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# Radiation dose to patients and image quality evaluation from coronary 256-slice computed tomographic angiography

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ABSTRACT

The aim of this study is to assess radiation dose and the corresponding image quality from suggested CT protocols which depends on different mean heart rate and high heart rate variability by using 256-slice CT. Fifty consecutive patients referred for a cardiac CT examination were included in this study. All coronary computed tomographic angiography (CCTA) examinations were performed on a 256-slice CT scanner with one of five different protocols: retrospective ECG-gating (RGH) with full dose exposure in all R–R intervals (protocol A), RGH of 30–80% pulsing window with tube current modulation (B), RGH of $78 \pm 5\%$ pulsing window with tube current modulation (C), prospective ECG-triggering (PGT) of 78% R–R interval with 5% padding window (D) and PGT of 78% R–R interval without padding window (E). Radiation dose parameters and image quality scoring were determined and compared. In this study, no significant differences were found in comparison on image quality of the five different protocols. Protocol A obtained the highest radiation dose comparing with those of protocols B, C, D and E by a factor of 1.6, 2.4, 2.5 and 4.3, respectively ($p < 0.001$), which were ranged between 2.7 and 11.8 mSv. The PGT could significantly reduce radiation dose delivered to patients, as compared to the RGH. However, the use of PGT has limitations and is only good in assessing cases with lower mean heart rate and stable heart rate variability. With higher mean heart rate and high heart rate variability circumstances, the RGH within 30–80% of R–R interval pulsing window is suggested as a feasible technique for assessing diagnostic performance.



## 1. Introduction

Coronary computed tomographic angiography (CCTA) has increasingly become important as a fast, accurate and non-invasive method for diagnosing coronary artery disease (CAD). However, high radiation dose in CCTA compared with conventional angiography still remains a challenge to its widespread use. While a reasonable image quality of CCTA necessarily maintains, many modifications of multi-slice CT scanning protocols have been implemented in order to keep radiation dose as low as reasonably achievable (ALARA). Currently, two modes of phase synchronization have been used, i.e., retrospective electrocardiography (ECG)-gating technique, so-called RGH [1,2], which obtains continuous data in a helical mode and prospective ECG-triggering technique, PGT [3,4], which obtains predefined time points of the cardiac cycle in an axial step-and-shoot mode. Comparing the two techniques, the latter is usually associated with a lower radiation dose, but radiation dose could also be significantly reduced in the RGH mode by using ECG-controlled modulation of the X-ray output [5].

The recently introduced 256-slice CT addresses the aforementioned limits by superior spatial and temporal resolutions with around 270-ms gantry rotation. A minimum temporal resolution of 50% of gantry rotation time, i.e., 135 ms can be achieved by applying the common half-scan reconstruction techniques. This novel scanner also provides larger *z*-coverage of 80 mm, allowing scan time for the whole heart of as low as 5 s for a 120 mm *z*-axial coverage using a RGH technique [5]. The currently reported scanning time for single-source and dual-source 64-slice CT studies was up to 6–10 s [6,7]. This potentially allows cardiac scanning of diagnostic image quality even at higher and irregular heart rates. The aim of this study is therefore to assess radiation

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dose and the corresponding image quality from suggested CT protocols which depends on different heart rates and heart rate variability using the 256-slice CT.

## 2. Materials and methods

### 2.1. Patient population

Fifty consecutive patients (28 males, 22 females; mean age $57.3 \pm 9.0$ years; range 41–76 years) referred for a cardiac CT examination were included in this study. Patients with previous allergic reactions to iodinated contrast media, hemodynamic instability, pregnancy, insufficient renal function (creatinine level $> 1.5$ mg/dL) and patients who were unable to follow breath-hold compliances were excluded from this study. Patient characteristics were shown in Table 1. The mean body mass index (BMI) of these patients was $22.9 \pm 1.7$ kg/m$^2$ (range 18.1–24.9 kg/m$^2$). The mean heart rate and variability for these patients was $62.3 \pm 7.4$ and $0.9 \pm 0.4$ bpm, respectively, excluding one group (protocol B) was belonging to high mean heart rate and high heart rate variability among $77.3 \pm 2.5$ and $5.1 \pm 4.8$ bpm.

### 2.2. MDCT acquisition protocol

All CCTA examinations were performed on a 256-slice CT scanner (Brilliance iCT; Philips Medical Systems, Eindhoven, Netherlands). Patients were scanned in a cranial–caudal direction, covering the region from about the carina to the diaphragm. The following acquisition parameters were used in this study: $256 \times 0.625$ mm$^2$ slice collimation by means of a dynamic *z*-focal spot (ZFS) for double sampling; 270 ms gantry rotation time. A tube voltage of 120 kV and an effective tube current-time product of 700–900 mAs were applied according to the patient body weights. The total acquisition time was $< 5$ s with one breath-hold. No beta-receptor antagonists for heart rate control were administered prior to CT examination.

