Original

Optimization of Retrospective Gated-ECG Coronary Computed Tomography Angiography by Dose Reduction in Patients with Different Body Mass Indexes

Behzad Fazlkhah (MSc)[1], Mona Fazel Ghaziyani (PhD)[1], Leyla Dinparast (MD)[2], Vahid Alinejad (PhD)[3], Yunus Soleymani (MSc)[4], Davood Khezerloo (PhD)[1]*

[1]Department of Radiology, Faculty of Alliance Medical Sciences, Tabriz University of Medical Sciences, Tabriz, Iran
[2]Department of Radiology, Faculty of Medicine, Urmia University of Medical Sciences, Urmia, Iran
[3]Department of Biostatistics, Faculty of Medicine, Urmia University of Medical Sciences, Urmia, Iran
[4]Department of Neuroscience and Addiction Studies, School of Advance Technologies of Medicine, Tehran University of Medical Sciences, Tehran, Iran

ABSTRACT

Background: The reduction of patient radiation dose in coronary Computed Tomography Angiography (CCTA) with acceptable image quality is considered an important factor in the research.

Objective: This study aims to optimize the CCTA protocol using a retrospective Electrocardiogram (ECG)-gated axial scan protocol in patients with different Body Mass Indexes (BMIs).

Material and Methods: In this cross-sectional study, 66 patients into three main groups: 80 kVp (Group A), 100 kVp (Group B), and 120 kVp (Group C), underwent CCTA. Each group was then divided into two subgroups of BMI<25 and >25 kg/m^2. Image noise, mean vascular attenuation at the aorta, signal-to-noise ratio (SNR), and Contrast-to-Noise Ratio (CNR) at five regions of coronary arteries, in which Coronary artery anomalies are common were qualitatively evaluated by subjective image quality analysis.

Results: At each kVp, there were no significant differences in CNR, SNR, noise level, and the effective dose between BMI>25 kg/m^2 and BMI<25 kg/m^2. The effective radiation dose of groups A, B, and C were 4.16, 8.46, and 14.3 mSv, respectively. Subjective image quality assessment scores were 3.18, 3.5, and 3.73 out of 4 in groups A, B, and C, respectively.

Conclusion: Patient radiation dose using retrospective ECG-gated CCTA can be reduced by about 70% at 80 kVp, which is almost close to the prospective CCTA dose ranges. The retrospective CCTA at 80 kVp can be optimized even in overweight patients (BMI>25 kg/m^2).

Citation: Fazlkhah B, Fazel Ghaziyani M, Dinparast L, Alinejad V, Soleymani Y, Khezerloo D. Optimization of Retrospective Gated-ECG Coronary Computed Tomogra-phy Angiography by Dose Reduction in Patients with Different Body Mass In-dexes. *J Biomed Phys Eng*. 2025;15(3):281-290. doi: 10.31661/jbpe.v0i0.2209-1537.

Keyword

Computed Tomography Angiography; Retrospective Computed Tomography Angiography; Electrocardiography; Low Dose CT Angiography; Radiation Dosage; Effective Radiation Dose; Tube Voltage Reduction

*Corresponding author: Davood Khezerloo
Department of Radiology, Faculty of Alliance Medical Sciences, Tabriz University of Medical Sciences, Tabriz, Iran
E-mail: khezerlood@tbzmed.ac.ir

Received: 12 September 2022
Accepted: 15 January 2023

Introduction

Coronary CT Angiography (CCTA) has an important role in the assessment of atherosclerotic Cardiovascular Disease (CAD), with a sensitivity of up to 97% and a specificity of up to 78% compared with invasive coronary angiography [1, 2]. However, CCTA is noninvasive with impressive diagnostic accuracy, and the high patient radiation dose level of CCTA is considered a disadvantage. The average dose of CCTA is about between 15 and 21 (mSv) [3]. Reduction of the radiation dose of CCTA with constant image quality is known as a challenging issue in medical imaging procedures. With the technical advances in Computed Tomography (CT), various strategies have been developed to decrease the radiation dose [4].

Prospective and retrospective gated CT angiographies as two different data acquisition methods in coronary artery disease (CAD) assessment are used in clinics despite their disadvantages [5]. However, prospective ECG- CCTA shows promising results in the diagnosis of CAD with low patient effective dose, prospective CCTA is performed by strict exclusion criteria, careful patient selection, and preparation. Patients with a high-heart rate and irregular heart rhythm are not suitable for prospective CCTA [6, 7]. Instead, retrospectively ECG-gated CCTA is obtained in cases, in which information is needed on ventricular or valvular function, or control of heart rate is not sufficient for a diagnostic perspective ECG gated acquisition (e.g., high heart rate or irregular rhythm) [7, 8]. Moreover, the perspective CCTA technique provides fewer cardiac phases for interpretation [9]. Previous studies have shown that more than 50% of coronary angiography procedures in developing countries and less developed countries are still performed as retrospectively CCTA [10-15]. However, most recent studies about the strategies of radiation dose reduction in CT angiography have mainly focused on prospective ECG-gated CCTA methods, retrospective CCTA methods are still routinely performed in clinics [15-17]. Patients with a high-heart rate and tachyarrhythmia have higher body mass index (BMI) than 25 kg/m^2 [18, 19].

