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Cardiac Image

Non-Gated Triple Flash Coronary Computed Tomographic Angiography in Patients with Atrial Fibrillation

Rami M Abazid,[1] Osama A Smettei,[1] Akram F Eldesoky,[1] Hanaa Al Saqqah,[1] Habiba S Alenzi,[2] Nora A Altorbak,[2] Sarah S Altorbak[2] and Mehboob Ali Dar[1]

Background: Atrial fibrillation (AF) presents a potential challenge when performing coronary computed tomography angiography (CTA). To date, there is no ideal protocol for CTA in patients with AF. We sought to design a protocol for single-heartbeat coronary CTA in patients with AF.

Methods: We enrolled 32 patients with AF and a very low probability of coronary artery disease who were referred for CTA to assess pulmonary vein anatomy for catheter ablation. A 256-slice scanner was used. Twelve patients underwent CTA using non-gated triple Flash (NGTF) consisting of three prospective electrocardiogram (ECG)-triggered helical scans with a built-in ECG simulator, while retrospectively gated helical (RGH) was used in 20 patients. Radiation dose, and a 4-point scale was used to assess coronary artery image quality between CTA scan modes.

Results: A total of 96 vessels were analyzed. The 4-point score showed no significant differences between the RGH and NGTF scans (2.9 $\pm$ 0.6 vs. 2.8 $\pm$ 0.8, respectively; p = 0.34). The number of coronary arteries with extensive blurring did not significantly differ between the protocols, and included four vessels (6.6%) in RGH vs. three vessels (8.3%) in NGTF (p = 0.5). Radiation exposure was significantly higher with RGH scans, with a dose-length product of 835 $\pm$ 146 mGy compared with 382 $\pm$ 35 mGy for NGTF (p < 0.0001).

Conclusions: Single heartbeat NGTF CTA has comparable image quality and significantly lower radiation dose compared to RGH scans in patients with AF. Whether this protocol can be used in next-generation computed tomography scanners has yet to be determined.

Key Words: Computed tomographic angiography • Flash spiral • Non-gated • Radiation • Retrospectively gated helical

INTRODUCTION

Coronary computed tomography angiography (CTA) has become a well-established tool in the diagnosis of coronary artery disease in patients with sinus rhythm. CTA can be used to rule out coronary artery stenosis in patients with stable chest pain with a negative predictive value of 99%.[1-3] The diagnostic accuracy of CTA is considerably affected by multiple factors, particularly tachyarrhythmia and an irregular heartbeat. The presence of atrial fibrillation (AF) is considered to be a relative contraindication for CTA, mainly when controlling heart rate cannot be maintained.[4-6] Furthermore, an abnormal heart rhythm during scan acquisition such as AF, atrial flutter, and extrasystole can significantly increase radiation exposure with CTA.[7]

A retrospectively-gated helical (RGH) CTA scan is the recommended protocol in the presence of an irregular

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[1]Prince Sultan Cardiac Center Qassim (PSCCQ), King Fahad Specialist Hospital; [2]Qassim College of Medicine, Qassim University, Buraydah, Qassim, Saudi Arabia.
Corresponding author: Dr. Rami M Abazid, King Fahad Specialist Hospital, Prince Sultan Cardiac Center Qassim PSCCQ, Qassim, Burydah, King Addullah Street, PO Box: 4560, Postal code: 51412, Saudi Arabia. E-mail: ramiabazid@yahoo.com

rhythm. RGH has the advantage of enabling reconstruction of images in different phases of the cardiac cycle, which may improve the diagnostic accuracy in the presence of motion artifacts. However, RGH is associated with an increase in radiation exposure compared with a prospective electrocardiography (ECG)-triggered scan.[8,9] The latest generation of dual-source multi-detector computed tomography scanners has introduced a new scan mode, prospectively ECG-triggered helical data acquisition (flash spiral),[10] with very high pitch values of more than 3.0. This technique enables acquisition of the entire heart volume within a fraction of a single cardiac cycle with sub-millisievert radiation exposure.[11] The flash spiral mode is only possible with dual-source CTA as it can provide a high temporal resolution, and is specifically recommended in patients with a slow and regular heart rate.[12,13] This study aimed to introduce a new scanning protocol for patients with AF that can achieve a diagnostic accuracy similar to RGH with a decrease in radiation exposure.

