Prospectively Gated Coronary Computed Tomography Angiography: Uncompromised Quality with Markedly Reduced Radiation Exposure in Acute Chest Pain Evaluation

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ABSTRACT: **Background:** Coronary computed tomography angiography (CCTA) is an established modality for ruling out coronary artery disease. However, it has been suggested that CCTA may be a source of non-negligible radiation exposure.

Objectives: To evaluate the potential degradation in coronary image quality when using prospective gated (PG) CCTA as compared with retrospective gated (RG) CCTA in chest pain evaluation.

Methods: The study cohort comprised 216 patients: 108 consecutive patients in the PG CCTA arm and 108 patients matched for age, gender and heart rate in the RG CCTA arm. Scans were performed using a 64-slice multidetector CT scanner. All 15 coronary segments were evaluated subjectively for image quality using a 5-point visual scale. Dose-length product was recorded for each patient and the effective radiation dose was calculated

Results: The PG CCTA technique demonstrated a significantly higher incidence of step artifacts in the middle and distal right coronary artery, the distal left anterior descending artery, the second diagonal, the distal left circumflex artery, and the second marginal branches. Nevertheless, the diagnostic performance of these scans was not adversely affected. The mean effective radiation doses were 3.8 ± 0.9 mSv vs.17.2 ± 3 mSv for PG CCTA and RG CCTA, respectively ($P < 0.0001$).

Conclusions: Artifacts caused by the PG CCTA technique (64 MDCT) scanners tended to appear in specific coronary segments but did not impair the overall diagnostic quality of CCTA and there was a marked reduction in radiation exposure. We conclude that 64-slice PG CCTA is suitable for clinical use, especially for acute chest pain "fast track" evaluation targeted at relatively young subjects in a chest pain unit.

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KEY WORDS: coronary computed tomography angiography, prospective electrocardiographic gating, chest pain unit

Coronary computed tomography angiography has been shown to be an effective modality for ruling out coronary artery disease in a chest pain unit [1-3]. However, the radiation exposure inherent in CCTA has been suspected to be a non-negligible cause of lifetime attributable risk for cancer, especially if repeated studies are performed [4,5]. The original CCTA technique utilizes helical acquisition with overlapping retrospective electrocardiographic gating. This results in relatively high radiation doses in the range of 13–20 mSv using 64 slice multidetector CT scanners [6-9]. Extensive efforts have been made to reduce the radiation exposure related to CCTA, including dose modulation during the R-R interval, prospective axial ECG gating, and voltage lowering to 100 KvP [10,11].

An important step towards this goal was the introduction of the prospective axial electrocardiographic gated technique, which employs axial scanning instead of the continuous helical scanning used in retrospective gated CCTA. The PG CCTA mode employs ECG triggering of the X-ray tube. Thus, radiation exposure is prospectively targeted to a single predetermined mid-diastolic phase during the R-R interval, resulting in a considerable dose reduction of up to 70–80% [10,12-20]. The PG CCTA method has been shown to be an optional radiation-saving CCTA strategy. The applicability of this technique in the evaluation of moderate-risk relatively young patients with acute chest pain is of great importance. The significant dose reduction related to PG CCTA offers exclusion of CAD and the possibility of triaging patients suffering from acute chest pain with a much lower "radiation price tag" than previously.

The purpose of the present study was to evaluate the potential reduction in coronary image quality when using PG CCTA as compared with RG CCTA using 64 MDCT, in the framework of "fast track" evaluation of acute chest pain.

CCTA = coronary computed tomography angiography
PG = prospective gated
CAD = coronary artery disease
RG = retrospective gated
MDCT = multidetector CT

Image quality and radiation exposure of both techniques were compared.