In dose reduction strategies, the society of cardiovascular computed tomography recommends the use of a tube voltage of 100 kV for patients with a BMI<25 kg/m^2 [20, 21]. In the last decade, some studies have been conducted on the reduction of the radiation dose in CCTA by lowering the tube voltage to 80 or 100 kVp and iodine doses [17, 22-25]. The radiation dose can be reduced by 38-83% and 3-80% at 80 and 100 kVps with a BMI<25 kg/m^2, respectively, without compromising the image quality [26]. Advanced reconstruction algorithms reduce the radiation dose without compromising image noise [27, 28]. IMR (Iterative Model Reconstruction) can improve the CCTA image quality of patients with BMI higher than 30 kg/m^2 even in low tube voltage [29].

There is no consensus on appropriate low-dose approaches at different BMIs and their impact on image quality in retrospective CCTA. This study aims to evaluate the image quality at low kilovoltages (80, 100 kV) in retrospective CCTA using the IMR method in patients with different BMIs (<25 and >25 kg/m^2) and find out whether the new protocol (80 kVp) can lead to reducing radiation dose in patients with high BMI with an acceptable the image quality.

Material and Methods

Participants

This cross-sectional research, is approved by the research ethics committee of Tabriz University of Medical Sciences. After the research procedure was clearly explained to the participants, the patients who accepted to participate in our research completed the informed consent form. In this cross-sectional study, 66 patients, referred to the department of radiology participated. The ECG-gated CCTA examination. Patients, with heart rates>70, were provided beta-blockers (25-50 mg/mL propranolol and 0.5 mg/mL alprazolam) orally for 1 h before CCTA examination. The patients with heart rate<70 after administration of beta-blockers, a history of arrhythmia, congenital heart disease, iodine sensitivity, renal failure (creatinine>150 µ mol/L), and a history of bypass surgery were included in the study. After obtaining their informed consent, they were divided into three groups of 22, in which patients underwent CCTA at 80 kVp (Group A), 100 kVp (Group B), and 120 kVp (Group C). Each group was then divided into two subgroups with BMI<25 and with BMI>25 kg/m^2.

Imaging Protocol

All CT scans were in the head-foot direction (craniocaudal) from the carina area to the diaphragm with a breath hold using a 64-slice Philips Brilliance CT scanner (Koninklijke Philips N.V., 2004-2022. All rights reserved). A retrospective ECG-gating technique was used to collect information based on the scan parameters, such as gantry rotation period of 400 ms, peak kilovoltage of 80, 100, and 120 for two BMIs, and tube current-time product fixed at 800 mAs. An 18-gauge angiocatheter was used in the antecubital vein to inject a contrast-safe water-soluble substance at a concentration of 350 mg/mL and speed of 5-6 mL/s. Subsequently, 50 mL of 0.9% normal saline was injected with a double-barrel injector at a rate of 5 mL/s. Body weight was used to determine the volume of the injected contrast medium (1 mL/kg). The descending aorta was used at the region of interest (ROI). The scan began with the ROI threshold>120 HU in the descending aorta. The effective absorption dose was calculated by multiplying the dose length product (DLP) by the conversion factor of 0.014 mSv/mGy×cm [30].

Image Reconstruction and Evaluation

All CT images were reconstructed with the IMR algorithm with the reconstruction parameters as follows: 0.9 mm slice thickness, 0.45 mm increment, 15-23 cm Field of View (FOV), and 512×512 pixels image matrix. The image was then reconstructed and analyzed by Philips Extended Brilliance Workspace. After reconstruction, post-processing of data was performed with multiplanar reformatted, curved planar reformatted, and maximum intensity projection images using the scanner CT viewer software of Philips Brilliance CT scanner. The image quality was then assessed objectively and subjectively. For objective analysis, in axial images, several circular ROIs with an area of 0.5 cm^2 in the upper segments of the right coronary artery (RCA), left coronary artery (LCA), Left anterior descending (LAD) coronary artery, circumflex (CX) coronary artery, and the ROI with an area of 1.5 cm^2 in the ascending aorta were defined to measure vascular attenuation in Picture Archiving and Communication Software (PACS) workstation software. CCTA image noise level was estimated by measuring the standard deviation of attenuation values in all vessels. The contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) were calculated as follows:

$$CNR = \frac{S_{obj} - S_{adj}}{\sigma} \quad (1)$$

$$SNR = \frac{S_{obj}}{\sigma} \quad (2)$$

In which, S_{obj} and S_{adj} are the signal of ROI inside the coronary object and adjacent background region, respectively; σ is image noise.

The image quality was subjectively evaluated by a 10-year experienced expert in radiology in cardiac CT, who was unaware of the scan condition and the dosages applied to patients (Table 1).

A 4-point grading scale for the four main arteries of the heart (RCA, LCA, LAD, and CX) and the ascending aortic root.

