11/15 of the spiral group), the reconstructions obtained during systole with an absolute delay of 200 ms to 300 ms derived the best image quality, for the other patients some segments had better IQ in diastolic cardiac phases.

In the per-segment analysis, IQ scores in both of the sequential and spiral group showed equally good without significant differences (1.27 ± 0.19 and 1.25 ± 0.22 , $Z=-0.834$, $P=0.404$; Table 2, Figs. 1, 2).

Table 1. Demographic information, HR and dose parameters of the two groups

Group	Case no.	Male/female (n)	Age [§] (yrs)	Minimum HR (bpm)	Maximum HR (bpm)	Mean HR [§] (bpm)	Variation of HR [§] (bpm)	DLP [§] (mGy·cm)	Effective dose [§] (mSv)
Spiral group	15	9/6	65±8	40	192	86±22	65±24	729±260	10.20±3.64
Sequential group	17	9/8	66±7	36	193	96±27	73±25	349±126	4.88±1.77
<i>t</i> value						1.91	0.950	-5.372	-5.372
<i>P</i> value						0.234	0.350	0.000	0.000

§: Plus-minus values are means±SD.

HR: heart rate; DLP: dose-length product.

Table 2. IQ grading per-segment of CT coronary angiography

Group	Radiologist	Excellent IQ [grade 1, n (%)]	Good IQ [grade 2, n (%)]	Moderate IQ [grade 3, n (%)]	Poor IQ [grade 4, n (%)]	Total (n)
Spiral group (n=15)	Reader1	177 (82)	28 (13)	10 (5)	2 (1)	217
	Reader2	174 (81)	32 (15)	4 (2)	4 (2)	214
Sequential group (n=17)	Reader1	190 (78)	46 (19)	4 (2)	4 (2)	244
	Reader2	197 (80)	37 (15)	5 (2)	6 (2)	245

IQ: image quality.

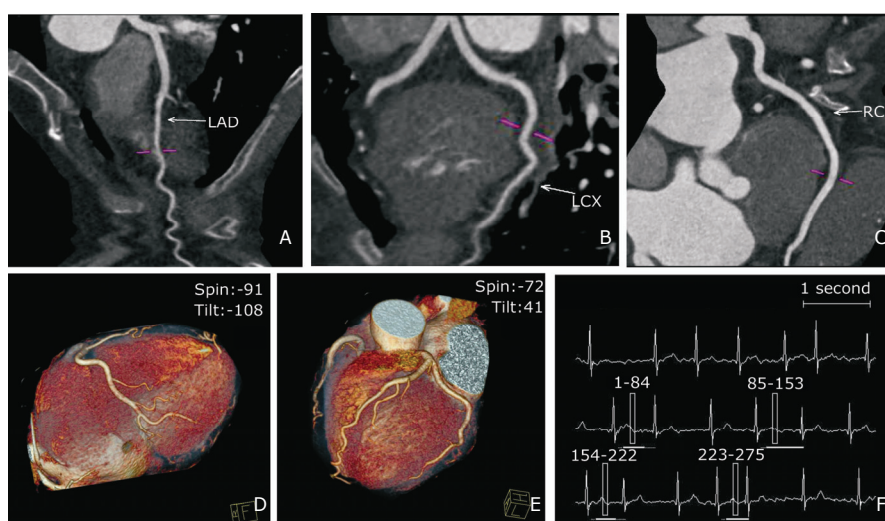


Figure 1. Results of prospectively electrocardiogram-triggered sequential CT angiography of a 62-year-old woman with permanent atrial fibrillation and no significant coronary artery stenosis.

A, B, and C. curved planar reformation images; D and E. volume-rendered images; F. electrocardiogram.

Heart rate was irregular (F; mean, 85 bpm; range, 61-130 bpm). Images reconstructed at 250 ms after R wave shows excellent image quality for all of the three coronary arteries (LAD, LCX, RCA). The dose-length product was 258 mGy·cm thus the effective radiation dose was 3.61 mSv.

LAD: left anterior descending artery; LCX: left circumflex artery; RCA: right coronary artery.

