

Assessment of radiation safety in cardiac CT angiography

Yuan-Hao Lee, PhD^a, Po-Yen Chang, MD^{a,b}, Shee Yen Tay, MD^{a,b}, Cheng-Yu Tsai, BS^a, Po-Hsin Cheng, BS^a, Wilson T. Lao, MD^{a,b,*}, Wing P. Chan, MD^{a,b}

Abstract

This study investigates the radiation dose and image quality of patients not receiving β -blockers for cardiac CT angiography (CCTA) with or without the optimization of electrocardiographic (ECG) pulsing window. The differences in patient characteristics are also characterized.

Normal-weight and obese patients ($n = 154$) with heart rates between 65 and 80 beats per minutes (bpm) during the prospective axial scanning were enrolled retrospectively. The ECG pulsing windows were set at 50% to 75% (Group A) or 60% to 75% (Group B) of the R-R interval for patients with heart rate variability higher than or not exceeding ± 5 bpm, respectively. The effective doses of individual patient were estimated from the dose length product of the CCTA scan. Two radiologists independently reviewed the images and applied a 4-point Likert scale for image quality assessment. The patients' characteristics were compared along with the patients' effective doses between groups.

The optimized pulsing window significantly reduced the average radiation dose for normal-weight and obese patients by 33% and 27%, respectively. The CCTA image quality of patients in Group A was not different overall from those obtained from Group B. Nondiabetic obese patients were more likely to be accepted for the use of the optimized pulsing window. Unlike obese patients, normal-weight patients revealed no characteristic difference between Groups A and B.

This study indicates an equivalent efficacy of using optimized pulsing windows for reducing the radiation dose for patients without β -blocker administration between different body weight groups. Nevertheless, gender and diabetic status became prominent characteristics in the obese group when matching up with the optimized pulsing window.

Abbreviations: BMI = body mass index, bpm = beats per minutes, CCTA = cardiac CT angiography, CT = computed tomography, CTDIvol = CT dose index volume, ECG = electrocardiographic.

Keywords: cardiac computed tomography angiography, image quality, obese patients, patient safety, radiation dose

1. Introduction

Cardiac computed tomography angiography (CCTA) is widely used to detect coronary artery disease.^[1] However, the high degree of ionizing radiation involved can lead to higher risks for cancer.^[2,3] In 2006, Hausleiter et al^[4] reported performing CCTA with retrospective gated protocols using 16- and 64-slice computed tomography (CT) scanners, which resulted in very high radiation doses of approximately 6.4 and 11.0 mSv, respectively. After the introduction of iterative reconstruction techniques in 2009, significant reductions in radiation dose were achieved in

CT by decreasing the tube current while preserving the signal-to-noise ratios.^[5,6]

The overall radiation output required for CCTA depends on the patient's body habitus and heart rate. Typically, tube potentials of 120 to 140 kV are used to scan obese patients, and potentials of 80 and 100 kV have been proposed for scanning thin patients and children. Reducing the tube potential from 120 to 100 kV decreases the dose needed by 31% (assuming that no other changes are made to the dose-related parameters).^[7] Fuminari Tatsugami et al reported using body mass index (BMI)-adapted scanning parameters, which resulted in similar image noise regardless of BMI and a mean effective radiation dose in the range of 1.0 to 3.2 mSv.^[8]

Current CT scanners can use topogram-based automated selection for tube voltage and current to reduce radiation dose without degrading image quality. The automated selection system favors the lowest possible combination of tube voltage and current. Nevertheless, to obtain acceptable image quality for obese patients, the system may increase the tube voltage and subsequent effective dose. In addition, CCTA image artifacts can occur when using high-pitch helical scanning and a low tube current on obese patients with heart rates greater than 65 beats per minute (bpm).^[9,10] Thus, medical institutions have used β -blockers to stabilize and decrease patients' heart rates during prospectively ECG-triggered CCTA.^[11] Nevertheless, the use of β -blockers in patients with poor glycemic control and allergic reactions may lead to adverse effects.^[12] As a consequence, patients with moderately high heart rates are not given any β -blockers before being admitted to the optimization of ECG-gated pulsing windows in our hospital.