PATIENTS AND METHODS

We conducted a retrospective review of 108 consecutive patients who underwent PG CCTA and a matched control group of 108 patients who underwent RG CCTA (during the period prior to the installation of the PG CCTA option on the 64-slice MDCT scanner). Baseline characteristics of patients in the study group (PG CCTA, N=103) were: mean age 49 ± 9 years, gender 69% males, heart rate 54 ± 5, body mass index 27 ± 4, and smoking, hypertension diabetes and hyperlipidemia 36%, 25%, 5% and 45% respectively. Patients in the control group (RG CCTA, N=104) were matched for age, gender, heart rate and body mass index. Their baseline characteristics were: mean age 50 ± 9 years, gender 69% males, heart rate 55 ± 6, body mass index 28 ± 4, and smoking, hypertension diabetes and hyperlipidemia 30%, 23%, 6% and 42% respectively. To avoid selection bias, both the study and the control group patients originated from the patient population that presented at the CPU. Due to inborn technical limitations, inclusion criteria for the 64 MDCT PG CCTA technique included a stable heart rate (HR with HR variability < 10 beats/min), HR ≤ 65 beats/min and weight ≤ 110 kg.

Nine patients were excluded from further analysis (5 in the PG CCTA group, 4.6%, and 4 in the RG CCTA group, 3.7%) due to heart rate acceleration during the study (N=4), breathing artifacts (N=3), or irregular heart rhythm (N=2).

In all patients who presented at the CPU with chest pain the pain was suspected to be of ischemic origin. No ECG or enzyme abnormalities were detected upon admission and during a monitored minimum 12 hour period. Patient selection for CCTA is part of the day-to-day decision making in the CPU, as previously described. CCTA results are used for clinical patient management as part of the CPU protocol [21]. Institutional review board approval was obtained for this study, and the informed consent requirement was waived due to the retrospective study design.

CCTA PROTOCOL

All scans were obtained using a 64 MDCT scanner (Brilliance 64™, Philips Medical Systems, Cleveland, OH, USA). Oral and/or intravenous beta-blockers (propranolol 10–40 mg, metoprolol 5–15 mg) were administered to all patients with HR > 65 bpm. Oxazepam 10 mg (per os) was administered to all patients to eliminate stress-related increase in heart rate. Non-ionic contrast (Iopamiro® 370, Iopamidol, BRACO s.p.a, Milan, Italy) was administered into an antecubital vein via a dual head injector (GE Nemoto dual head injector, GE health care systems). Automatic triggering with a region of interest at the descending aorta (threshold of 120 HU) was used. Technical parameters were as follows: mean contrast bolus 82 ± 6 ml, mean injection rate 5 ml/second, average scan time 9.6 seconds, tube voltage 120 KvP, collimation 64 x 0.25, gantry rotation 0.4 seconds, and pitch 0.17–0.2 (according to patient habitus).

CPU = chest pain unit
HR = heart rate

IMAGE ANALYSIS

Segmental evaluation of the coronary arteries was performed according to the American Heart Association classification, using a 15-segment model [22]. Curved multiplanar reformats were reconstructed for each vessel (extended workspace, version 3.5, Philips Medical Systems, Cleveland). Evaluation of image quality was obtained by a consensus of two dedicated experienced radiologists (O.G. and E.K). A previously described 5-point subjective scale for coronary artery assessibility was used as follows: 5 = no artifacts (continuous vessels course, no step artifacts); 4 = minor artifacts (discrete blurring of vessel margin, minor step artifacts, not affecting vessel evaluation); 3 = moderate artifacts (moderate blurring, or moderate step artifacts); 2 = severe artifacts (doubling or severe step artifacts causing coronary segments discontinuity); 1 = unassessible (vessel structures not differentiable). A score of 3 or higher is considered of diagnostic quality [23].

Each study was summarized as either normal (no evidence of CAD), non-significant CAD (stenosis ≤ 50%) or significant CAD (stenosis > 50%).

RADIATION DOSE

A dose report, expressed as dose-length product (DLP, measured in milligray/centimeters), was recorded from the CT scanner for each patient. Effective dose *(E)* was calculated using the accepted following equation: $E = k \times \text{DLP}$, where k is equal to 0.017 $\text{mSv} \times \text{mGy}^{-1} \times \text{cm}^{-1}$ [7]. This value is considered applicable for chest and cardiac scans and represents the average between male and female models [7] .

STATISTICAL ANALYSIS

Comparison of quality scores between the study and control group was done using the Fisher exact test. We compared the incidence of all artifacts (score 5 vs. score 1–4, qualitative *P* value), as well as the incidence of "non-diagnostic" artifacts (scores 5–3 vs. scores 1–2, diagnostic *P* value). All values were two sided. Stata 10.SE software was used for statistical analysis.