METHODS

Selection of patients

We performed this prospective study in a tertiary care center between 2012 and 2015. We included 32 patients who planned to undergo pulmonary vein isolation for AF who were at a low risk of coronary artery disease. Twelve consecutive CTAs were performed using our new non-gated triple Flash spiral (NGTF) scanning protocol during the study period, and were compared with 20 CTAs that had been previously performed using the RGH technique. Patients with a heart rate greater than 65 beats/minor with sinus rhythm during the CTA acquisition were excluded. The study was approved by the regional ethics committee, and all patients provided informed consent.

Acquisition of CTA using the NGTF protocol

Twelve patients underwent CTA with a 256-row dual-source computed tomography scanner (Siemens Definition Flash®; Siemens Healthcare, Forchheim, Germany) using the NGTF protocol consisting of three sequential Flash spiral scans as follows: cranio-caudal, caudal-cranial, and cranio-caudal scan directions. Built-in ECG simulation with regular rhythm and heart rate of 60 beats/min was used for gating during the NGTF scan (Figure 1).

Cardiac monitoring was continued to ensure a controlled heart rate during the scan for all of the patients. Beta-blockers were used to maintain a resting heart rate of less than 65 beats/min. CTA data were acquired with a breath hold in deep inspiration. All of the patients received sublingual nitroglycerine during the procedure. A test bolus of 20 mL of contrast agent XENETIX 350® (350 mg iodine/mL) followed by a 40-mL saline flush, both at flow rates of 6 mL/s, were administered to determine the time to peak enhancement in a region of interest in the ascending aorta. For coronary CTA, 80-95 mL of contrast media followed by a 45-mL saline flush were administered, both at flow rates of 6 mL/s. Image acquisition was started after the predetermined delay time plus 5 seconds.

Acquisition of CTA using RGH

Twenty-two patients underwent CTA using RGA with ECG-controlled tube current modulation where the X-ray was on throughout the cardiac cycle. The maximum intensity was between 40% and 70% of the RR interval, but fell to 5% at the rest of the cardiac cycle (Figure 2). A test bolus of 20 mL was used similar to that in the NGTF procedure, and 65-75 mL of contrast medium (calculated according to the delay and the scan time) was used for CTA with the same flow rate of 6 mL/s. Image acquisition was started after the predetermined delay time plus 3 seconds.

CTA image reconstruction

Data from the three NGTF scans were reconstructed, while data from the systolic and diastolic phases were

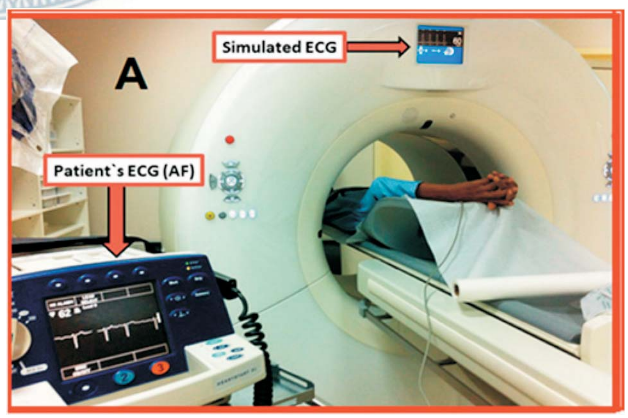

Figure 1. *Patient position and monitoring during NGTF scan. The scan considered non gated scan as it triggered by a built-in simulated ECG but not the patient's ECG.*

used for RGH. The reconstructed slice thickness was 0.6 mm. Axial images and curved multiplanar reconstruction images (Figure 3) were reviewed by two readers using a workstation (MMWP®; Siemens Healthcare) with a window level of 200 HU and width of 700 HU.

