

Lower Radiation Dosing in Cardiac CT Angiography: The CONVERGE Registry

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Coronary artery disease is the leading cause of morbidity and mortality. Tools have been developed to accurately diagnose and evaluate coronary artery disease. Coronary CT angiography (CCTA) provides detailed imaging to deliver precise analysis and prognostic information. We sought to compare the radiation dose from a 256-detector-row CT scanner with that from a 64-detector-row CT scanner across a similar profile of patients.

Methods: Consecutive patients were screened for the Converge Registry study and, after consenting to be included, were enrolled in accordance with an Institutional Review Board–approved protocol. A control group who underwent 64-row CCTA were matched by age, sex, and body mass index (BMI) with a group who underwent 256-row CCTA. **Results:** We compared 110 patients in each group. We found that mean dose–length product (DLP) was significantly lower in the 256-row group than in the 64-row group ($P < 0.05$). The radiation dose was reduced by 32% with use of the 256-row scanner for BMIs of 18.5–24.9 (DLP, 111.2 vs. 76.1 mGy-cm [1.56 vs. 1.07 mSv]; $P < 0.05$). For each BMI subgroup, there was a significant decrease in dose. Regression analysis found that with increasing BMIs, DLP significantly increased for both scanners. **Conclusion:** The 256-row scanner provided CCTA scans at significantly lower radiation doses than the 64-row scanner in different BMI groups, with all other variables accounted for. Lower radiation exposure along with lower contrast requirements can provide images with high diagnostic accuracy and less risk to the patient.

Key Words: cardiac computed tomographic angiography; radiation dosing; radiation safety; coronary artery disease

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Coronary artery disease is the leading cause of morbidity and mortality around the world. Tools have been developed to accurately diagnose and evaluate coronary artery

disease, allowing physicians to directly target both atherosclerosis and significant stenosis. Coronary CT angiography (CCTA) scans provide detailed imaging and deliver precise analysis and prognostic information to a clinician and patient. Because of its high negative predictive value for coronary artery disease, CCTA has become a gatekeeper for the assessment of patients with chest pain of recent onset (1). At times, these modalities can be combined with other imaging techniques (e.g., myocardial perfusion scanning or fractional flow reserve) to provide additional diagnostic information, even in the acute setting (2,3). Patients and clinicians are increasingly concerned about the amount of radiation used in medical imaging. With advances in imaging technology and techniques, CCTA can be obtained with more diagnostic information at lower radiation doses (including structural information, along with information about atherosclerosis and obstruction) (4–7). A new wide-volume scanner with 256 detector rows, 16-cm cranial–caudal coverage, and a fast gantry rotation time of 280 ms (Revolution CT; GE Healthcare) that is now available allows acquisition of the whole heart within a single heartbeat with prospective triggering. Additionally, this scanner uses a new iterative reconstruction algorithm (adaptive statistical iterative reconstruction V [ASIR-V]) that can allow for lower-milliamperage acquisitions. These technologies allow for lower-dose imaging. CCTA has been shown to be more accurate compared to other imaging modalities such as nuclear or echocardiography imaging for assessment of obstructive disease in both the acute and the outpatient settings (8). Hamilton-Craig et al. and Dedic et al. described how the use of CCTA in the acute care setting allows for less outpatient testing and lower medical costs (9,10). We sought to compare the radiation dose from the 256-row scanner with that from a 64-row scanner (LightSpeed VCT; GE Healthcare) across 2 similar groups of patients, matched for age, sex, and size.

MATERIALS AND METHODS

One hundred ten consecutive patients were screened for the Converge Registry study and, after consenting to be included, were

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enrolled in accordance with an Institutional Review Board–approved protocol. These patients underwent CCTA on the 256-row scanner. A control group of 110 patient matching the test group for age, sex, and body mass index (BMI) underwent CCTA on the 64-row scanner. The scans were conducted at multiple sites including the United States, Italy, and Australia. All studies were read by 2 expert physicians, with adjudication by consensus if there was disagreement on stenosis severity, plaque severity, or image quality.