RESULTS

The study cohort included 108 consecutive patients who underwent PG CCTA, and a matched control group of 108

DLP = dose-length product

patients who underwent RG CCTA (during the period prior to the installation of the PG CCTA option on the 64 MDCT scanner). Patients in the control group were matched for age, gender, heart rate and BMI. Baseline characteristics for the PG CCTA group (N=103) and the RG CCTA group (N=104) are presented in Table 1. The combination of beta-blockers and oxazepam administration led to efficient heart rate lowering as well as patient stress reduction. Thus, only nine patients were excluded from further analysis – five in the PG CCTA group (4.6%) and four in the RG CCTA group (3.7%) – due to heart rate acceleration during the study (N=4), breathing artifacts (N=3), and irregular heart rhythm (N=2).

Comparison of coronary artery image quality for all 15 coronary segments in PG CCTA vs. RG CCTA techniques is presented in Table 1.

There was a significantly higher incidence of artifacts (scores 1–4) in the PG CCTA group as compared with the control group (RG CCTA). Artifacts were mainly observed in specific segments: middle and distal right coronary artery, the distal left anterior descending artery, the second diagonal, the distal left circumflex and the second marginal branches [Table 1 and Figure 1].

When comparing the incidence of "non-diagnostic" vs. diagnostic studies (scores 1–2 vs. 3–5) no significant differences were noted between the two groups for all segments [Table 1].

No CAD was demonstrated in 51.4% of the PG CCTA and 54.8% of the RG CCTA groups. Non-significant CAD (stenosis ≤ 50%) was present in 41.6% and 34.6% of the PG CCTA and RG CCTA groups respectively. Significant CAD (stenosis > 50%) was present in 4.9% and 10.6% of the PG CCTA and RG CCTA groups respectively.

The measured DLP for the PG CCTA group was 222.7 ± 53 mSv x mGy^{-1} x cm^{-1} vs. 1011 ± 178 mSv x mGy^{-1} x cm^{-1} in the RG CCTA group. The resulting estimated effective doses were 3.8 ± 0.9 mSv vs. 17.2 ± 3 mSv respectively ($P < 0.0001$).

DISCUSSION

CCTA has been shown to be an effective modality for triaging acute chest pain patients [1-3,21]. Until recently, the only technique available for coronary imaging was based on helical scanning with retrospective ECG gating, low pitch values and slow table feed. This led to rather high radiation doses in the range of 13 to 20 mSv [6-9]. CCTA and the entailed radiation exposure have been suggested to be related to a non-trivial lifetime attributable risk for cancer [4,5]. The "as low as reasonably achievable" (ALARA) principle emphasizes the need to perform justifiable CT scans with

BMI = body mass index

Table 1. Comparison of coronary segment image quality for all 15 segments in PG CCTA and RG CCTA groups

Coronary segment	Image q score RG CCTA				Image q score PG CCTA				D *P* value	Q *P* value
	2	3	4	5	2	3	4	5		
1	0	3	2	99	0	1	2	100	1	0.721
2	0	3	8	92	0	5	20	78	1	0.016*
3	0	10	4	89	0	12	24	67	1	0.001*
4	1	2	2	88	0	3	1	95	0.484	0.741
5	0	0	1	103	0	0	0	103	1	1.00
6	0	1	2	101	1	0	7	94	0.495	0.132
7	0	4	4	96	1	5	10	87	0.498	0.086
8	0	1	0	103	1	3	9	89	0.495	0.001*
9	0	3	0	101	0	1	9	92	1	0.048
10	0	1	0	82	0	2	6	61	1	0.012*
11	1	3	0	100	1	3	7	91	1.00	0.064
12	0	3	0	93	1	2	13	82	1.00	0.003*
13	0	4	2	96	2	2	18	80	0.498	0.002*
14	0	0	0	72	0	1	2	95	1	0.263
15	0	0	0	12	0	0	0	5	1	1

Image quality score: visual subjective scale 1 (worst) to 5 (best). Score 1 is not represented in the table since none of the segments had a visual score of 1.

