Comparison of image quality and radiation dose between prospectively ECG-triggered and retrospectively ECG-gated CT angiography: Establishing heart rate cut-off values in first-generation dual-source CT

Emre Ünal, A. Elçin Yıldız, Ezgi Güler, Muşturay Karcaaltıncaba, Deniz Akata, Abidin Kılınçer, Eray Atlı, Melih Topçuoğlu, Tuncay Hazırolan

Department of Radiology, Faculty of Medicine, Hacettepe University; Ankara-*Turkey*

Abstract

Objective: To evaluate radiation dose and image quality of prospectively electrocardiography (ECG)-triggered and retrospectively ECG-gated coronary computed tomography (CT) angiography and to establish cut-off values of heart rates (HRs) for each technique in first-generation dual-source CT.

Methods: A total of 200 consecutive patients with suspected coronary artery disease were accepted into the study. Patients were selected randomly for each technique (prospective triggering group n=99, mean age 55.85±10.74 and retrospective gating group n=101, mean age 53.38±11.58). Two independent radiologists scored coronary artery segments for image quality using a 5-point scale. Also, attenuation values of each coronary artery segment and dose-length product values were measured. For each technique, cut-off HR values were determined for the best image quality.

Results: Mean image quality scores and attenuation values were found to be higher in the prospective triggering group ($p<0.05$). Mean radiation dose was 73% lower for the prospective triggering group ($p<0.01$). The cut-off HR values for good image quality scores were ≤67 beats per minute (bpm) and ≤80 bpm for the prospective triggering and retrospective gating groups, respectively ($p<0.05$). Increased HR (≥68 and ≥81 bpm, respectively) had negative effects on image quality ($p<0.05$).

Conclusion: The prospective ECG triggering technique has better image quality scores than retrospective ECG gating, particularly in patients who have an HR of less than 68 bpm. Also, a 73% radiation dose reduction can be achieved with prospective ECG triggering. In patients with higher heart rates, retrospective ECG gating is recommended. *(Anatol J Cardiol 2015; 15: 759-64)*

Keywords: multidetector computed tomography, coronary angiography, radiation protection, cardiac gated imaging techniques, comparative study

Introduction

In studies with coronary computed tomography angiography (CTA), researchers have found high negative predictive value (95%-99%) and high sensitivity (93%-97%) and specificity (95%-99%) for the detection of coronary artery disease (CAD) (1, 2). Especially with the advent of 64-slice and dual-source CT (DSCT), coronary CTA has become a powerful alternative to catheter coronary angiography for the diagnosis of CAD. The increased use of CTA has brought with it concerns about the radiation dose. With retrospective electrocardiography (ECG) gating, the mean effective radiation dose reaches up to 12 mSv, even with dose reduction protocols (3).

Because of the major concern about high radiation, dose reduction strategies, such as tube current modulation (3-5), lower tube voltage (6-8), high pitch acquisition (9, 10), and prospective ECG triggering (11, 12), were developed and introduced. Among these strategies, prospective ECG triggering is the most effective way to reduce radiation dose while preserving high diagnostic image quality. In prospectively ECG-triggered coronary CTA, the scan is performed in a non-helical way instead of volumetric acquisition (13). The x-ray tube is on in only a selected cardiac phase and turns off during the rest of the cardiac cycle; thus, only a restricted cardiac phase is imaged by a series of axial images. This method is also known as step-and-shoot acquisition. However, in retrospectively

Address for Correspondence: Dr. Tuncay Hazırolan, Hacettepe Üniversitesi Tıp Fakültesi, Radyoloji Bölümü, Ankara-*Türkiye*
Phone: +90 312 305 11 88 / 305 41 60 Fax: +90 312 311 21 45 E-mail: tuncayhazirolan@yahoo.com
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ECG-gated CTA, the x-ray tube is on for the entire cardiac cycle; thus, the retrospective gating technique is known to acquire images regardless of heart rate (HR), particularly by DSCT.