Statistical Analysis

Age, DLP, effective dosage, signal intensity, noise, SNR, and CNR were analyzed based on the ANOVA test using SPSS (v.22). The data were described as mean±standard deviation (SD). The quality of images was compared between groups using Fisher's test. *P*-value<0.05 was considered as the significant level.

Results

A total of 40 and 26 of 66 were males and females, respectively, with a mean age of 51.62±11.45 years. Figure 1 illustrates the CCTA images of patients with different BMIs (>25 and <25 kg/m²) at three tube voltages of 80, 100, and 120 kVp, which had good and acceptable diagnostic quality.

The mean vascular attenuation values in groups A, B, and C were 810, 530, and 430

Table 1: Description of the grading scale for subjective evaluation of image quality

Grade Level	Description
Grade 1 (Non-diagnostic)	Images with high motion artifacts, overlapped blood vessels, high blurring around arteries, dark blood vessels, and indistinguishable vessels
Grade 2 (Acceptable)	Images with small artifacts but sufficient for evaluation marked blur around blood vessels and visible blood vessels
Grade 3 (Good)	Images with no motion artifacts, slight blurring around blood vessels, and clear blood vessels
Grade 4 (Excellent)	Images with no motion artifacts, no distinct noise, and light blood vessels

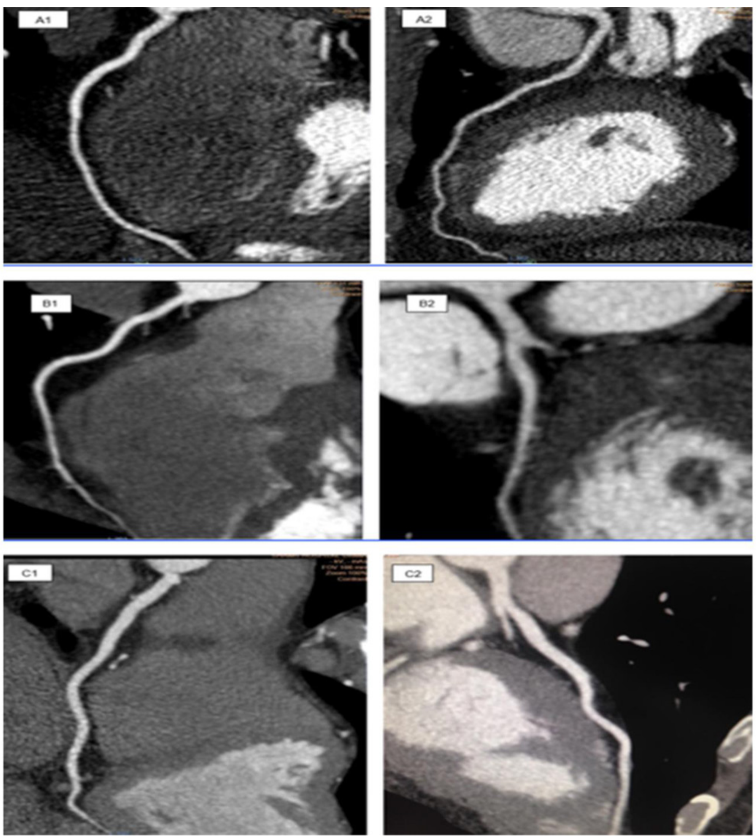

Figure 1: Retrospective ECG-gated CCTA images of subjects for RCA and LCA with different BMI and tube voltages. (**A1**) 80 KVp and 24.59 kg/m², (**A2**) 80 KVp and 27.79 kg/m², (**B1**) 100 KVp and 23.89 kg/m², (**B2**) 100 KVp and 27.42 kg/m², (**C1**) 120 KVp and 25 kg/m², (**C2**) 120 KVp and 28.2 kg/m². (ECG: Electrocardiogram, CCTA: Coronary Computed Tomography Angiography, RCA: Right coronary artery, LCA: Left coronary artery, BMI: Body Mass Index)

HU, respectively. The mean effective dose of CCTA was significantly different between the three groups (P=0.0001) as shown in Figure 2. The effective radiation dose of group A was 51% and 71% less than group B and group C, respectively. Figure 3 shows the mean noise levels in the three groups. In group A, the noise level was significantly higher than in Group B (P-value=0.0001). The values of CNR and SNR are summarized in Tables 2 and 3, respectively. There was no significant difference in mean CNR and SNR between the three groups. Moreover, there was no significant difference in CNR, SNR, noise level, and effective dose between subgroups with BMI>25 and <25 kg/m^2 at any kVp (Tables 2-4).

The subjective quality assessment section included the interpretation of 330 segments of CA by radiologists. The mean scores of the subjective quality assessment are illustrated in Figure 4. As can be seen, there was no significant difference between groups (P-value>0.85). Subjective quality scores in groups A, B, and C were 3.18, 3.5, and 3.73, respectively. In group A, about 76% of diagnostics were in grades 3 and 4 (good and excellent), while it was 90% and 95% for groups B and C, respectively.

