

Objective and subjective image quality with prospectively gated versus ECG-controlled tube current modulation using 256-slice computed tomographic angiography



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Introduction: Radiation exposure is one of the major limitations of computed tomographic coronary angiography (CTA). The purpose of this study was to compare the objective and subjective image quality and radiation dose using prospective ECG gating (PGA) versus ECG-controlled tube current modulation (ECTCM) scanning techniques.

Methods: A prospective, single-center study was performed at Prince Sultan Cardiac Centre, Qassim, Saudi Arabia. A total of 104 patients with low-to-intermediate probability of coronary artery disease (CAD) underwent CTA with either PGA or ECTCM acquisition. PGA was performed during the study period and compared with the last 50 CTAs previously done using ECTCM. A 4-point scale was used to assess the image quality subjectively. Objective image quality was assessed using image signal, noise, and signal-to-noise ratio (SNR).

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Results: Patient's Baseline characteristics were not different between the two scanning protocols. The 4-point score of subjective image quality showed no significant differences between the PGA and ECTCM scans (2.9 ± 0.7 , 2.96 ± 0.7 , respectively; $p = 0.87$). The objective image quality showed significantly higher noise and lower SNR with PGA compared with ECTCM (31 ± 9 , 27 ± 9 , respectively; $p < 0.001$ for noise) and (15 ± 5 , 17 ± 7 , respectively; $p < 0.001$ for SNR), with no statistical difference in the image signal (434 ± 123 , 425 ± 103 HU, respectively, $p = 0.7$).

Radiation exposure was significantly lower with PGA than with ECTCM. The dose-length product (DLP) for PGA was 334 ± 130 mGy, compared with 822 ± 286 mGy for the ECTCM. This corresponds to a 59% reduction in radiation exposure ($p < 0.0001$).

Conclusions: Although prospective ECG-triggered axial scanning increased image noise, it maintained subjective image quality and was associated with a 59% reduction in radiation exposure when compared with ECTCM.

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Keywords: Image noise, Radiation exposure, Coronary angiography

Introduction

Coronary computed tomography angiography (CTA) has become an important tool in the diagnosis of coronary artery disease. Despite developments in multi-detector computed tomography (MDCT) technology, exposure to ionizing radiation and the subsequent lifetime potential risk of cancer remains a limitation [1–4]. The 16-row MDCT has a 1.9–3.9-fold increase in effective radiation dose compared to conventional invasive coronary angiography, but this is less than

Abbreviations

BMI	body mass index
CAD	coronary artery disease
CTA	computed tomographic coronary angiography
DLP	dose-length product
ECTCM	ECG-controlled tube current modulation
HR	heart rate
HU	Hounsfield unit
MPR	multi-planar reconstruction
PGA	prospective gated axial
RGH	retrospectively-gated helical
SNR	signal-to-noise ratio