Patient Preparation

Certified CCTA technicians performed all the scans. Patients received an oral or intravenous β -blocker (metoprolol), or both, as needed to achieve a goal heart rate (HR) of less than 70 beats/min. Individuals presenting with a baseline HR of greater than 65 beats/min were administered oral β -blocker therapy as the preferred method for slowing the HR. Intravenous administration was used when patients had a persistent HR of greater than 65 beats/min while on the scanner table, using metoprolol at 5-mg increments to a total possible dose of 30 mg to achieve a resting HR of less than 65 beats/min.

Acquisition Protocol

Contrast Administration. After a scout radiograph of the chest (anteroposterior and lateral) had been obtained, a timing bolus (using 10–20 mL of contrast medium) was performed to determine the time to optimal contrast opacification in the axial image at a level immediately superior to the ostium of the left main coronary artery. Sublingual nitroglycerin (0.4 mg) was given immediately before the contrast injection. During the CCTA acquisition, 80 mL of iodinated contrast medium (Visipaque; GE Healthcare) was injected using a triple-phase protocol: 60 mL of iodixanol, followed by 40 mL of a 50:50 mixture of iodixanol and saline, followed by a 50-mL saline flush.

64-Row Acquisition. The 64-row acquisition was performed with prospective gating, using a commercially available protocol (SnapShot Pulse, GE Healthcare) and the following parameters: sixty-four 0.625-mm slices, the smallest x-ray window (only 75% of the R-R interval), a z-axis coverage of 40 mm with an increment of 35 mm, a gantry rotation time of 350 ms, tube voltage of 120 mV, and an effective milliamperage of 350–780 mA. The field of view was 25 cm. Scanning was performed from 10 mm above the origin of the left main coronary artery (determined on a calcium scan) to the diaphragm. By choosing the smallest possible window at only 1 distinct end-diastolic phase of the R-R interval (i.e., 75%), we ascertained the lowest effective dose delivery achievable. The amount of radiation used to evaluate both intensity and scan length was registered in DLP (mGy-cm) and was later converted to millisieverts using a factor of 0.014.

256-Row Acquisition. The 256-row scanner is a volumetric device that has high-definition spatial resolution and a 16-cm detector array. The field of view (z-axis) included the mid-ascending aorta to the upper abdomen. No table movement occurred during axial volumetric scanning because of the 16 cm of z-axis coverage, and no patient required more than 16 cm of z-axis coverage. Selection of the z-axis collimation was based on the scout images demonstrating the heart size. Tube voltage was fixed at 120 kVp, to provide comparable radiation between scans and scanners. Tube current ranged from 122 to 740 mA. A medium field of view (25 cm) was selected for all patients. The gantry rotation time was 0.28 s, with a minimum temporal resolution of 140 ms. The scanner is equipped with autogating capability, which automatically adjusts

HR-dependent settings for triggered acquisition and gated reconstruction. Autogating was used to automatically acquire diastolic phases for lower HRs and both systolic and diastolic phases for higher HRs. Electrocardiographic dose modulation, which reduces the milliamperage for nontarget phases, was used in the higher-HR acquisitions. All acquisitions were prospectively gated. Approximately 50–80 mL of contrast medium was used. Each scan was done in a 1-heartbeat acquisition within 1 cardiac cycle, regardless of the HR. Motion-correction software (SnapShot Freeze; GE Healthcare) was used to correct motion artifacts in patients with higher HRs. The amount of radiation used to evaluate both intensity and scan length was registered in DLP (mGy-cm) and was later converted to millisieverts using a factor of 0.014.

Image Reconstruction

Thin (0.625-mm) image reconstruction was used, with intervals ranging from 60% to 80%; most data were reconstructed at 75% of the R-R interval. Fifty percent ASIR-V was used. The images were transferred to an external workstation (Advantage Workstation, version 4.4; GE Healthcare) for interpretation.