Discussion

In this study, the effective dose for retrospec-

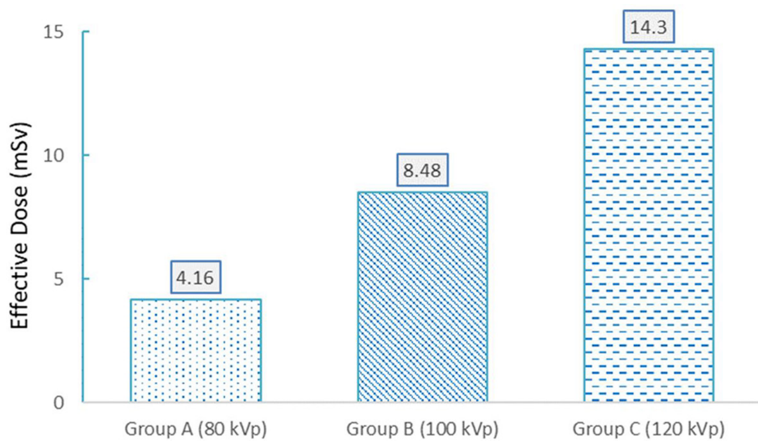

Figure 2: Effective Dose at different tube voltages in the study groups

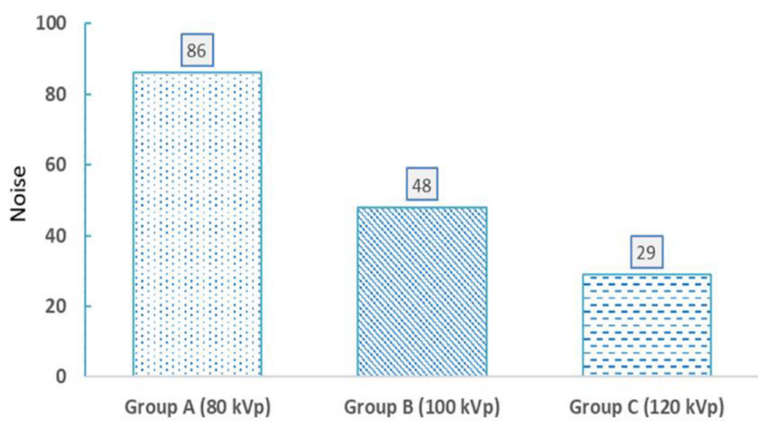

Figure 3: Noise levels at different tube voltages in the study groups

tive ECG-gated CCTA was reduced by about 70% at 80 kVp; this amount of radiation dose is close to a routine prospective CCTA procedure. The low dose strategy (80 kVp) could be applied in patients with BMI>25 kg/m^2, a finding that has not been observed in previous studies. In the last decade, various studies have focused on the reduction of patient dose in CCTA by lowering the tube voltage to 80 kVp for patients with BMI<25 kg/m^2 [7, 14, 25]. In this study, modulation of tube current based on BMI range may not be necessary since there is a square root mAs relationship between image quality and radiation dose, which is parallel with previous studies [21, 31]. In addition, the IMR algorithm may compensate for the

Table 2: Contrast-Noise Ratio (CNR) values in the study groups at different tube voltages and Body Mass Indexes (BMIs) in the selected Region of Interest (ROIs)

	CNR (Contrast-Noise Ration)						
	Group A (80 kVp)		Group B (100 kVp)		Group C (120 kVp)		***P*-value>**
	BMI<25	BMI>25	BMI<25	BMI>25	BMI<25	BMI>25	
RCA (Right coronary artery)	15.76	14.64	13.42	14.43	19.56	20.42	0.97
LCA (Left coronary artery)	10.28	12.67	11.59	12.08	14.52	15.14	0.43
LAD (Left anterior descending)	9.26	9.33	8.61	9.45	12.51	10.8	0.46
CX (Coronary artery, circumflex)	17.30	13.98	16.01	14.80	19.21	20.74	0.13

BMI: Body mass index

Table 3: Signal-to-Noise Ratio (SNR) values in the study groups at different tube voltages and Body Mass Indexes (BMIs) in the selected Region of Interest (ROIs)

	SNR(Signal-to-Noise Ratio)						
	Group A (80 kVp)		Group B (100 kVp)		Group C (120 kVp)		***P*-value>**
	BMI<25	BMI>25	BMI<25	BMI>25	BMI<25	BMI>25	
RCA (Right coronary artery)	11.68	10.67	11.2	12.76	10.72	10.94	0.63
LCA (Left coronary artery)	10.45	11.66	9.40	10.54	11.72	12.04	0.65
LAD (Left anterior descending)	10.58	11.52	9.74	10.57	10.78	9.32	0.62
CX (Coronary artery, circumflex)	15.99	12.71	14.27	12.32	15.97	17.05	0.2

BMI: Body mass index

Table 4: Effective dose and Noise levels in the study groups at different tube voltages and Body Mass Indexes (BMIs) in the selected Region of Interest (ROIs)

	Effective dose and Noise levels						
	Group A (80 kVp)		Group B (100 kVp)		Group C (120 kVp)		***P*-value<**
	BMI<25	BMI>25	BMI<25	BMI>25	BMI<25	BMI>25	
Effective dose (mSv)	4.19	4.14	8.56	8.37	13.95	14.67	0.00001
Noise level	85.33	86.55	41.10	54.63	26.90	30.30	0.0001