Despite the significant radiation dose reduction, there are still concerns about the diagnostic accuracy and image quality of the prospective ECG triggering technique. This limitation can be explained by two main reasons. First, stair-step artifacts, which occur due to misalignment of two adjacent structures, mainly arise from respiratory motion and heart rate variability, which lead to motion of the heart and unevaluable coronary artery segments (13, 14). Second, cardiac images are acquired during only a small portion of the R-R interval; thus, only a portion of data is acquired when compared to retrospective ECG gating, which contains whole volumetric data. Consequently, functional information about cardiac valve motion or wall motion is not available (13, 14). The purpose of our study is to compare image quality and radiation dose between prospectively ECG-triggered and retrospectively ECG-gated CT angiography and also to establish HR cut-off values for each technique to obtain high-quality images in first-generation DSCT scanners.

Methods

Patient population

This study was undertaken in Radiology Department of Hacettepe University, Faculty of Medicine. Our study was approved by the local Ethics Committee and conducted in accordance with the Declaration of Helsinki. Between December 2011 and February 2012, 200 consecutive patients were accepted into the study. Patients were randomly assigned to each group. The indication for CTA was suspected CAD. Patients' clinical data and information were gathered prospectively.

Exclusion criteria for the study were a history of coronary artery bypass graft, coronary artery stent, cardiac pacemaker, known allergy to iodinated contrast agents, history of renal parenchymal disease or failure, arrhythmia, and pregnancy.

Each group was divided into three subgroups by the patients' HR (prospective triggering group ≤60, 61-67, ≥68 beats per minute [bpm] and retrospective gating group ≤71, 72-80, ≥81 bpm). Some patients HR exceeded 70 bpm in the prospective group during scanning.

Pre-scanning medication

In patients with an HR above 70 bpm, IV 5 mg β-blocker (metoprolol) was applied 5 minutes before the prospectively ECG-triggered CTA. No β-blocker was applied before retrospectively ECG-gated CTA.

Prior to scanning, patients received one sublingual dose of nitroglycerin aerosol spray. There was no contraindication to β-blockers (such as diabetes mellitus, heart failure) or to nitroglycerin aerosol spray (such as usage of vasodilators). Also, there were no side effects/complications concerning the premedication procedure.

CT technique, scan protocol, and post-processing of the images

All coronary CTAs were performed with a first-generation DSCT scanner (SOMATOM Definition, Siemens Healthcare, Forchheim, Germany). A pilot view of the thorax was obtained, and the scanning was performed from 2 cm below the level of the carina to the diaphragm, in a cranio-caudal direction.

ECG lines were placed in their standard positions, and this was followed by the placement of an 18-gauge needle in the antecubital vein. Then, 80 mL non-ionic contrast agent (Ultravist 370 mg/mL; Bayer Schering Pharma, Berlin, Germany) at a flow rate of 5 mL/sec was administered intravenously and followed by a 50-mL saline flush at 5 mL/sec with an automatic injector (Ulrich, Germany). The volume of the contrast agent was regardless of the patient's weight. The bolus was tracked by using an automated bolus triggering technique in the ascending aorta (CARE Bolus; Siemens Healthcare, Forchheim, Germany). The examination was automatically started 7 seconds after the triggering threshold (100 Hounsfield unit [HU]) was reached.

CT images were acquired with a detector collimation of 2 x 32 x 0, 6 mm, and a gantry rotation time of 0.33 seconds. Tube voltage was set at 100 kVp for patients who had a body mass index (BMI) <25 (only one patient's BMI was <25, so we excluded the dose-length product [DLP] and attenuation values of this patient) and 120 kVp for ≥25 BMI.

In the prospective triggering group, the step-and-shoot method was used, as the x-ray tube was on only in 70% of the R-R interval (without padding). In the retrospective gating group, the ECG tube current modulation technique was used, as the tube current (mA) was changed during the examination for each body part. In 30%-80% of the R-R intervals, the maximum effective mA was set, and during the rest of the R-R interval, the mA was lowered to 20% of the effective dose.

For both groups, acquired images from raw data were reconstructed with a slice thickness of 0.75 mm with traditional filtered back projection and soft-tissue kernel (B26f).

Images were sent directly to the workstation for post-processing and evaluation (Leonardo, Siemens AG, Healthcare Sector, Forchheim, Germany). In the retrospective gating group, the best reconstruction phase was selected and sent to the workstation. The post-processing procedure included maximum intensity projection (MIP), multiplanar reformation (MPR), and volume rendering (VR).