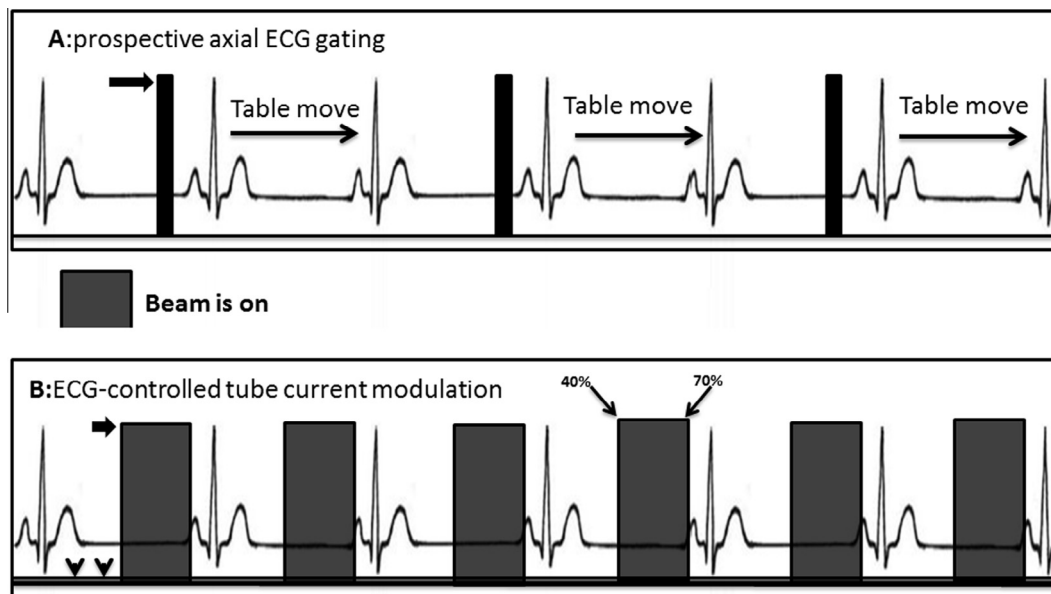


Figure 1. Model shows ECG Gating in PGA vs ECTCM: (A) prospective axial ECG gating: the X-ray is on during the scan only at the best diastolic phase (black arrow). (B) ECG-controlled tube current modulation: X-ray is on throughout the cardiac cycle with maximum intensity between 40% and 70% of RR interval (black arrow), while it drops to 5% at the rest of RR (arrow head).

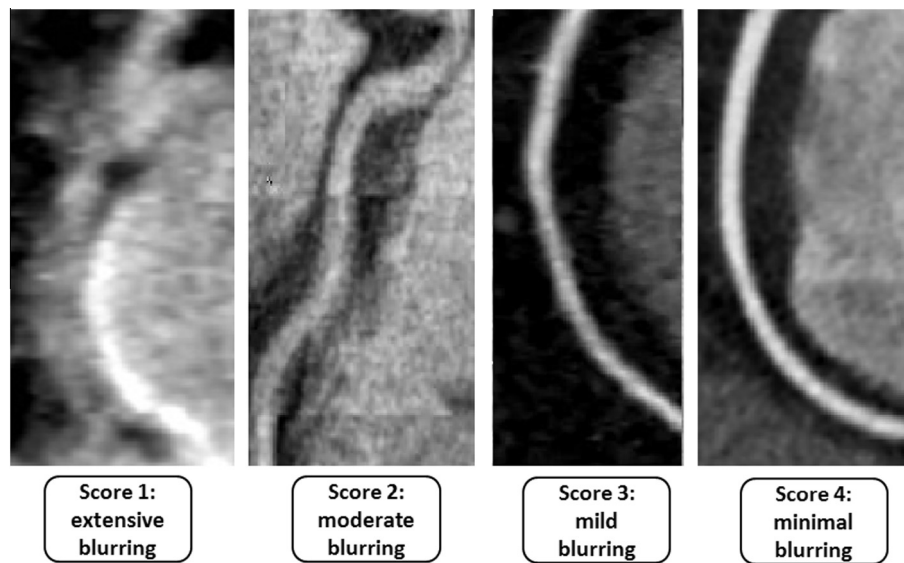


Figure 2. Subjective image quality assessed by 4 point score.

the reported radiation dose using 64 MDCT which ranges between 9.5 to 21.4 mSv [5–9]. In fact, there are many CTA acquisition protocols and strategies [10] that can be used to reduce radiation exposure, such as using a lower tube voltage (100 kVp) [11]. ECG-controlled tube current modulation (ECTCM) [12] and prospective axial ECG gating (PGA) [13–17] represent the latest techniques associated with a reduction of up to 70% in radiation exposure compared with retrospectively-gated helical CT (RGH). However, these different techniques may affect image quality by increasing image noise or susceptibility to heart rate irregularities [18,19] and which, in turn, may impair diagnostic accuracy. In this study, we hypothesize that PGA will lower radiation exposure without compromising the quality of the CTA.

The aim of our study is to compare subjective and objective image quality and radiation reduction using PGA versus ECTCM (with a 40%–70% ECG window) using 256-slice CTA.

Material and methods

Study design

We designed a prospective single-center study of patients referred to Prince Sultan Cardiac Center, Qassim, Saudi Arabia for CTA between May 2012 and March 2013. We included 104 patients with low-to-intermediate risk of coronary artery disease (CAD), all of whom were referred from outpatient clinics. We performed 54 consecutive CTAs using PGA scan during the study period and compared these with the last 50 CTAs

previously performed using ECTCM technique. Patients with a serum creatinine level of more than 130 $\mu\text{mol/L}$ or atrial fibrillation were excluded. The center's Research Ethics Committee approved the study, and informed written consent was obtained from each participant.

CTA acquisition

Imaging was performed using 256-row dual source CT scanners (Siemens Definition Flash[®], Siemens Healthcare, Forchheim, Germany) with



Figure 3. Objective image quality assessment using a region of interest (1 cm^2) in the ascending aorta at the level of Left main coronary artery, Noise = standard deviation (HU). signal = the mean(HU).