BMI: Body mass index

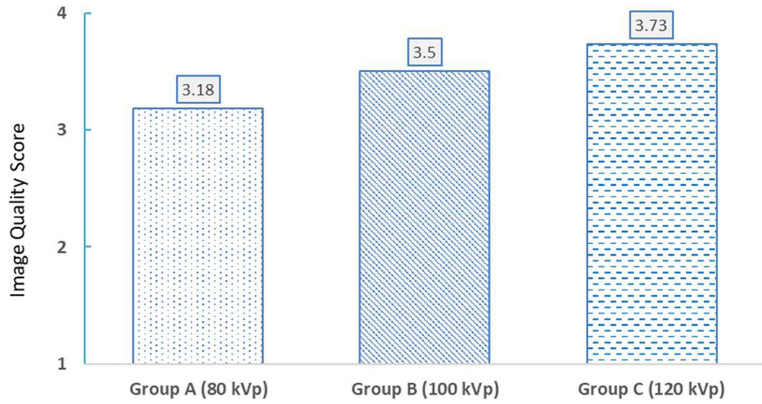

Figure 4: Subjective quality scores of computed tomography angiography (CCTA) images at different tube voltages in the study groups

increased image noise in overweight patients (BMI>25 kg/m^2) [32]. However, the low tube voltage technique may result in increased vascular attenuation in CCTA. Previous studies suggested that a vascular attenuation value of >400 HU in the aorta was required for CCTA interpretability [14, 17, 33]. In the present study, the mean CT attenuation in selected ROIs at three studied groups was all higher than 400 HU (810 HU for group A, 530 HU for group B, and 430 HU for group C). Despite the increase in noise level by decrement of kVp, the CNR and SNR in three studied tube voltages (80, 100, 120 kVp) were not significant because of the high vascular attenuation values at low kVp. The society of cardiovascular computed tomography suggests that a tube voltage of 100 kVp should be used in patients with BMI<25 kg/m^2. However, in subjective assessment of CCTA image quality, we found that the image quality at 80 kVp was not significantly compromised in patients with the BMI>25 kg/m^2 compared to those with the BMI<25 kg/m^2.

In this study, the effective dose of retrospective CCTA decreased, based on the constant image quality with an acceptable interpretation, to 4.16 mSv, which is almost close to prospective CCTA values [14, 16, 24]. In a meta-analysis that was conducted to compare image quality, diagnostic accuracy, and radiation dose of prospective vs. retrospective ECG-gated CCTA, 91.3% of CCTA images had diagnostic quality with prospective CCTA and 93.3% with retrospective CCTA among 3,330 patients from 20 included studies [16]. In that study among 664 patients from 5 studies, the sensitivity/specificity of diagnostic CCTA was 98.7%/91.3% with prospective CCTA and 96.9%/95.8% with retrospective CCTA [16]. The effective dose was 3.5 mSv with prospective CCTA, which was 3.5 lower than the effective dose of retrospective CCTA (12.3 mSv) [16]. Hausleiter et al. reported that the estimated radiation dose of retrospective ECG-aged CCTA in 50 study sites was about 12 mSv; they concluded that there is a strong need for efforts to reduce radiation dosage [34]. Advanced reconstruction methods, such as Model-based Iterative Reconstruction (MBIR), and knowledge-based IMR can improve image quality by reduction of radiation dose [35, 36]. MBIR as a systematic approach combined with statistics decreases noise by iteratively minimizing the differences between acquired data and their ideal form [35-37]. In previous studies, it has been reported that lowering the tube voltage in patients with BMI<25 kg/m^2 using IMR algorithm can reduce image noise by up to 80% compared to Filter Back Projection (FBP) in clinical CCTA studies [29, 38]. Oda et al. reported that CCTA with

100 kVp using MBIR could improve qualitative and quantitative image quality; according to their results, 100-300 mAs and the range of reported radiation dosage varied from 0.9 to 2.6 mSv [37].

There were some limitations and disadvantages in this study as follows: 1) results cannot be generalized to other algorithms such as Advanced Modeled Iterative Reconstruction or MBIR, due to using the IMR algorithm, 2) the quantitative or qualitative qualities of CCTA images were compared without evaluating the diagnostic accuracy for coronary artery disease, and 3) a phantom study was not conducted for spatial resolution assessment of the CT system.

Conclusion

Patient radiation dose can be decreased by about 70%, which is approximately close to the prospective CCTA dose ranges, by reducing the tube voltage to 80 kVp in retrospective ECG-gated CCTA. This approach can be applied even in overweight patients (BMI>25 kg/m^2) without increasing the patient radiation dose. Therefore, the low-dose approach also produces acceptable diagnostic image quality.

Authors' Contribution

D. Khezerloo conceived the idea. M. Fazel Ghaziyani, B. Fazlkhah, and Y. Soleymani gather the images and the related literature and also help with the writing of the related works. The method implementation was carried out by B. Fazlkhah and L. Dinparast. Results and Analysis were carried out by D. Khezerloo, V. Alinejad, and M. Fazel Ghaziyani. The initial framework of the paper was written by B. Fazlkhah. The research work was proofread and supervised by D. Khezerloo. All the authors read, modified, and approved the final version of the manuscript.