Image analysis, evaluation method, and radiation dose assessment

Images were evaluated by two radiologists (double blinded) who had at least 8 years of experience in cardiac CTA. The observers had no information about the patients and the CTA algorithms. The image interpretation was performed 3 to 5 weeks after the coronary CTA.

The segments that had a diameter of 1.0 mm or higher were interpreted according to the American Heart Association guidelines (15).

The observers evaluated each coronary artery segment and rated scores for the quality of the images by using a 5-point Likert scale. The Likert scale was defined as 1: poor image quality, poor vessel wall definition; 2: adequate, decreased image quality with poor vessel wall definition; 3: good vessel wall definition and image quality; 4: very good, good attenuation of vessel lumen and delineation of contours, coronary wall definition; and 5: excellent, excellent attenuation of the vessel lumen and clear delineation of the vessel walls and excellent image quality. Additionally, the observers measured the attenuation values of the coronary artery segments.

The DLP values, which can be found on the CT scanner panel, were recorded for each examination in both groups. The effective radiation dose (RD: in millisieverts; mSv) was calculated using the equation that is used traditionally (RD= DLP x k, k=0.017).

Statistical analysis

For the statistical analysis, the Stata (v.9.0 Stata Corporation, Texas, USA) and SPSS (v.15.0 for Windows; Chicago, IL, USA) statistical software programs were used. Numerical quantitative data variables were summarized as mean, ± standard deviation, and median [maximum-minimum]. Frequencies-percentages were used for categorical variables. The interobserver correlation between the two radiologists was evaluated with κ statistics (weighted kappa). The correlation was classified as moderate (κ=0.41-0.60), good (κ=0.61-0.80), and very good (κ=0.81-1.00). The image quality scores for each HR group were evaluated with the Kruskal-Wallis test. Pairwise comparisons were done by Bonferroni-adjusted Mann-Whitney U test.

The numerical variable differences between the two groups (prospective triggering and retrospective gating) were calculated using t-test and Mann-Whitney U test. A value of p<0.05 was considered a statistically significant difference.

Results

Characteristics of the population

A total of 200 subjects (prospective triggering group n=99; 49.5%, retrospective gating group n=101; 50.5%) were enrolled in the study. The mean age in the overall study population was 54.60±11.14 years (55.85±10.74 years in the prospective group and 53.38±11.58 years in the retrospective group; p: 0.1193). There were 53 (53.5%) and 52 (51.5%) males in the prospective triggering and retrospective gating groups, respectively (p: 0.7715). The comparison of patient characteristics, cardiovascular risk factors, and scan parameters of the groups is presented in Table 1.

Image quality scores

The mean image quality scores were higher (p<0.05) in the prospective triggering group (3.998±0.9) than in the retrospective gating group (3.776±0.7) (Fig. 1). Mean luminal attenuation values were higher (p<0.05) in the prospective triggering group (363.96±78.31 HU) than in the retrospective gating group (334.39±77.03 HU). The standard deviations both in mean image quality scores and attenuation values were high because of the distal coronary artery segments (assessment and region of interest [ROI] placements were limited due to lumen diameter).

Table 1. Patient characteristics, cardiovascular risk factors, and scan parameters of the two groups

	Prospective triggering (n: 99)	Retrospective gating (n: 101)	*P*
Patient characteristics			
Men, n, (%)	53 (53.5)	52 (51.5)	0.7715
Age, years	55.85±10.74	53.38±11.58	0.1193
Body mass index, kg/m²	29.08±5.57	29.25±4.53	0.8121
Cardiovascular risk factors			
Smoker, n (%)	25 (25.3)	21 (20.8)	0.5609
Hypertension, n (%)	43 (43.4)	55 (54.5)	0.119
Diabetes mellitus, n (%)	16 (16.2)	21 (20.8)	0.5085
Family history for CAD, n (%)	54 (54.5)	56 (55.4)	0.8982
Hypercholesterolemia, n (%)	38 (38.4)	44 (43.6)	0.4564
Scan parameters			
Mean heart rate, bpm	63.5 [44-80]*	77 [52-103]*	0.0001*
Mean attenuation values, HU	363.96±78.31	334.39±77.03	0.008
Effective radiation dose, mSv	3.128±1.01	11.538±4.62	0.0001