*Protocol A*: retrospective ECG-gating with full dose exposure of all of the R–R interval as a standard reference in this study.

*Protocol B*: retrospective ECG-gating with ECG-pulsing of full dose exposure at 30–80% of R–R interval, and a reduction of tube current to 20% outside the reconstruction window.

*Protocol C*: retrospective ECG-gating with ECG-pulsing of a full dose exposure at $78 \pm 5$% of the R–R interval, and a reduction of tube current to 20% outside the reconstruction window.

*Protocol D*: prospective ECG-triggering at 78% of R–R interval with 5% of padding window.

*Protocol E*: prospective ECG-triggering at 78% of R–R interval without padding window regarded as snapshot images.

All Images were reconstructed using the 180° cardiac interpolation algorithm [8] and the adaptive cardio volume (ACV) approach [9]. The CT data were reconstructed at their optimal phase of R–R interval, likely 78% in protocol E, using a slice thickness of 0.9 mm with reconstruction increment of 0.5 mm. All images were transferred to a separate workstation equipped with cardiac post-processing software (Extended Brilliance Workspace 4.0, Philips).

### 2.3. Coronary artery image quality analysis

All reconstructed images were evaluated and graded by a radiologist (with five years of experience in cardiovascular radiology) blinded to the mean heart rate, heart rate variability and BMI during scanning. Based on the criteria suggested by the American Heart Association [10], the coronary arteries were classified into 15 segments. Image quality was analyzed on a per segment, per vessel and per patient basis according to a four-point Likert ranking scale as follows: a score of 1, no motion artifacts and clear delineation of the segment; a score of 2, minor artifacts and mild corresponds to of the segment; a score of 3, moderate artifacts and moderate blurring without structure discontinuity; a score of 4, severe artifacts and doubling or discontinuity in the course of the segment preventing diagnostic evaluation.

### 2.4. Radiation dose

The parameters relevant to radiation dose were obtained from the scan protocol generated by the CT system after each CCTA study. The parameters included the CT volume dose index ($CTDI_{vol}$) and dose length product (DLP). The effective dose ($Dose_{eff}$) was derived from the product of DLP and a conversion coefficient for the anatomical region examined, i.e., 0.017 mSv mGy$^{-1}$ cm$^{-1}$ for the chest.

### 2.5. Statistical analysis

Quantitative data were performed as mean $\pm$ standard deviation and categorical data were given in proportions and percentages. Data analysis was performed by using commercially

**Table 1**
Patient characteristics.

| | Retrospective | | | Prospective | | *p*-Value |
|---|---|---|---|---|---|---|
| | Protocol A (RGH, full) | Protocol B (RGH, 30–80%) | Protocol C (RGH, $78 \pm 5$%) | Protocol D (PGT, $78 \pm 5$%) | Protocol E (PGT, 78%) | |
| Number of patients | 10 | 10 | 10 | 10 | 10 | NS |
| Male | 5 | 3 | 7 | 8 | 5 | NS |
| Age (year) | $56.3 \pm 8.30$ (47–70) | $57.9 \pm 10.4$ (42–69) | $57.5 \pm 11.4$ (41–76) | $60.0 \pm 6.5$ (53–69) | $54.8 \pm 8.7$ (46–69) | NS |
| BMI | $23.4 \pm 1.3$ (20.2–24.8) | $22.0 \pm 1.9$ (18.5–24.9) | $22.8 \pm 1.5$ (19.6–24.6) | $23.0 \pm 1.5$ (19.7–24.7) | $23.1 \pm 2.1$ (18.1–24.9) | NS |
| Heart rate (bpm) | $67.2 \pm 6.3$ (54–74)[a] | $77.3 \pm 2.5$ (73–81)[b] | $66.9 \pm 5.8$ (53–73)[a] | $58.7 \pm 6.3$ (50–69)[a] | $56.6 \pm 5.0$ (48–64)[a] | $< 0.001$ |
| HR Variability (bpm)[c] | $1.3 \pm 0.4$ (0.4–1.8) | $5.1 \pm 4.8$ (2.2–19.3)[c] | $0.7 \pm 0.1$ (0.4–0.9) | $1.0 \pm 0.6$ (0–1.5) | $0.7 \pm 0.3$ (0–1.3) | $< 0.001$ |

*Note*: Data were presented as frequencies or means $\pm$ S.D.Chi-square and Kruskal–Wallis tests were used to assess for significant difference.

[a] Mean heart rate showed a significant difference for RGH versus PGT ($p < 0.001$).
[b] Means heart rate showed a significant difference for other protocols.
[c] Means heart rate variability showed a significant difference compared to other protocols.