Statistical Analysis

Regression analysis and *t* testing were used to compare the test group with the control group. Further analysis was also performed on subgroups of clinical variables within the test group.

RESULTS

The mean DLP was significantly lower in the 256-row test group than in the 64-row control group ($P < 0.05$) (Table 1). Use of the 256-row scanner reduced the radiation dose by 32% for BMIs of 18.5–24.9 (DLP, 111.2 vs. 76.1 mGy-cm [1.56 vs. 1.07 mSv]; $P < 0.05$). For each BMI subgroup, there was a significant decrease in dose for the 256-row scanner as compared with the 64-row scanner. Regression analysis found that with increasing BMIs (Table 2), DLP (and radiation exposure) significantly increased for both scanners for BMIs of 18.5–24.9, compared with BMIs of 25–29.9 or BMIs of greater than 30 (all $P < 0.05$).

DISCUSSION

The 256-row scanner provided CCTA scans at lower radiation doses than the 64-row scanner, with all other variables controlled for (sex, age, and BMI). As previous studies have demonstrated, with improved technology, lower radiation exposure along with lower contrast requirements can provide quality imaging with high diagnostic accuracy and less risk to the patient (11,12). The 256-row scanner allows improved image quality and clinical capabilities through the convergence of coverage, spatial resolution, and temporal resolution advantages over the 64-row scanner. The rotation speed is faster (280 ms, vs. 350 ms with the 64-row scanner), reducing patient exposure by at least 20% (Table 1). Furthermore, the whole-heart coverage allows the heart to be imaged in a single rotation (1 heartbeat) because of the 16-cm z-axis coverage with no table movement, as compared with the 5-heartbeat acquisition of the 64-row scanner (which has z-axis coverage of only 4 cm). Improved imaging protocols and technology can aid in obtaining adequate imaging despite

TABLE 1
Demographic and Clinical Characteristics

Characteristic	Control group (n = 110)	Test group (n = 110)	P
Age (y)	60.2 ± 12.5	61.1 ± 12.5	0.615
Female (n)	34 (31.5%)	35 (31.8%)	0.957
Weight (kg)	83.5 ± 17.0	83.3 ± 17.1	0.949
BMI	28.7 ± 6.1	27.2 ± 4.4	0.326
Total DLP (for 110 patients) (mGy-cm)	141.0 ± 78.8 (1.97 ± 1.10 mSv)	113.5 ± 53.6 (1.59 ± 0.75 mSv)	0.0037
DLP stratified by BMI (mGy-cm)			
Normal weight (BMI, 18.5–24.9)	111.2 ± 84.7 (1.56 ± 1.19 mSv)	76.1 ± 49.0 (1.07 ± 0.69 mSv)	0.044
Overweight (BMI, 25–29.9)	133.0 ± 55.1 (1.86 ± 0.77 mSv)	112.4 ± 52.1 (1.57 ± 0.73 mSv)	0.047
Obese (BMI, >30)	169.2 ± 74.1 (2.37 ± 1.04 mSv)	142.3 ± 28.9 (1.99 ± 0.40 mSv)	0.0004

Values are expressed as mean ± SD, except for age.

large body habitus or arrhythmias. Zhao et al. showed that CCTA images can be evaluated with high diagnostic accuracy even in patients with arrhythmias (e.g., atrial fibrillation) (13). In addition, the dose reduction is independent of iterative dose-reduction algorithms. ASIR-V allows for more advanced modeling because it deemphasizes the system optics modeling, enabling reconstruction speeds similar to those of filtered backprojection. Because ASIR-V was used on both systems, the dose reduction associated with use of 256-row scanning is incremental to this technique (14). With the new-generation 256-row CT scanner along with accompanying protocols, we are able to perform CCTA at significantly lower radiation doses.

Physicians' and patients' concerns about radiation doses should be alleviated. Studies have shown that CCTA images can be acquired with as little as 1.1 ± 0.4 mSv (15–17). Studies by Schmermund et al. and Dogan et al., along with multiple other studies, were able to demonstrate a reduction in CCTA radiation dose over a 5-y period, attributed to a combination of improvements in data acquisition protocols and patient preparation, as well as installation of new CT scanners with advanced technology (18–20).