Ethical Approval

This research is approved by the research ethics committee of Tabriz University of Medical Sciences with a code of IR.TBZMED.REC.1399.158.

Informed consent

All participants filled out the informed consent form.

Funding

This research was supported by the Vice Chancellor for Research, Tabriz University of Medical Sciences grant number: 64445.

Conflict of Interest

None

References

1. Meinel FG, Schoepf UJ, Townsend JC, Flowers BA, Geyer LL, Ebersberger U, et al. Diagnostic yield and accuracy of coronary CT angiography after abnormal nuclear myocardial perfusion imaging. *Sci Rep.* 2018;**8**(1):9228. doi: 10.1038/s41598-018-27347-8. PubMed PMID: 29907855. PubMed PMCID: PMC6003932.
2. Maurya VK, Ravikumar R, Sharma P, Agrawal N, Bhatia M. Coronary CT angiography: A retrospective study of 220 cases. *Med J Armed Forces India*. 2016;**72**(4):377-83. doi: 10.1016/j.mjafi.2016.03.008. PubMed PMID: 27843187. PubMed PMCID: PMC5099437.
3. Gupta S, Meyersohn NM, Wood MJ, Steigner ML, Blankstein R, Ghoshhajra BB, Hedgire SS. Role of Coronary CT Angiography in Spontaneous Coronary Artery Dissection. *Radiol Cardiothorac Imaging*. 2020;**2**(6):e200364. doi: 10.1148/ryct.2020200364. PubMed PMID: 33778640. PubMed PMCID: PMC7978024.
4. Deseive S, Chen MY, Korosoglou G, Leipsic J, Martuscelli E, Carrascosa P, et al. Prospective Randomized Trial on Radiation Dose Estimates of CT Angiography Applying Iterative Image Reconstruction: The PROTECTION V Study. *JACC Cardiovasc Imaging.* 2015;**8**(8):888-96. doi: 10.1016/j.jcmg.2015.02.024. PubMed PMID: 26189118.
5. Sabarudin A, Siong TW, Chin AW, Hoong NK, Karim MKA. A comparison study of radiation effective dose in ECG-Gated Coronary CT Angiography and calcium scoring examinations performed with a dual-source CT scanner. *Sci Rep.* 2019;**9**(1):4374. doi: 10.1038/s41598-019-40758-5. PubMed PMID: 30867480. PubMed PMCID: PMC6416329.
6. Stocker TJ, Deseive S, Leipsic J, Hadamitzky M,

Chen MY, Rubinshtein R, et al. Reduction in radiation exposure in cardiovascular computed tomography imaging: results from the PROspective multicenter registry on radiaTion dose Estimates of cardiac CT angIOgraphy iN daily practice in 2017 (PROTECTION VI). *Eur Heart J.* 2018;**39**(41):3715-23. doi: 10.1093/eurheartj/ehy546. PubMed PMID: 30165629. PubMed PMCID: PMC6455904.