Editor: Rani Al-Senan.

This study was not supported by any funding organization.

The authors have no conflicts of interest to disclose.

^a Department of Radiology, Wan Fang Hospital, Taipei Medical University,

^b Department of Radiology, School of Medicine, College of Medicine, Taipei Medical University, Taipei, Taiwan, Republic of China.

* Correspondence: Wilson T. Lao, Department of Radiology, Wan Fang Hospital, Taipei Medical University, 111 Hsing-Long Road, Sec 3, Taipei 116, Taiwan, Republic of China (e-mail: laowilson@hotmail.com).

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Medicine (2017) 96:51(e9305)

Received: 13 September 2017 / Received in final form: 23 November 2017 /

Accepted: 27 November 2017

<http://dx.doi.org/10.1097/MD.0000000000009305>

This retrospective study evaluates the degree of radiation dose reduction on patients undergoing CCTA health screening without any β -blocker-induced side effects. In addition to mentioned factors that affect radiation outputs, we looked into other patient characteristics as well as cardiovascular risk factors to delineate their association with the use of an optimized pulsing window on patients without heart rate control.

2. Methods

The Ethics Committee of the Joint Institutional Review Board at Taipei Medical University approved this retrospective study (No. N201608006). The requirement for informed consent was waived.

2.1. Participants

Patients who had at least one cardiovascular risk factor and underwent CCTA from January 2013 to December 2015 at our institution were retrospectively enrolled. The cardiovascular risk factors included hypertension, diabetes mellitus, hyperlipidemia, smoking, senility, a family history of cardiovascular disease, and a coronary calcium score >10. Obese subjects were selected according to the following criteria: a BMI of 27 kg/m² or higher according to the standard set by the Ministry of Health and Welfare of Taiwan, no history of coronary bypass surgery or stenting, a heart rate between 65 and 80 bpm, and no administration of any β -blocker. Normal-weight subjects were selected if they had a normal BMI (range: 18.5–24.0 kg/m²), no history of coronary bypass surgery or stenting, heart rate between 65 and 80 bpm, and no administration of any β -blocker.

The enrolled subjects were stratified into 2 groups based on the percentage of acquisition phase in the R-R interval used in the CCTA. Group A patients had heart rate variability exceeding ± 5 bpm and underwent ECG-triggered axial scanning with a default pulsing window (50–75% of the R-R interval). In addition, a narrow pulsing window (60–75% of the R-R interval) was applied to patients with heart rates that deviated between ± 5 bpm (Group B).

2.2. Heart rate measurements and nitroglycerin administration

The patients' heart rates were monitored using the built-in electrocardiogram of a dual-source CT system (specified in the section of *Cardiac CT Angiography and Dose Estimation*) before and throughout the CCTA scanning. Before CCTA scanning, the patients' calcium scores were determined using coronary calcium scans. Patients with calcium scores higher than 100 were given oral nitroglycerin.

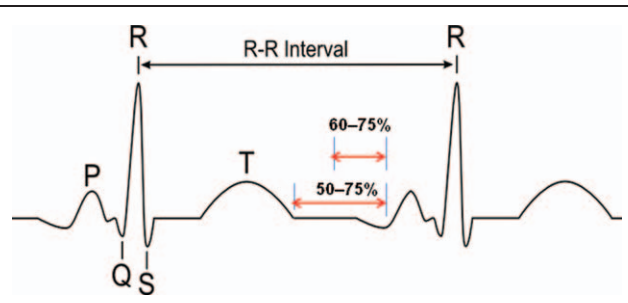


Figure 1. Pulsing windows within a cardiac cycle of an ECG-triggered axial scan.^[19] The red lines and arrows indicate the selected phase of a cardiac cycle for imaging the heart in the diastolic phase—that is, 50% to 75% phase (Group A) and 60% to 75% phase (Group B) of the R-R interval.