D *P* value: *P* value for comparison of diagnostic scores (scores 3–5) vs. non-diagnostic scores (scores 1–2)

Q *P* value: *P* value for comparison of incidence of all artifacts (scores 1–4) vs. the incidence of no artifacts (score 5).

*Significant at the 0.05 level after FDR (false discovery rate) correction for multiple comparisons.

Figure 1. A 45 year old man with atypical chest pain admitted to the CPU. Maximal intensity projection of a cardiac "globe" representation, with "step" artifacts demonstrated in the **[A]** middle and distal right coronary artery (white ellipses), and **[B]** middle and distal left anterior descending artery, and the D1 and D2 branches (white ellipses)

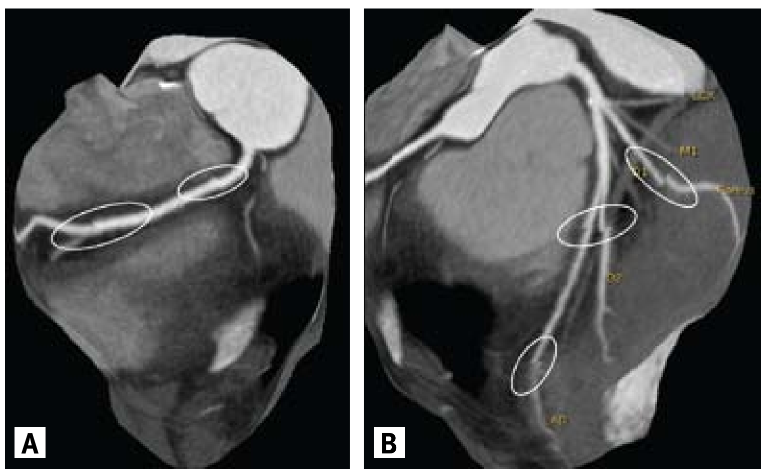


Figure 2. A 47 year old man with atypical chest pain admitted to the CPU. "Step and shoot" scan showing **[A]** left anterior descending artery and **[B]** right coronary artery. Subtle “step” artifacts are indicated by arrowheads (image quality score = 4).

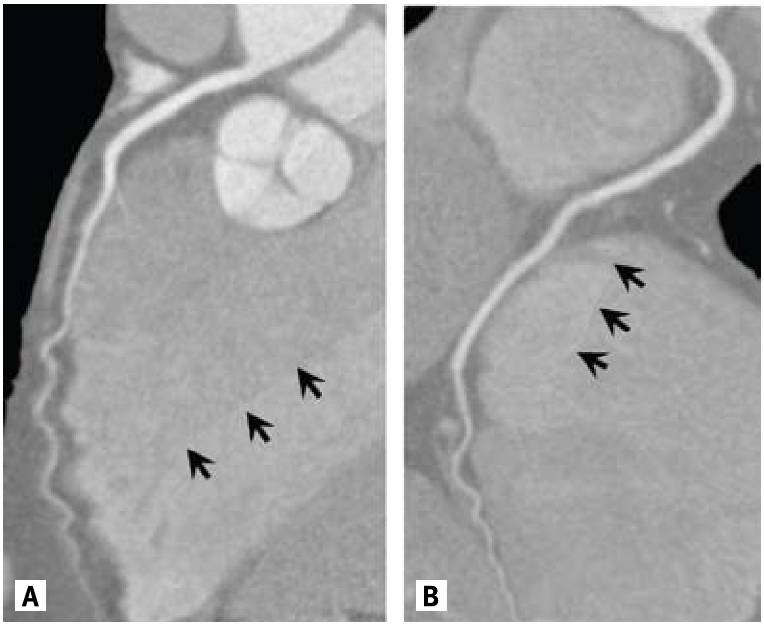
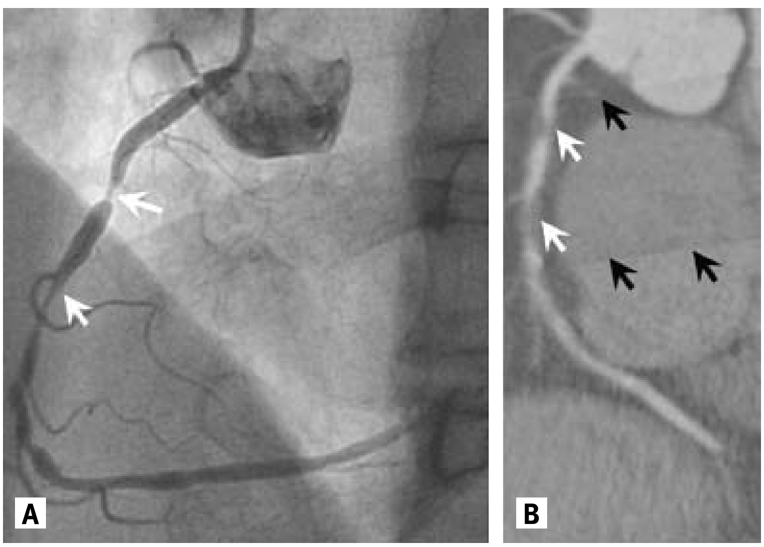