7. Achenbach S, Manolopoulos M, Schuhbäck A, Ropers D, Rixe J, Schneider C, et al. Influence of heart rate and phase of the cardiac cycle on the occurrence of motion artifact in dual-source CT angiography of the coronary arteries. *J Cardiovasc Comput Tomogr.* 2012;**6**(2):91-8. doi: 10.1016/j.jcct.2011.11.006. PubMed PMID: 22381662.
8. Abdelrahman KM, Chen MY, Dey AK, Virmani R, Finn AV, Khamis RY, et al. Coronary Computed Tomography Angiography From Clinical Uses to Emerging Technologies: JACC State-of-the-Art Review. *J Am Coll Cardiol.* 2020;**76**(10):1226-43. doi: 10.1016/j.jacc.2020.06.076. PubMed PMID: 32883417. PubMed PMCID: PMC7480405.
9. Law WY, Huang GL, Yang CC. Effect of Body Mass Index in Coronary CT Angiography Performed on a 256-Slice Multi-Detector CT Scanner. *Diagnostics (Basel).* 2022;**12**(2):319. doi: 10.3390/diagnostics12020319. PubMed PMID: 35204410. PubMed PMCID: PMC8871507.
10. Velankar P, Chaikriangkrai K, Dewal N, Bala SK, Elferjani B, Alchalabi S, Chang SM. Prognostic Performance of Prospective versus Retrospective Electrocardiographic Gating in Coronary Computed Tomographic Angiography. *Tex Heart Inst J.* 2018;**45**(4):214-20. doi: 10.14503/THIJ-17-6270. PubMed PMID: 30374228. PubMed PMCID: PMC6183632.
11. Tavakoli M, Faraji R, Alirezaei Z, Nateghian Z. Assessment of Effective Dose Associated with Coronary Computed Tomography Angiography in Isfahan Province, Iran. *J Med Signals Sens.* 2018;**8**(1):60-4. PubMed PMID: 29535926. PubMed PMCID: PMC5840898.
12. Chua A, Adams D, Dey D, Blankstein R, Fairbairn T, Leipsic J, et al. Coronary artery disease in East and South Asians: differences observed on cardiac CT. *Heart.* 2022;**108**(4):251-7. doi: 10.1136/heartjnl-2020-318929. PubMed PMID: 33985989.
13. Sun Z, Ng KH. Prospective versus retrospective ECG-gated multislice CT coronary angiography: a systematic review of radiation dose and diagnostic accuracy. *Eur J Radiol.* 2012;**81**(2):e94-100. doi: 10.1016/j.ejrad.2011.01.070. PubMed PMID: 21316887.
14. Pflederer T, Rudofsky L, Ropers D, Bachmann S, Marwan M, Daniel WG, Achenbach S. Image quality in a low radiation exposure protocol for retrospectively ECG-gated coronary CT angiography. *AJR Am J Roentgenol.* 2009;**192**(4):1045-50. doi: 10.2214/AJR.08.1025. PubMed PMID: 19304712.
15. Otaki Y, Berman DS, Min JK. Prognostic utility of coronary computed tomographic angiography. *Indian Heart J.* 2013;**65**(3):300-10. doi: 10.1016/j.ihj.2013.04.028. PubMed PMID: 23809386. PubMed PMCID: PMC3861125.
16. Menke J, Unterberg-Buchwald C, Staab W, Sohns JM, Seif Amir Hosseini A, Schwarz A. Head-to-head comparison of prospectively triggered vs retrospectively gated coronary computed tomography angiography: Meta-analysis of diagnostic accuracy, image quality, and radiation dose. *Am Heart J.* 2013;**165**(2):154-63. doi: 10.1016/j.ahj.2012.10.026. PubMed PMID: 23351817.
17. Roobottom CA, Mitchell G, Morgan-Hughes G. Radiation-reduction strategies in cardiac computed tomographic angiography. *Clin Radiol.* 2010;**65**(11):859-67. doi: 10.1016/j.crad.2010.04.021. PubMed PMID: 20933639.
18. Li H, Wang Y, Liu P, Chen Y, Feng X, Tang C, et al. Body Mass Index (BMI) is Associated with the Therapeutic Response to Oral Rehydration Solution in Children with Postural Tachycardia Syndrome. *Pediatr Cardiol.* 2016;**37**(7):1313-8. doi: 10.1007/s00246-016-1436-1. PubMed PMID: 27350278.
19. Szepietowska B, Polonsky B, Sherazi S, Biton Y, Kutyifa V, McNitt S, Aktas M, Moss AJ, Zareba W. Effect of obesity on the effectiveness of cardiac resynchronization to reduce the risk of first and recurrent ventricular tachyarrhythmia events. *Cardiovasc Diabetol.* 2016;**15**:93. doi: 10.1186/s12933-016-0401-x. PubMed PMID: 27388610. PubMed PMCID: PMC4936234.
20. Abbara S, Blanke P, Maroules CD, Cheezum M, Choi AD, Han BK, et al. SCCT guidelines for the performance and acquisition of coronary computed tomographic angiography: A report of the society of Cardiovascular Computed Tomography Guidelines Committee: Endorsed by the North American Society for Cardiovascular Imaging (NASCI). *J Cardiovasc Comput Tomogr.* 2016;**10**(6):435-49. doi: 10.1016/j.jcct.2016.10.002. PubMed PMID: 27780758.
21. Gill MK, Vijayananthan A, Kumar G, Jayarani K, Ng KH, Sun Z. Use of 100 kV versus 120 kV in computed tomography pulmonary angiography in the detection of pulmonary embolism: effect on radiation dose and image quality. *Quant Imaging Med Surg.* 2015;**5**(4):524-33. doi: 10.3978/j.issn.2223-4292.2015.04.04. PubMed PMID: 26435916.

PubMed PMCID: PMC4559980.