2.3. Contrast administration

Ultravist 370 nonionic contrast medium (Bayer Schering Pharma AG, Berlin, Germany) was given to all patients at a constant rate of 5 mL/second via either the right or left antecubital vein using a dual-head power injector (Mallinckrodt, Santa Monica, CA). The dosage was tailored to aortic enhancement using the test-bolus technique recommended by the manufacturer. The test boluses were conducted with 15 mL of contrast media followed by 20 mL of normal saline. The volumetric quantity of administered contrast was then determined using the following equation:

$$\text{Total volume of injection [mL]} = v[\text{mL/second}] \times (7 + T_{\text{peak}})[\text{second}]$$

where v is the injection rate of 5 mL/second, and T_{peak} is the time to peak contrast enhancement in seconds.

2.4. Cardiac CT angiography and dose estimation

Cardiac CTA was performed using a second-generation, dual-source CT system (SOMATOM Definition Flash, Siemens Healthcare, Forchheim, Germany). All scans were performed using the automated techniques for tube current and voltage selection (Siemens Care Dose 4D and Siemens CARE kV with imaging parameters, Table 1). A prospective ECG-triggered sequential scanning protocol was used with or without a reduction in the cardiac phase-specific pulsing window at a pitch adjusted according to the patient's heart rate. The default of 50% to 75% of the R-R interval was reduced to 60% to 75% for patients whose ECG waveforms were stable and who exhibited beat-to-beat variability not exceeding ± 5 bpm (Fig. 1). The craniocaudal volume scan had an average rotation time of 0.28 seconds. The scan was initiated one centimeter below the tracheal bifurcation to the diaphragm and covered an axial length of up to 20 cm. The patients were instructed to breathe quietly before the

Table 1

Imaging and reconstruction parameters for the default and narrow pulsing windows in prospective ECG-triggered axial scanning.

Parameters	Default pulsing window (Group A)	Narrow pulsing window (Group B)
Window width within the R-R interval	50–75%	60–75%
Tube voltage and current	100 or 120 kVp with tube current programmatically modulated by topogram evaluation	
Gantry rotation time	0.28 s/rotation	
Detector collimation	128 × 0.6 mm	
Slice thickness: increment	0.75 mm: 0.7 mm	
Reconstruction filter kernel	I26f medium smooth ASA	

ASA=advanced smoothing algorithm (an image filter that reduces the image noise without loss of sharpness of edges/structures).

administration of contrast and to hold their breath during the actual scanning. The effective dose in the cardiac scans was estimated by multiplying the CT dose index volume (CTDIvol) by the scan length and a standard thoracic conversion coefficient of $0.014 \text{ mSv (mGy cm)}^{-1}$.

2.5. Image reconstruction and quality evaluation

All of the images were reconstructed using syngo.via software (Siemens, Erlangen, Germany) and reviewed using a 4-point Likert scale by 2 radiologists, who had 8 (P.-Y.C.) and 9 (W.T.L.) years of experience in cardiac CT interpretation.^[13] A score of 1 was assigned to coronary segment visualization that lacks vessel wall definition in relation with marked motion artifacts, poor vessel opacification, prominent structural discontinuity, or high noise-related image blurring. Segments that could provide diagnostic information were given scores of 2 for images exhibiting some motion artifacts or noise-related blurring, fair vessel opacification, or minimal structural discontinuity. A score of 3 was given for images displaying minor motion artifacts or noise-related blurring, good vessel opacification, and no structural discontinuity. Finally, a score of 4 was given for images with no motion artifacts or noise-related blurring, excellent vessel opacification, and zero structural discontinuity.

2.6. Statistical analysis

The population characteristics were converted into discrete or continuous numeric variables and expressed as percentages or means (\pm standard deviation), respectively. For statistical analyses of continuous numeric variables (such as age, BMI, and radiation dose), a 2-tailed Student *t* test was applied to assess statistically significant differences using a web-based 2-sample *t* calculator (Jeremy Stangroom, Social Science Statistics). Group differences between discrete numeric or categorical variables were detected using a web-based Fisher exact probability test (VassarStats, Poughkeepsie, NY) or Chi-squared test (Microsoft Excel 2007 v12.0, Microsoft, Redmond, WA).