Data are presented as number (percentage) and mean±SD values. *Mann-Whitney U-test median (minimum-maximum).
bpm - beats per minute; CAD - coronary artery disease; HU - Hounsfield unit; mSv - millisieverts

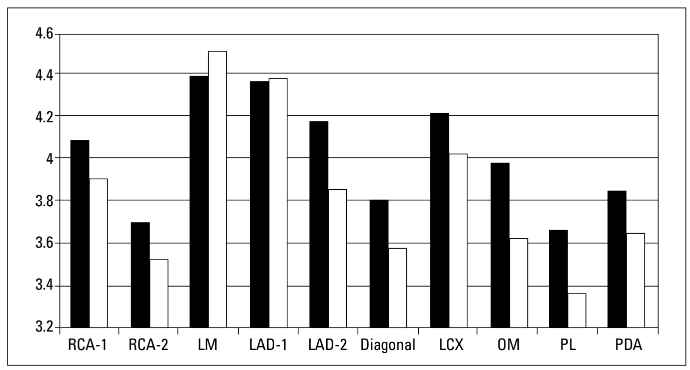

Figure 1. Image quality scores for main coronary artery segments
■: Prospective, □: Retrospective

Image quality scores and attenuation values were evaluated together, and a statistically significant (p<0.05) correlation between these two (direct proportion) parameters was found.

Mean HRs were 63.5 [44-80] bpm and 77 [52-103] bpm in the prospective triggering and retrospective gating group, respectively (p<0.001, Mann-Whitney U test). The mean HR had a biphasic influence on image quality scores. In the prospective triggering group, under 68 bpm, there was no significant effect (p>0.05) on scores; however, when the HR reached 68 bpm, there was a statistically significant negative effect on image quality

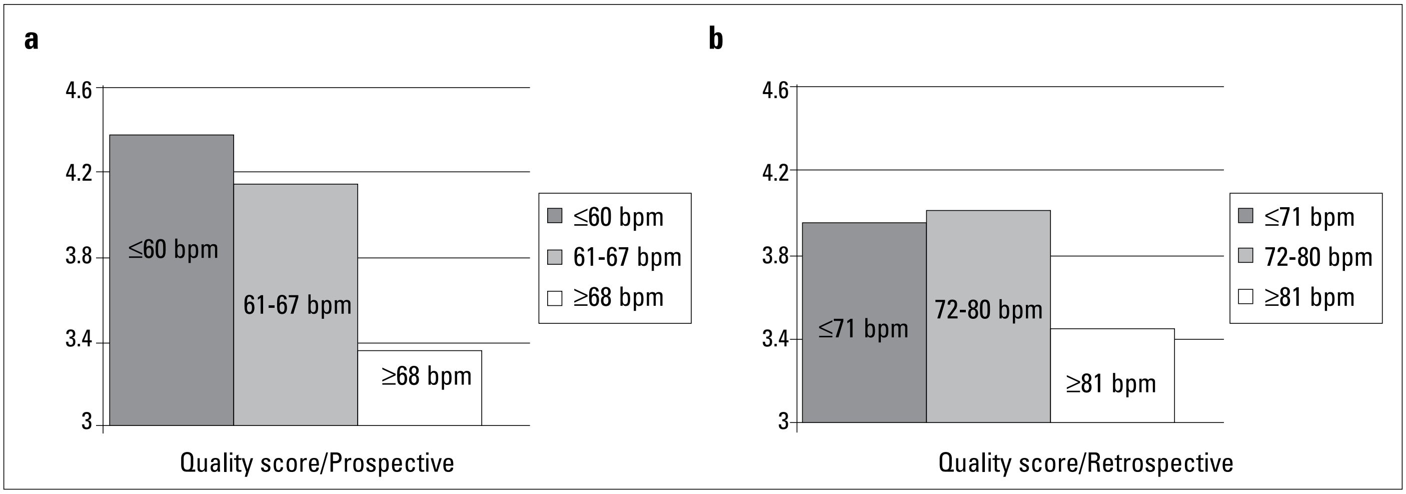

Figure 2. a, b. Image quality scores for coronary artery segments correlation with heart rates (cut-off values) for prospectively triggered (a) and retrospectively ECG-gated (b) CTA

scores (p<0.05) (Fig. 2). The influence of HR was evaluated for the retrospective gating group, and there was no statistically significant effect (p>0.05) on scores when the HR was ≤80 bpm. In patients with an HR above 80 bpm, there was a statistically significant negative effect on scores (p<0.05).