Figure 3. A 51 year old woman with atypical chest pain admitted to the CPU. **[A]** RCA at coronary angiography with significant stenosis in the proximal and middle RCA (white arrowhead). **[B]** RCA "step and shoot" scan showing subtle “step” artifacts (dark arrowheads) (IQ = 4), not affecting diagnosis of significant stenosis in the proximal and middle RCA (white arrowhead).



the minimum radiation dose necessary to meet clinical and diagnostic objectives.

Various solutions for lowering radiation exposure in CCTA have been developed in the past few years [11]. One of the most efficient dose-reduction strategies is PG CCTA, which combines axial scanning while targeting the radiation exposure to a single predetermined R-R interval phase, resulting in a significant dose reduction of up to 70–80% [10,12-20,24]. When using a 64 MDCT scanner each gantry rotation ("step") covers only 31.2 mm (8 mm overlap), thus each cardiac acquisition is scanned within four to five steps. Thus, "step artifacts," less frequently encountered in retrospective helical scanning, are a common phenomenon. In the present study we sought to evaluate the diagnostic significance of image deterioration when using the 64 MDCT PG CCTA technique for acute chest pain triage in a CPU. Our study demonstrated a significantly higher rate of "step artifacts" in specific coronary segments: middle and distal RCA, the distal LAD, the second diagonal, the distal LCX and the second marginal branches. However, analysis of diagnostic quality scores (scores 3–5) vs. non-diagnostic quality scores (scores 1–2) showed no significant differences between curved multiplanar reformats obtained using these two techniques [Figures 1–3]. Therefore, most artifacts caused by the PG CCTA mode do not hamper the diagnostic value of the scan. Similar results were demonstrated by Pontone et al. in patients undergoing coronary angiography [25]. In addition, we found a 70–80% effective radiation dose reduction from an average of 17.18 ± 3 mSv when using retrospective gating to 3.77 ± 0.9 mSv when using the PG CCTA mode. This is in accordance with previous reports [10,12-20,24,25]. The present study discusses the implementation of PG CCTA for acute chest pain triage in a dedicated CPU. Such a significant reduction in radiation exposure with an insignificant decline in image quality is a major advantage, especially when considering the relatively young age of patients encountered in a typical CPU (median 50 years in our cohort) [21]. MDCT scanners that cover 8 cm or more, in each gantry rotation, are currently being introduced into the market. Hopefully, with these technical advances, each cardiac scan will require only one or two gantry rotations and the incidence of "step artifacts" is expected to decrease.

The study has some limitations. First, the study was retrospective. Second, since only patients with significant coronary stenosis underwent coronary angiography, no standard of reference was used. Third, the radiologist interpreting the study was not "blinded" to the scanning mode due to the presence of step artifacts.

CONCLUSIONS

The 64 MDCT PG CCTA technique should be used for all suitable patients. The marked reduction in radiation dose along with minor quality degradation in the PG CCTA

RCA = right coronary artery
LAD = left anterior descending artery
LCX = left circumflex artery

renders this technique attractive for non-invasive coronary assessment when triaging patients with acute chest pain.

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