The use of CCTA has the potential to significantly alter the management of coronary artery disease. An American Heart Association statement on assessment of coronary artery disease by CCTA provides a Class IIa recommendation for the use of CCTA in the assessment of obstructive disease in symptomatic patients (21). Studies have shown CCTA to be the most accurate of the noninvasive imaging

modalities in detecting obstructive coronary artery disease, especially when compared with functional tests (22,23). In the multicenter PROMISE study, the prevalence of normal test results and the incidence of cardiac events were significantly lower in patients randomized to CCTA than in patients randomized to functional testing (33.4% vs. 78.0% and 0.9% vs. 2.1%, respectively; both $P < 0.001$) (24). In a study by Lee et al., after adjustment for confounding risk factors, obstructive coronary artery disease remained an independent predictor of major adverse cardiac events (hazard ratio, 3.11 [95% confidence interval, 2.00–4.86]; $P < 0.001$). Their prediction model for detecting adverse events improved significantly (C-index, 0.788 [95% confidence interval, 0.747–0.829]; $P = 0.0349$) when adjusted for traditional risk factors (e.g., age, male, hypertension, hyperlipidemia, smoking, estimated glomerular filtration rate, and hemoglobin A_{1c}) (25). The 2010 Appropriate Use Criteria for Cardiac CT list CCTA as an appropriate modality in the evaluation of patients with a low to intermediate pretest probability of coronary artery disease, along with evaluation after CABG and structural disease (26). The current study and others demonstrate that the prognostic and diagnostic information can be obtained at lower radiation doses without compromising image quality irrespective of HR, heart rhythm, or obesity (27).

Multiple trials have consistently shown the safety of using a negative CCTA result as a criterion for discharging patients with a low-to-intermediate pretest probability of coronary artery disease from the emergency department. Such patients

TABLE 2
Association of DLP Levels and BMI Between Test Group and Control Group

BMI	DLP (mGy-cm) (n = 110)	β	95% confidence interval	P
18.5 ≤ BMI ≤ 24.9	76.1 ± 49.0 (1.07 ± 0.69 mSv)	0 (reference)		
25 ≤ BMI ≤ 29.9	112.4 ± 52.1 (1.57 ± 0.73 mSv)	28.3 (SE, 11.1)	6.5–50.1	0.011*
30 ≤ BMI	142.3 ± 28.9 (1.99 ± 0.40 mSv)	53.8 (SE, 11.9)	28.2–75.8	<0.001*

*Adjusted for age and sex.

DLP values are expressed as mean ± SD.

subsequently have low rates of major adverse cardiovascular events and are discharged sooner and at significantly lower cost (28). Meyersohn et al. demonstrated a significant reduction in radiation dose with higher-generation CT scanners in the emergency room setting (29). With these improvements in technology allowing for greater volume coverage with single acquisitions, centers can reduce the radiation dose and the amount of contrast medium given to a patient during a CCTA acquisition. For example, Van Cauteren et al. demonstrated up to a 50% reduction in iodine dose (30). Doses can go even lower with use of a lower kilovolt potential, further reducing doses well below background radiation levels and even lower than for calcium scoring, which is fixed at 120 kVp (31,32). One does not need to alter scanning techniques to obtain similar image quality at lower radiation doses (33,34).

A limitation of our study is that rather than scanning the same patients with both protocols, we chose to match the 256-row test group to a 64-row control group by age, sex, and BMI to create approximately similar cohorts. More prospective studies using larger sample sizes need to be conducted to further study CCTA radiation doses.

CONCLUSION

Compared with the 64-row scanner, the 256-row scanner provided CCTA scans with more clinically relevant information at significantly lower radiation doses, enabling clinicians to make appropriate clinical diagnoses and decisions, and alleviating patient concerns about radiation.

DISCLOSURE

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