BMI had a negative influence on image quality scores. The negative effect of BMI on image quality was not statistically significant (p>0.05) in the prospective triggering group but was significant in the retrospective gating group (p<0.05).

There was good agreement between observers (mean κ value was 0.72).

Radiation dose

Mean DLP was 184.050±59.47 mGy (3.128±1.01 mSv) in the prospective triggering group and 678.73±272.19 mGy (11.538±4.62 mSv) in the retrospective gating group. There was a significant difference between the two groups (p<0.001). The mean effective radiation dose was 73% lower in the prospective triggering group.

Discussion

Our results revealed that, significant radiation dose reduction can be achieved in prospective ECG triggering technique without compromising image quality. However, in both coronary CTA techniques heart rate should be lowered to obtain better image quality.

Improvements in CT scanners led to minimization of gantry rotation time and the evolution of temporal resolution. The technological developments improved the image quality and diagnostic accuracy of CT images when compared to conventional catheter coronary angiography imaging. With the evolution of CT scanners, the high radiation dose became the main limitation of coronary CTA. To reduce the radiation dose, some strategies were developed, and among them, the prospective ECG triggering technique is the most effective way to reduce dose while maintaining good image quality. The most important limitation of the prospective ECG triggering technique is that image data include only a restricted part of the entire cardiac cycle. Therefore, functional evaluation of the cardiac valve/muscle motion and functional analysis can not be performed, in contrast to the retrospective ECG gating technique. Another limitation of prospective triggering is stair-step artifacts. These artifacts arise mainly from respiratory motion and heart rate variability during the scan, thus leading to unevaluable coronary artery segments, which is important for the prospective triggering technique because of the limited reconstruction phase (13, 14). To prevent this limitation, some CT scanner producers added a different parameter in the protocol, called padding. Padding allows for the acquisition of additional data that are user-definable, before and after the selected phase of the R-R interval. Thus, several reconstruction phases can be achieved to avoid stair-step artifacts. However, they found out that when using 100 msec of padding (40%-50% radiation dose rising), there was no evidence of improvement in image interpretability in patients with low heart rates (16, 17). We also discovered that there was no need for padding in the prospective triggering technique, particularly in patients who had an HR of less than 68 bpm.

In the present study, we compared two techniques of coronary CTA. Patients who had an HR ≤70 bpm and ≥71 bpm underwent prospectively triggered and retrospectively ECG-gated CTA, respectively. We found that in the prospective triggering group, there was a 73% radiation dose reduction while maintaining similar and even slightly better image quality scores and high luminal attenuation values. Similar results have been reported in several studies (18-20). Also, it is reported in the literature that high vessel luminal attenuation increases the diagnostic evaluation, particularly in calcified coronary artery segments (21). We considered that the reason for the high image quality and attenuation values in low HR is due to the lengthening of the diastolic phase, which lets coronary arteries fill with contrast material. In addition, our results show that the negative effect of BMI on image quality was not statistically significant (p>0.05) in