Table 1. Patients demographic data.

Variable	PGA 54 patient	ECTCM 50 patient	P value
Age	50 ± 10	52 ± 11	0.23
Male sex n(%)	32 (60%)	31 (62%)	0.8
Diabetes mellitus n(%)	18 (33%)	21 (42%)	0.4
Hypertension n(%)	21 (39%)	24 (48%)	0.4
Dyslipidemia n(%)	20 (37%)	22 (40%)	0.5
Family history of CAD n(%)	2 (4%)	3 (6%)	0.6
Current smoking n(%)	10 (19%)	10 (20%)	0.9
Body weight kg	80 ± 15	82 ± 12	0.5
BMI kg/m ²	30.3 ± 5.8	30.7 ± 4.3	0.6
Waist cm	94 ± 28	99 ± 20	0.2
Hip cm	99 ± 28	103 ± 21	0.4
WHR	0.95 ± 0.07	0.97 ± 0.07	0.08
Heart rate HR bpm	67 ± 8	67 ± 9	0.9
100 kV	29 (54%)	28 (56%)	0.8
CTA finding			
Patients with CAC > 0	14 (26%)	21 (42%)	0.099
CCS	20 ± 72	42 ± 71	0.13
Normal coronary n(%)	38 (70.4%)	28 (56%)	0.158
Mild stenosis n(%)	12 (22.2%)	19 (38%)	0.08
Moderate stenosis n(%)	1 (1.9%)	2 (4%)	0.5
Sever stenosis n(%)	3 (5.5%)	1 (2%)	0.34

Baseline characteristics and CTA finding showed no significant different between PGA and ECTCM groups. Stenosis was graded as mild (1–30% stenosis) moderate (30–70%) and severe (>70% stenosis). BMI, body mass index; WHR, Waist-hip ratio; CAC, coronary artery calcification; CCS, coronary calcium score.

Table 2. Subjective and objective image quality.

Variable	PGA: 54 patient	ECTCM: 50 patient	P value
Noise	31 ± 9	27 ± 9	0.013
Signal	434 ± 123	425 ± 103	0.7
SNR	15 ± 5	17 ± 7	0.012
Image quality score	2.89 ± 0.7	2.96 ± 0.7	0.6
Calcium score	40 ± 181	43 ± 72	0.89
Radiation msV	4.67 ± 1.8	11.5 ± 4	<0.001
Radiation dose DLP	334 ± 128	823 ± 287	<0.001

a gantry rotation time of 0.28 s, temporal resolution of 75 ms, 0.6-mm collimation, tube current 320 mAs for PGA. For patients with a body weight of <85 kg, a 100-kVp tube voltage was used, while 120 kVp was used for patients with a body weight of ≥85 kg.

CTA data were acquired with a breath hold in deep inspiration. Beta-blockers were used to keep resting heart rate (HR) < 65 beats per minute (the mean HR during the scan was 67 ± 9), and all patients received sublingual nitroglycerine during the procedure. A test bolus of 15 mL of contrast agent XENETIX 350® (350 mg iodine/mL) followed by a 25-mL saline flush, both at flow rates of 6 mL/s, was administered to determine the time to peak enhancement in a region of interest in the ascending aorta. For coronary CTA, 80 mL followed by a 45-mL saline flush, both at flow rates of 6 mL/s, was administered. Image acquisition was started after the predetermined delay time plus 3 s.

ECG gating

CTA was performed using either PGA or ECTCM (Fig. 1).

CTA image reconstruction

Data from the best diastolic phase was reconstructed for PGA while data from the best systolic and best diastolic phases were used for ECTCM. Reconstructed slice thickness was 0.6 mm, with a medium sharp filter B26.

Reconstructed axial images and oblique multiplanar reconstruction (MPR) images were reviewed by two readers using a workstation (MMWP®; Siemens Healthcare) with window width 700 HU and level 200 HU.