Image quality

The objective and subjective image quality was evaluated separately by two readers for all CTAs.[8] Four-point scale was used to score subjective image quality (1 for non-diagnostic quality, 2 for acceptable quality, 3 for good quality, and 4 for excellent image quality). The final subjective scores were averaged (Figure 4). Objective CTA quality was assessed by measuring the image noise and signal using a 1-cm^2 region of interest in the aortic root at the level of the left main coronary artery. Image noise was defined as the standard deviation (SD) in HU and signals were defined as mean HU (Figure 4).

Effective radiation dose

The effective radiation dose was derived from the dose-length product, which was multiplied by a conversion factor of 0.014 for chest computed tomography in adults.[14]

Statistical analysis

Quantitative variables were expressed as means ± SD, and categorical variables were expressed as frequencies or percentages. Subjective and objective image quality and radiation exposure between the NGTF and RGH protocols were compared. For normally distributed continuous variables, the two-sample t-test was used, and the chi-square or Fisher's exact test was used for categorical variables. A p value < 0.05 was considered to be statistically significant for all tests. SPSS for Windows (version 20.0 SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

RESULTS

Baseline characteristics of the patients

The mean (SD) age of the patients was 41 ± 6 years

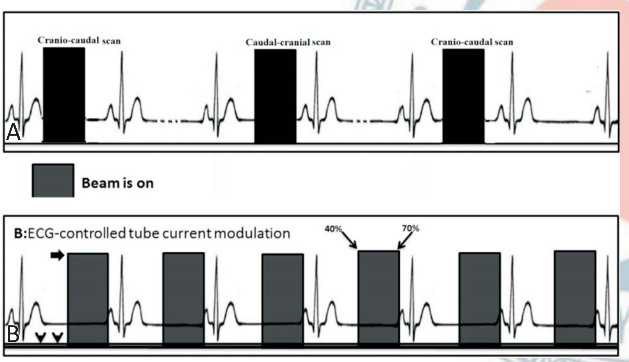

Figure 2. *Model shows ECG gating in Flash vs. RGH: (A) in flash high pitch gating: the X-ray is on during the scan only (single heart beat) in cranio-caudal direction, caudal-carnial and cranio-caudal scan. (B) in RGH scan: X-ray is on throughout the cardiac cycle with maximum intensity between 40% and 70% of RR interval (black arrow), while it drop to 5% at the rest of RR (arrow head).*