3. Results

3.1. Comparisons of clinical characteristics

A slightly greater proportion of the enrolled obese patients qualified for the use of optimized pulsing window compared with

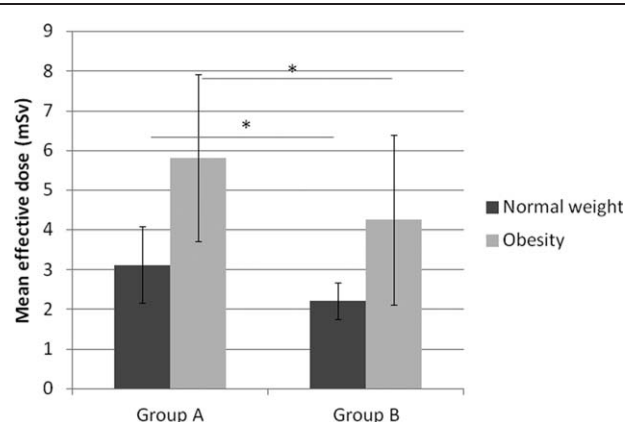


Figure 2. Comparison of radiation doses between Groups A and B. Normal weight: 18.5 to 24.0 kg/m²; Obese: BMI \geq 27 kg/m². *Significant statistical difference ($P < .050$) in patient effective dose. Group A= image acquired using the 50% to 75% pulsing window of the R-R interval, Group B= image acquired using the 60% to 75% pulsing window of the R-R interval. Error bars indicate standard deviations within each group.

the enrolled normal-weight patients (obese population vs. normal-weight population, 28% vs 17%, $P = .120$). There was intergroup disparity in the characteristics of obese patients in terms of gender and cardiovascular conditions. In the obese population, male gender and diabetes mellitus were less favorable for CT imaging using the narrow pulsing window technique (Table 2).

3.2. Dose reduction via the optimization of pulsing window

Cardiac imaging of normal-weight and obese patients using the default pulsing window resulted in mean effective doses of 3.4 ± 3.8 and 5.8 ± 2.1 mSv, respectively (Fig. 2). When the pulsing window was narrowed, we observed a significant reduction in the mean effective doses (normal-weight subjects: 33% dose reduction to 2.3 ± 0.5 mSv, $P = .026$; obese subjects: 27% dose reduction to 4.3 ± 2.1 mSv, $P = .006$).

3.3. Image quality assessment

The overall rating of image quality was not statistically different between Groups A and B (Table 3). Nevertheless, the visualiza-

Table 2
Participants' demographics and clinical characteristics.

Variables	Group A		Group B		P	
	Obese (n = 57)	Normal (n = 62)	Obese (n = 22)	Normal (n = 13)	Obese	Normal
Demographic characteristics						
Age*	57.7 ± 11.1	59.2 ± 12.4	55.4 ± 11.2	56.9 ± 6.0	.418	.322
Gender [male (n, %)] [†]	44 (77%)	28 (45%)	13 (57%)	4 (31%)	.003 [‡]	.340
BMI, kg/m ² *	29.7 ± 2.6	21.8 ± 1.4	29.0 ± 2.3	22.1 ± 1.6	.264	.539
Heart rate, beats per minute*	67.0 ± 7.0	71.5 ± 3.4	63.6 ± 7.3	70.2 ± 3.1	.063	.193
Clinical characteristics						
Diabetes mellitus (n, %) [†]	14 (25%)	12 (19%)	0 (0%)	2 (15%)	<.001 [‡]	.738
Hypertension (n, %) [†]	39 (68%)	18 (29%)	14 (61%)	7 (54%)	.301	.084
Hyperlipidemia (n, %) [†]	35 (61%)	23 (37%)	12 (52%)	5 (38%)	.199	.926
Smoking (n, % ever smoking) [†]	16 (28%)	16 (26%)	7 (32%)	1 (8%)	.537	.156

Group A = image acquired using 50% to 75% pulsing window within the R-R interval, Group B = image acquired using 60% to 75% pulsing window within the R-R interval, Normal = patients whose BMIs were in the normal range (18.5–24.0 kg/m²), Obese = patients whose BMIs were equivalent to or higher than 27 kg/m².

BMI = body mass index = body weight (kg)/height² (m²).