22. Andreini D, Mushtaq S, Conte E, Segurini C, Guglielmo M, Petullà M, et al. Coronary CT angiography with 80 kV tube voltage and low iodine concentration contrast agent in patients with low body weight. *J Cardiovasc Comput Tomogr.* 2016;**10**(4):322-6. doi: 10.1016/j.jcct.2016.06.003. PubMed PMID: 27357327.
23. Wu Q, Wang Y, Kai H, Wang T, Tang X, Wang X, Pan C. Application of 80-kVp tube voltage, low-concentration contrast agent and iterative reconstruction in coronary CT angiography: evaluation of image quality and radiation dose. *Int J Clin Pract*. 2016;**70**(Suppl 9B):B50-5. doi: 10.1111/ijcp.12852. PubMed PMID: 27577515.
24. Chen Y, Liu Z, Li M, Yu Y, Jia Y, Ma G, et al. Reducing both radiation and contrast doses in coronary CT angiography in lean patients on a 16-cm wide-detector CT using 70 kVp and ASiR-V algorithm, in comparison with the conventional 100-kVp protocol. *Eur Radiol*. 2019;**29**(6):3036-43. doi: 10.1007/s00330-018-5837-9. PubMed PMID: 30506217.
25. Euler A, Taslimi T, Eberhard M, Kobe A, Reeve K, Zimmermann A, et al. Computed Tomography Angiography of the Aorta-Optimization of Automatic Tube Voltage Selection Settings to Reduce Radiation Dose or Contrast Medium in a Prospective Randomized Trial. *Invest Radiol.* 2021;**56**(5):283-91. doi: 10.1097/RLI.0000000000000740. PubMed PMID: 33226202.
26. Tan SK, Yeong CH, Raja Aman RRA, Ng KH, Abdul Aziz YF, Chee KH, Sun Z. Low tube voltage prospectively ECG-triggered coronary CT angiography: a systematic review of image quality and radiation dose. *Br J Radiol.* 2018;**91**(1088):20170874. doi: 10.1259/bjr.20170874. PubMed PMID: 29493261. PubMed PMCID: PMC6209486.
27. Mohammadinejad P, Mileto A, Yu L, Leng S, Guimaraes LS, Missert AD, et al. CT Noise-Reduction Methods for Lower-Dose Scanning: Strengths and Weaknesses of Iterative Reconstruction Algorithms and New Techniques. *Radiographics.* 2021;**41**(5):1493-508. doi: 10.1148/rg.2021200196. PubMed PMID: 34469209.
28. Wu D, Kim K, Li Q. Low-dose CT reconstruction with Noise2Noise network and testing-time fine-tuning. *Med Phys*. 2021;**48**(12):7657-72. doi: 10.1002/mp.15101. PubMed PMID: 34791655.
29. Park CH, Lee J, Oh C, Han KH, Kim TH. The feasibility of sub-millisievert coronary CT angiography with low tube voltage, prospective ECG gating, and a knowledge-based iterative model reconstruction algorithm. *Int J Cardiovasc Imaging.* 2015;**31**(Suppl 2):197-203. doi: 10.1007/s10554-015-0795-7. PubMed PMID: 26521066.
30. Deak PD, Smal Y, Kalender WA. Multisection CT protocols: sex- and age-specific conversion factors used to determine effective dose from dose-length product. *Radiology.* 2010;**257**(1):158-66. doi: 10.1148/radiol.10100047. PubMed PMID: 20851940.
31. Mokhtar A, Aabdelbary Z, Sarhan A, Gad H, Ahmed M. Studies on the radiation dose, image quality and low contrast detectability from MSCT abdomen by using low tube voltage. *Egypt J Radiol Nucl Med.* 2021;**52**(1):1-7. doi: 10.1186/s43055-021-00613-y.
32. Trattner S, Pearson GDN, Chin C, Cody DD, Gupta R, Hess CP, et al. Standardization and optimization of CT protocols to achieve low dose. *J Am Coll Radiol.* 2014;**11**(3):271-8. doi: 10.1016/j.jacr.2013.10.016. PubMed PMID: 24589403. PubMed PMCID: PMC3969855.
33. Ghekiere O, Salgado R, Buls N, Leiner T, Mancini I, Vanhoenacker P, et al. Image quality in coronary CT angiography: challenges and technical solutions. *Br J Radiol.* 2017;**90**(1072):20160567. doi: 10.1259/bjr.20160567. PubMed PMID: 28055253. PubMed PMCID: PMC5605061.
34. Hausleiter J, Meyer T, Hermann F, Hadamitzky M, Krebs M, Gerber TC, et al. Estimated radiation dose associated with cardiac CT angiography. *JAMA*. 2009;**301**(5):500-7. doi: 10.1001/jama.2009.54. PubMed PMID: 19190314.
35. Oda S, Utsunomiya D, Funama Y, Katahira K, Honda K, Tokuyasu S, et al. A knowledge-based iterative model reconstruction algorithm: can super-low-dose cardiac CT be applicable in clinical settings? *Acad Radiol.* 2014;**21**(1):104-10. doi: 10.1016/j.acra.2013.10.002. PubMed PMID: 24331272.
36. Yuki H, Utsunomiya D, Funama Y, Tokuyasu S, Namimoto T, Hirai T, et al. Value of knowledge-based iterative model reconstruction in low-kV 256-slice coronary CT angiography. *J Cardiovasc Comput Tomogr.* 2014;**8**(2):115-23. doi: 10.1016/j.jcct.2013.12.010. PubMed PMID: 24661824.
37. Oda S, Weissman G, Vembar M, Weigold WG. Iterative model reconstruction: improved image quality of low-tube-voltage prospective ECG-gated coronary CT angiography images at 256-slice CT. *Eur J Radiol.* 2014;**83**(8):1408-15. doi: 10.1016/j.ejrad.2014.04.027. PubMed PMID: 24873832.
38. Lee J, Park CH, Oh CS, Han K, Kim TH. Coronary Computed Tomographic Angiography at 80 kVp and Knowledge-Based Iterative Model Reconstruction Is Non-Inferior to that at 100 kVp with Iterative Reconstruction. *PLoS One.* 2016;**11**(9):e0163410. doi: 10.1371/journal.pone.0163410. PubMed PMID: 27658197. PubMed PMCID: PMC5033462.