Image quality

The subjective and objective image quality of all CTAs was evaluated separately by two readers. Subjective image quality was scored visually

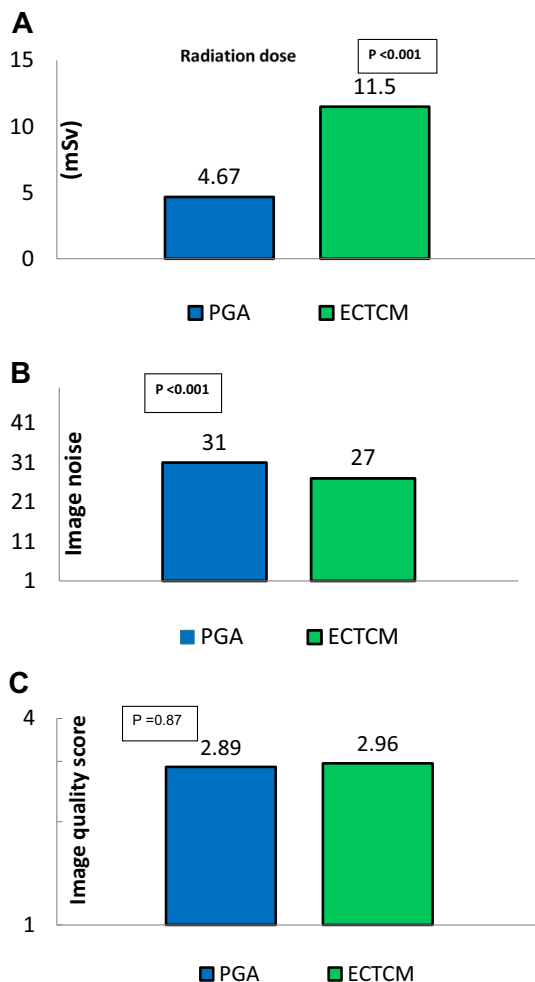


Figure 4. Comparing prospectively gated axial (PGA) acquisition with ECG controlled tube current modulation (ECTCM) scan. (A) Radiation exposure is significantly reduced using PGA vs. ECTCM. (B) PGA acquisition prone to have higher noise than ECTCM scans. (C) There is no significant difference in subjective image quality.

according to a four-point scale (4 for excellent image quality, 3 for good quality, 2 for acceptable, and 1 for non-diagnostic; Fig. 2). Final scores were averaged. Objective image quality was evaluated by calculating image signal and noise using a 1-cm² region of interest (ROI) in two sequential slices in the aortic root at the level of the left main coronary artery. Image signal was the mean Hounsfield units (HU) and noise was averaged standard deviation (SD) in HU (Fig. 3).

Coronary artery calcification CAC and CTA data:

We used MMWP software to calculate coronary calcium score (CCS) using the Agatston method.

CTA data: Coronary stenoses were graded using quantitative measurements using Syngo MMWP workstation by two readers into four categories: normal if no stenosis, mild (>0–30% stenosis), moderate (31–70% stenosis), and severe (>70%).

Effective radiation dose

The effective radiation dose was derived from the dose length product (DLP) multiplied by a conversion factor of 0.014 for chest CT in adults [20].

Statistical methods

Statistical analyses were performed with commercial software (SPSS for Windows[®] version 19.0; SPSS Inc., Chicago IL, USA). Data were expressed as mean ± standard deviation. A *p* value < 0.05 was considered statistically significant.

T-test analysis was used to compare numerical variables between the two groups, while Chi-square analysis was used to compare categorical variables.

Results

Fifty-four patients underwent CTA with PGA and 50 patients underwent CTA with ECTCM. The mean age was 51 ± 11 years; and 61% were male. The mean body weight was 81 ± 13 kg; the mean body mass index (BMI) was 30.6 ± 5.0 kg/m², and waist circumference was 96 ± 24 cm. Baseline characteristics, CCS, and CTA data of the two groups are shown in Table 1. The scores of subjective image quality showed no significant difference between PGA and ECTCM (2.9 ± 0.7 and 2.96 ± 0.7, respectively; *p* = 0.87). The objective image quality scores showed significantly increased image noise (31 ± 9 vs. 27 ± 9 HU, *p* < 0.001; Fig. 4) and decreased SNR (15 ± 5 vs. 17 ± 7, *p* < 0.001) with no changes in image signal (434 ± 123 vs. 425 ± 103 HU, respectively, *p* = 0.7; Table 2).

Radiation exposure was significantly lower with PGA than with ECTCM, with DLP 334 ± 130 mGy vs. 822 ± 286 mGy, respectively, and estimated effective dose 4.67 ± 1.8 mSv vs. 11.5 ± 4 mSv, respectively. This corresponds to a 59% reduction in radiation exposure (*p* < 0.0001; Fig. 4).