* Data are presented as mean \pm SD, analyzed using the Student *t* test.

[†] Data are presented as a number with the rounded-up percentage, analyzed using the Chi-squared test.

[‡] $P < .050$, denoting significant differences in the clinical characteristics of the normal-weight or obese population between Groups A and B.

Table 3
Summary of image quality for ECG-triggered axial scanning with default versus narrow pulsing window acquisition.

Image quality score*	Group A		Group B		P	
	Obese	Normal	Obese	Normal	Obese	Normal
Four points (n, %)	9 (16%)	14 (22%)	7 (32%)	6 (42%)	.057	.680
Three points (n, %)	38 (67%)	46 (75%) [‡]	14 (64%)	7 (58%) [‡]		
Two points (n, %)	8 (14%)	2 (3%)	1 (4%) [†]	0 (0%)		
One point (n, %)	2 (3%) [†]	0 (0%)	0 (0%)	0 (0%)		

Group A = image acquired using 50% to 75% pulsing window of the R-R interval, Group B = image acquired using 60% to 75% pulsing window of the R-R interval. Image quality was assessed using the 4-point Likert scale noted in the Materials and Methods Section.

* Data are presented as a number with the rounded-up percentage, analyzed using the Chi-squared test.

† The percentage was rounded down to ensure that 100% was the sum of all of the percentages.

‡ The averaged number was rounded down to result in the total number of subjects in the particular subgroup.

tion of coronary arteries was slightly better in Group B than in Group A for the obese population (average scores of Group A vs Group B: 2.96 vs 3.28; $P = .057$).

4. Discussion

The administration of β -blockers during cardiovascular health examinations can lead to discomfort. To avoid this, we optimized the pulsing window on selected patients to reduce the radiation dose associated with CCTA. Our results indicate that there is roughly a 28% chance for obese patients to avoid about a quarter of unnecessary radiation by reducing the ECG-pulsing window. Obese patients require increased radiation outputs to obtain CTA images at the same image quality level that normal-weight patients obtain at intrinsically lower doses.^[14]

There was a significantly higher propensity for obese patients with diabetes to be enrolled in Group A, which may be related to their higher susceptibility to cardiac arrhythmia compared to nondiabetic counterparts.^[15] The hypoglycemia associated with type 1 and type 2 diabetes can increase the heart rate and cardiac output and lead to abnormal heart rhythms, which are unfavorable for cardiac scans with a narrow pulsing window.^[16–18] Based on the 4-point Likert scale used for image quality assessment, images with a score of 2 or above were considered diagnosable in this study. Although the majority of images from both Groups A and B had scores of 3 or more, a higher average image quality score was observed in Group B. Therefore, we speculate that the fewer motion artifacts and decreased noise-related blurring in the images acquired from Group B resulted from both the relatively stable cardiac cycles of these patients and the decreased scan time.

The scan length of CCTA is fairly constant and extends from the carina to the cardiac apex with a range of 8 to 14 cm. This scan volume covers soft tissues in the breasts, lungs, and esophagus and it induces a higher excess lifetime cancer incidence than a chest X-ray.^[2] Without considering differences in the thickness and radiodensity of the chest between males and females, the same effective dose estimated for males and females often obscures a higher induced cancer risk for females due to gender-specific morphological differences in breast tissues.^[2] Thus, a significantly larger proportion of obese female patients assigned to undergo CT scans using a narrow pulsing window would benefit compared to their male counterparts.

Our study has a few limitations. First, the results were retrospectively consolidated based on examinations conducted with a specific CT scanner, which may limit the use of information provided in this study. Secondly, there were fewer

patients designated to Group B than to Group A, in accordance with the nature of the patients' heart rate variability.

5. Conclusions

This study revealed that selective optimization of the ECG-pulsing window did not deteriorate image quality for both normal-weight and obese patients who had moderately high heart rates and had not taken β -blockers. Furthermore, this study is the first to report significant associations between the risk factors/characteristics of obese populations and the efficacy of pulsing window optimization in reducing the radiation dose of CCTA for health screening.

Acknowledgment

The authors would like to thank Yen-Kuang Lin, PhD, for his assistance in the statistical analyses.

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