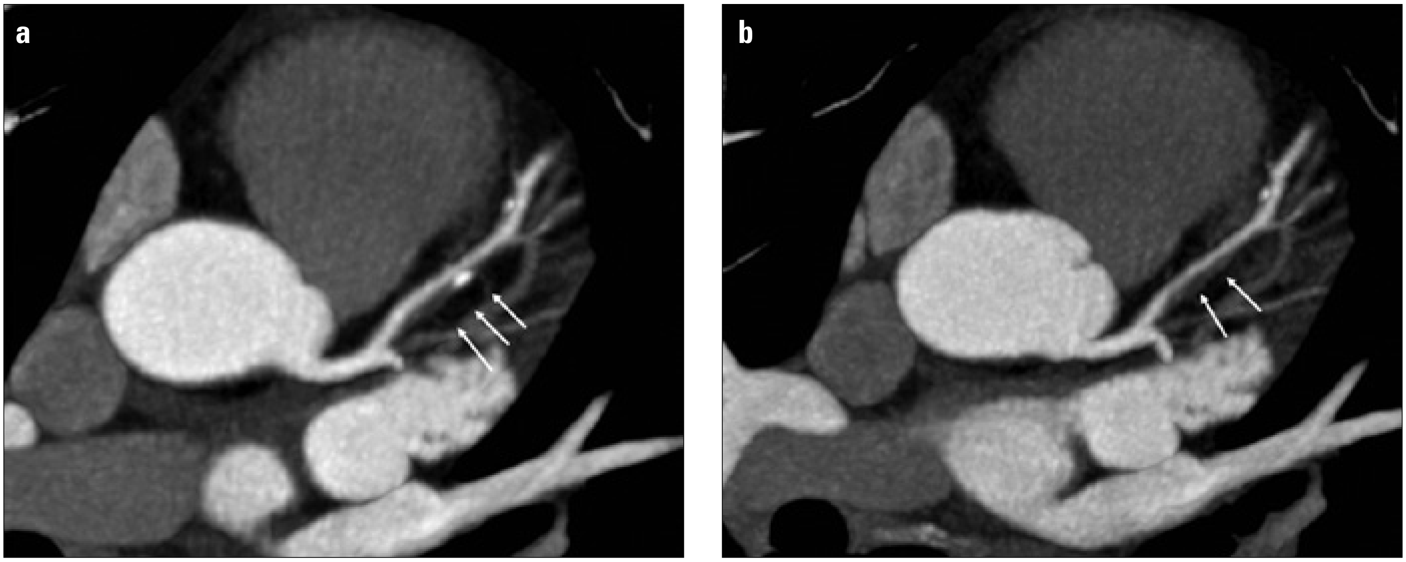

Figure 3. a, b. Prospectively ECG-triggered coronary CT angiograms of the left anterior descending coronary artery (LAD). A mixed plaque with moderate luminal narrowing in the proximal segment of LAD was demonstrated on serial (a and b) maximum-intensity projection images

the prospective triggering group but was significant in the retrospective gating group ($p<0.05$). We think that the reason for this contrast is due to usage of the x-ray tube at a certain time point of the R-R interval, allowing more efficient x-ray penetration and improving image quality (Fig. 3).

Hirai et al. (22) reported that on a 64-detector CT scanner, prospectively triggered and retrospectively gated CTA had similar diagnostic performance when assessing luminal obstructions in patients with an HR of less than 75 bpm. Lu et al. (23) reported that with an average HR of 67.7 bpm (without premedication) and using the paddle technique to extend the scan angle from 260° to 460°, there was no statistically significant difference between prospective ECG triggering and retrospective ECG gating for image quality and diagnostic accuracy in first-generation DSCT scanners. They also concluded that a 70% dose reduction was achieved in the prospective triggering group. Our results tend to be consistent with the findings of these authors. However, our study differs from other similar studies by providing an HR cut-off point for retrospective ECG-gated CT angiography, as well, which is known to acquire images regardless of heart rate in first-generation dual-source CT. We advocate that lowering the HR below 80 bpm increases the image quality in the retrospective ECG gating technique. With the advent of new second- and third-generation dual-source CT scan machines, it will be possible to use prospective ECG triggering CTA in patients with high heart rates due to the increased number of detectors. Also, the temporal resolution will improve due to the decreased gantry rotation time. Thus, stair-step artifacts may decrease.

Study limitations

Our study had two main limitations. First, we did not correlate the diagnostic accuracy of CTA with conventional catheter angiography, because most of our patients did not undergo invasive coronary angiography. Second, we used a Likert scale for the image quality assessment, which is a subjective scale. However, we had good agreement between the two readers.

Conclusion

Prospective ECG triggering should be preferred in patients with heart rates below 67 bpm to obtain diagnostic-quality CTA examinations, with a 73% radiation dose reduction compared to retrospective ECG gating, by a first-generation dual-source CT scanner. Also, in retrospective ECG gating, lowering the HR to below 80 bpm increases the image quality.

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