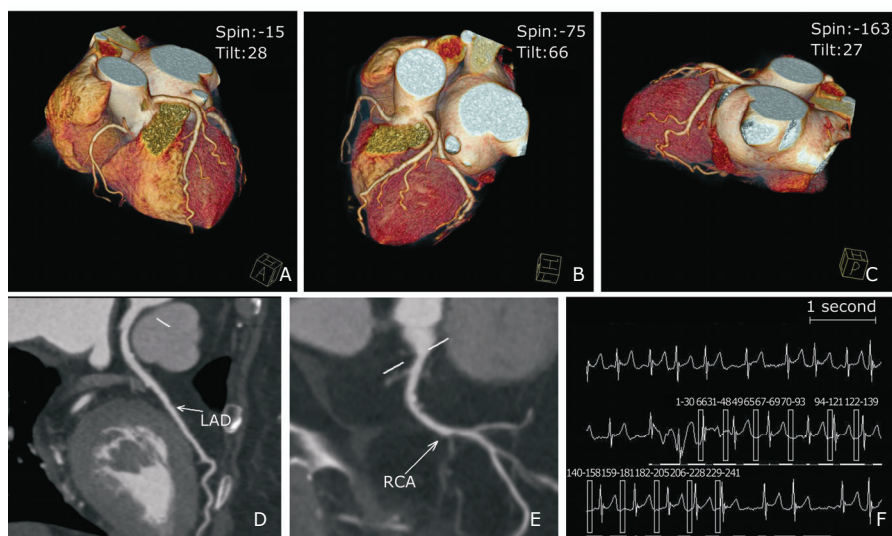


Figure 2. Results of retrospectively electrocardiogram-triggered sequential CT angiography of a 73-year-old woman with permanent atrial fibrillation and no significant coronary artery stenosis.

A, B, and C. volume-rendered images; D and E. curved planar reformation images; F. electrocardiogram.

Heart rate was irregular (F; mean, 93 bpm; range, 123-154 bpm). Images reconstructed at 300 ms after R wave shows excellent image quality for all of the three coronary arteries. The dose-length product was 688 mGy·cm thus the effective radiation dose was 9.63 mSv.

The inter-rater agreement in the evaluation of per-segment image quality was calculated as $\kappa=0.643$ (sequential group) and 0.629 (spiral group), corresponding to good agreement.

The estimated radiation dose of the sequential group was 4.88 ± 1.77 mSv, while that was 10.20 ± 3.64 mSv in the spiral group, with significant difference ($t=-5.372$, $P=0.000$).

DISCUSSION

Our study prospectively compared the IQ and radiation dose of prospectively ECG-triggered sequential scan mode and retrospectively ECG-gated spiral scan mode of 128-slice DSCT coronary CTA in AF patients, proved the clinical feasibility of both scan mode and the significant radiation dose reduction of the former one.

IQ in patients with AF is mainly dependent on HR variability, as it was published before in patients with high HR and normal sinus rhythm,¹² because variations in the duration of the individual R-R cycle resulted in insufficient data sampling and severe motion artifacts. For cardiac MDCT, there are 2 approaches for reconstruction of datasets: the projection data are reconstructed at a certain percentage of the R-R interval, or at a certain fixed time interval after the R peak (the absolute forward reconstruction algorithms). For AF patients have irregular HR with definitely different R-R intervals, the percentage approach is more sensitive to arrhythmia than the absolute

forward reconstruction algorithms. Usually, in patients with sinus rhythm and low HR, good IQ is achievable with reconstructions performed at around 70%-75% of the R-R interval, corresponding to the mid diastolic slow-filling phase in which cardiac motion is slowest. But the relaxation and slow filling phases are the parts of cardiac cycle that adapt most to the HR, whereas the duration of systolic contraction changes slightly. For patients with AF, end-systolic datasets yield a diagnostic IQ more frequently compared with diastolic datasets, because the position of the end-systolic phase after the R peak is generally relatively stable even if the duration of the R-R interval varies within arrhythmic heart beats.

In our study, we enrolled 32 patients with permanent AF clinically referred for CT coronary angiography. All patients had permanent AF and definitely irregular HR during the scan (Table 1). We obtained most of the images with best quality between the 200 ms to 300 ms after R waves, corresponding to end-systolic cardiac phase.

In prospectively ECG-triggered sequential scans, to reduce radiation dose, we used an advanced arrhythmia rejection/compensation algorithm, which immediately repeated the scan in the same position automatically in the case of an ectopic or widely irregular heart beat. At the same time, we used the ECG-pulsing technique (scan from 30%-80% of R-R interval and pulsing from 35%-75% R-R interval). This protocol got satisfactory IQ.

But we found that most of the best IQ was reconstructed between the 200 ms to 300 ms after R waves. So

if we set the ECG-pulsing parameters using absolute time, the full radiation dose exposure of which can cover the end-systolic cardiac phase, we may reduce more radiation dose. For arrhythmia patients, the arrhythmia rejection algorithm would also prolong scan time and enlarge radiation dose. Longer scan time brings more difficulties for patient breath-hold. We think whether the repeated scan is necessary and valuable for all types of arrhythmia patients still need to be studied and discussed.

In retrospectively ECG-gated spiral scans, we additionally used an automatically exposure control system to reduce radiation dose, the IQ was still satisfactory.

One of the limitations of our study was the small number of patients enrolled in our study group. The patients' indication mainly included exclusion of coronary heart disease and preparation for radiofrequency ablation, which resulted in a quite low prevalence of significant coronary stenosis in coronary CTA results, thus few enrolled patients underwent conventional coronary angiography. Although our study showed a good subjective IQ in both of the scan modes in AF patients, the comparison with a "golden" reference of conventional coronary angiography and a larger study population would be more supportive.

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