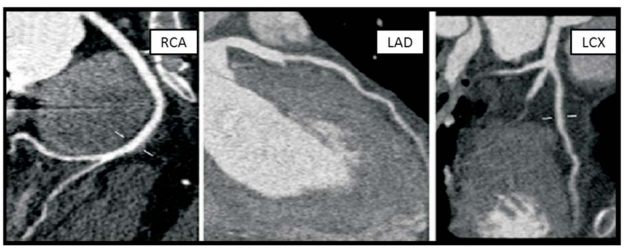

Figure 3. *Excellent image quality of the coronary artery using NGTF protocol.*

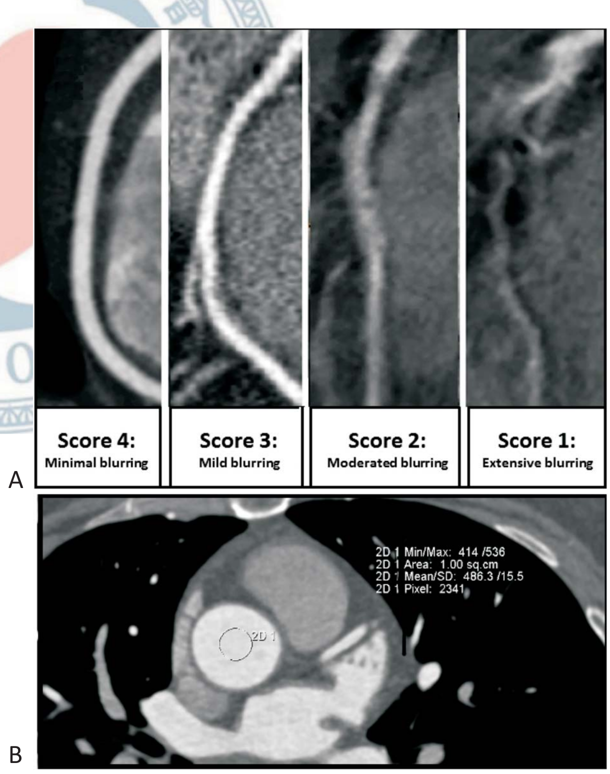

Figure 4. *Assessment of image quality. (A) Assessement of subjective image quality by 4 point score. (B) Assessment of objective image quality using a region of interest (1 cm^2) in the ascending aorta at the level of left main coronary arter yo noise defined as standard deviation in HU. Signal defined as the mean HU.*

and there were 25 (78%) men. We found no differences in baseline characteristics between the NGTF and RGH groups (Table 1).

Image quality

A total of 96 vessels were analyzed (36 vessels in the NGTF group and 60 vessels in the RGH group). The scores of subjective image quality were not significantly different between the NGTF and RGH groups (2.8 ± 0.8 vs. 2.9 ± 0.6, p = 0.34). The objective image quality scores were not significantly different regarding image noise (32 ± 7 vs. 30 ± 8 HU, p = 0.09) and image signal (421 ± 132 vs. 432 ± 124 HU, p = 0.8) between the NGTF and RGH groups (Table 2). The number of coronary arteries with extensive blurring (reliable assessment of vessels was impossible) was not significantly different between the protocols, with four (6.6%) vessels in the RGH group and three (8.3%) vessels in the NGTF group (p = 0.5).

Radiation exposure and contrast medium

Radiation was significantly lower in the NGTF group than in the RGH group. The dose-length product was 381 ± 35 mGy vs. 835 ± 146 mGy (p < 0.0001), and the estimated effective dose was 5.33 ± 0.49 mSv vs. 11.69 ± 2.04 mSv (p < 0.0001), respectively. This corresponded to a 54% reduction in radiation exposure in the NGTF group (p < 0.0001, Figure 5).

Significantly more contrast volume was used in the NGTF group than in the RGH group (112 ± 3 vs. 91 ± 2 mL, p < 0.0001, Figure 5). Importantly, contrast-induced nephropathy was not reported after CTA in the present study.

Table 1. Baseline characteristics and CTA finding showed no significant different between NGTF and RGH groups

Variable	NGFT group	RGH group	p value
Age	43 ± 6	40 ± 5	0.23
Male sex, n (%)	9 (75%)	16 (80%)	0.74
Diabetes mellitus, n (%)	4 (33%)	7 (37%)	0.9
Hypertension, n (%)	4 (33.3%)	9 (45%)	0.5
Dyslipidemia, n(%)	1 (8.3%)	2 (10%)	0.87
Family history of CAD, n (%)	2 (17%)	1 (5%)	0.27
Current smoking, n (%)	1 (8.3%)	3 (15%)	0.58
Body weight, kg	78 ± 13	81 ± 12	0.6
BMI, kg/m^2	28.3 ± 4.8	29.7 ± 5.3	0.67
Heart rate beat per minutes	56 ± 4	58 ± 5	0.4

BMI, body mass index; CCS, coronary calcium score.