Non-diagnostic studies with a subjective score of 1 were observed in three PGA patients (5.5%) and one ECTCM patient (2%; *p* = 0.647). All these patients had motion artifacts as a cause of degraded image quality.

Discussion

Radiation exposure remains one of the major concerns of CTA [21]. Achieving a lower radiation dose while maintaining optimal image quality is an important prerequisite when choosing the most appropriate scan protocol to minimize image-degrading artifacts caused by heart rate variation and tachycardia. ECTCM, lower tube voltages, automated exposure control, prospective

ECG-triggered high-pitch spiral scan, and prospective ECG-triggered axial scan are some techniques used to lower exposure. Studies have shown that these techniques can reduce radiation dose without significant effects on image quality [22,23].

With PGA, the scan is triggered by the ECG signal at a predefined time interval that is averaged using multiple cardiac cycles before the actual acquisition to obtain the data during the diastolic phase in which motion artifact is minimal. The scan is stopped at the rest of the cardiac cycle; with a scan pitch of 1, there is no overlap between slices. Thus, this scan mode is more susceptible to heart rate variation [24,25]. Conversely, in RGH, the data are acquired continuously throughout the entire cardiac cycle. Using a lower scan pitch (0.2–0.3) in cardiac imaging increases the overlapping of transverse slabs that causes over-scanning of the tissue at the Z axis. This leads to a linear increase in X-ray photons that contributes to each reconstructed slice even if the same X-ray technique settings (kVp and mAs) are used, and which may explain lower image noise and higher radiation exposure when using a smaller pitch value in an RGH scan [26–29]. The same technique is used with ECTCM; that is, dropping the tube current (mA) during systole (up to 5% compared with diastole) in an attempt to lower radiation [30]. With ECTCM, both the systolic and diastolic phases are acquired and available to assess cardiac function and left ventricle dimensions. The most significant drawback of PGA is its inability to assess cardiac wall motions or ejection fraction because of the lack of the systolic phase. Our study demonstrated a 59% lower radiation exposure using PGA, with preserved image quality compared with ECTCM. Most of the scan had good diagnostic quality, with 94.5% interpretable vessels for PGA vs. 98.0% for ECTCM. Multiple studies have compared PGA with RGH with respect to radiation and the changes in diagnostic image value. Hausleiter et al. [31] reported a 69% reduction in the radiation dose with PGA in a multicenter PROTECTION III study using a 64-slice scanner; however, acquisition in the RGH scan involved the entire cardiac cycle. Shuman et al. [32] reported non-inferior image quality and a 77% dose reduction with PGA compared with ECTCM when the tube current was set at 600–790 mA during 60%–80% and at 200–400 mA during the rest of the R-R interval. In our study, the mA was set to decrease by up to 5%. Similar results were shown by Hou et al. [33] using a 256-slice scanner. They demonstrated a 73% dose

reduction with comparable image quality between PGA and RGH. A recent meta-analysis of 20 different studies [34] involving 3330 patients showed 91.3% diagnostic quality of CTA with prospective triggering and 93.3% with retrospective triggering. Conversely, the pooled effective dose was lowered by a factor of 3.5 with prospective triggering. Our findings support the use of PGH with a dual-source 256-slice CT scanner in a select group of patients with stable heart rates. This technique can yield good diagnostic imaging value at a low radiation dose.

Study limitations

Our study has several limitations. First, only one vendor's CT machine was used. Second, the tube voltage was set according to the patient's body weight: 100 kV when the body weight was <85 kg and 120 kV when the body weight was ≥85 kg, regardless of the patient's BMI. Third, no patients with a high risk of coronary artery disease who tend to have higher coronary calcification were included [35]. Therefore, the effect of excess calcification and calcium-related artifact on image quality could not be evaluated. Fourth, patients with previous revascularization were excluded; thus, the effect of metallic clips and stents, which may induce artifacts on the diagnostic image quality in different scan modes could not be assessed. Finally, to compare the findings of CTA using two different acquisition techniques, invasive coronary angiographies – considered a gold standard – were performed on only four patients who had severe stenosis by CTA.

Conclusion

The use of PGA affords a 59% radiation reduction compared with ECTCM with a 40%–70% ECG window, with no significant effect on subjective image quality, while objective image quality was significantly affected by increased image noise and reduced SNR. According to the results of our study, PGA has high diagnostic accuracy with lower radiation exposure, suggesting it may be the preferred acquisition protocol in patients with regular heart rates.

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