Table 2. Subjective and objective image quality radiation expoure and contrast volume in both groups

Variable	NGFT group	RGA group	p value
Noise	32 ± 7	30 ± 8	0.09
Signal	421 ± 132	432 ± 124	0.8
SNR	13.4 ± 6	15.2 ± 5	0.5
Image quality score	2.8 ± 0.8	2.9 ± 0.6	0.34
Contrast volume(ml)	112 ± 3	91 ± 2	< 0.0001
Radiation msV	5.33 ± 0.49	11.69 ± 2.04	< 0.0001
Radiation dose DLP	381 ± 35	835 ± 146	< 0.0001

DLP, dose length product; SNR, signal to noise ratio.

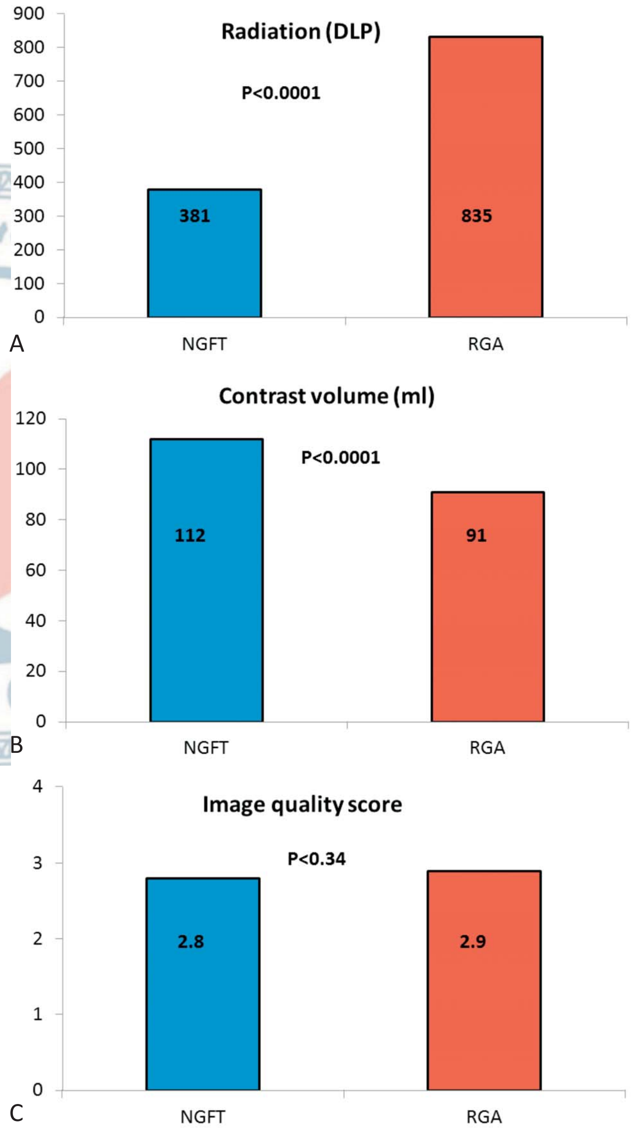

Figure 5. *Comparing NGTF acquisition with RGH scan. (A) Radiation exposure is significantly reduced using NGTF vs. RGH. (B) Contrast volume signifcantly higher in NGTF scan. (C) There is no significant difference in subjective image quality.*

DISCUSSION

In this study, we compared the new protocol NGTF with the standard RGH protocol in patients with AF. We found that there were no significant differences in objective or subjective image quality between protocols. However, radiation exposure was significantly lower and the volume of contrast medium was higher in the NGTF group compared with the RGH group.

There are multiple acquisition protocols for cardiac CTA such as the prospective ECG-triggered protocol, in which the scan is triggered by the ECG signal at a predefined time interval. This time interval is averaged using multiple cardiac cycles before actual acquisition to obtain data during the diastolic phase. The scan is stopped at the rest of the cardiac cycle, resulting in lower radiation exposure. However, this scan mode is more susceptible to variations in heart rate and is not recommended for patients with arrhythmias.[15-17] RGH allows scanning of the heart during systole and diastole, which makes it the recommended acquisition protocol for patients with cardiac arrhythmias such as AF. RGH enables the reconstruction of multiple scan phases to overcome motion artifacts and improve the diagnostic accuracy of CTA.[18-20] In addition, a prospective ECG-triggered helical data acquisition (flash spiral) scan can enable acquisition of a single heartbeat with a low radiation dose, although it ideally requires a regular and slow heart rate.[21,22]

In our study, we found that NGTF which consists of three flash spiral scans required a larger volume of contrast medium than RGH to maintain vascular contrast opacification. This can be explained by the longer total scan time with this protocol, which requires three different scans (cranio-caudal, caudal-cranial, and cranio-caudal) and two pauses between acquisitions.

Multiple studies have assessed the diagnostic accuracy of CTA in patients with AF. Oncel et al.[23] studied the diagnostic accuracy of the RGH protocol using dual-source CTA, and found that the sensitivity and specificity of computed tomography in detecting more than 50% stenosis were 87% and 98%, respectively. A similar result was reported by Marwan et al.[24] who found that the sensitivity of CTA in detecting significant coronary stenosis compared with invasive angiography was 95% (95% CI 77-100) with a specificity of 94% (95% CI 89-97). In addition, Yang et al.[25] investigated the accuracy of RGH in 64-slice CTA for patients with AF, and reported overall sensitivity and specificity per segment level of 86.4% and 99.3%, respectively. Xu et al.[26] showed that prospective ECG-triggered sequential CTA was feasible using dual-source computed tomography, and that it improved the diagnostic image quality and decreased the radiation dose by > 60% compared with RGH.

To the best of our knowledge, this is the first study to use a non-gated flash spiral protocol to scan patients with AF. We used built-in ECG gating because the flash protocol required a regular and slow heart rate as a prerequisite, and AF was rejected by the software. Furthermore, we used three scan phases to increase the chance of acquiring the coronary arteries at the diastolic phase, thus reducing the amount of motion artifacts in the images (Figure 5).

Our study has important clinical implications because it describes a new scanning protocol for imaging patients with controlled AF with a comparable image quality and a 54% reduction in radiation compared with RGH. Moreover, NGTF can probably be used in patients with other irregularities such as extrasystole, and in patients with a controlled heart rate when the ECG signal is inadequate for gating. Further studies should be performed including a larger number of patients to compare NGTF with standard invasive coronary angiography to determine the diagnostic accuracy of this new scanning protocol. Moreover, different strategies aimed at reducing the volume of contrast media can be applied, such as using a lower flow rate (5 mL/s), a smaller volume during the test bolus (15 mL), and/or using the bolus tracking technique as an alternative to the test bolus.[27]

There are several limitations to this study. Only a small number of patients was included. In addition, this scan protocol can only be used on a dual-source computed tomography machine. In addition, we only included patients at low risk of coronary artery disease. Including higher risk individuals such as patients with a large amount of coronary calcification, post-coronary intervention, or post-coronary bypass surgery may have affected the image quality of our protocol. Moreover, only patients with a heart rate < 65 beats/min were included. Therefore, the effect of a faster heart rate could not be assessed. Finally, invasive coronary angiography was not used as the gold standard imaging technique to analyze the diagnostic accuracy of CTA protocols in this study.

CONCLUSIONS

The use of single-heartbeat, non-gated, triple flash CTA had comparable subjective and objective image quality to RGH. In addition, this protocol resulted in a 54% reduction in radiation dose compared with RGH in the patients with AF. Further studies are needed to evaluate whether this protocol can be used in next-generation computed tomography scanners with faster gantry rotation.

ABBREVIATIONS

CTA, coronary computed tomography angiography; AF, atrial fibrillation; NGTF, non-gated triple flash; RGH, retrospectively gated helical; ECG, electrocardiogram.

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DISCLOSURES

The authors declare that there are no conflicts of interest.

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