SHORT COMMUNICATION

Feasibility of a radiation dose conserving CT protocol for myocardial function assessment

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Objective: Assessment of myocardial function can be performed at higher noise levels than necessary for coronary arterial evaluation. We evaluated image quality and radiation exposure of a dose-conserving function-only acquisition vs retrospectively electrocardiogram (ECG)-gated coronary CTA with automatic tube current modulation.

Methods: Of 26 patients who underwent clinically indicated coronary CTA for coronary and function evaluation, 13 (Group I) underwent prospectively ECG-triggered coronary CTA, followed by low-dose retrospectively ECG-gated scan for function (128-slice dual-source, 80 kVp; reference tube current, 100 mA; 8-mm-thick multiplanar reformatted reconstructions) performed either immediately (n = 6) or after 5- to 10-min delay for infarct assessment (n = 7). 13 corresponding controls (Group II) underwent retrospectively ECG-gated protocols (automatic tube potential selection with CARE kV/CARE Dose 4D; Siemens Healthcare, Forchheim, Germany) with aggressive dose modulation. Image quality assessment was performed on the six Group I subjects who underwent early post-contrast dedicated function scan and corresponding controls. Radiation exposure was based on dose-length product.

Results: Contrast-to-noise ratio (CNR) was preserved throughout the cardiac cycle in Group I and varied according to dose modulation in Group II. Visual image quality indices were similar during end systole but were better in Group II at end diastole. Although the total radiation exposure was equivalent in Group I and Group II (284 vs 280 mGy cm), the median radiation exposure associated with only the dedicated function scan was 138 mGy cm (interquartile range, 116–203 mGy cm).

Conclusion: A low-dose retrospective ECG-gated protocol permits assessment of myocardial function at a median radiation exposure of 138 mGy cm and offers more consistent multiphase CNR vs traditional ECG-modulation protocols. This is useful for pure functional evaluation or as an adjunct to single-phase scan modes.

Advances in knowledge: Radiation exposure can be limited with a tailored myocardial function CT protocol while maintaining preserved images.

Technological advances in coronary CT angiography (CTA) have resulted in a dramatic reduction in effective radiation exposure for patients. Various methods can and have been employed to decrease effective dose for evaluation of coronary arteries, including tube current modulation, reduction of tube voltage, use of prospectively triggered acquisitions and, more recently, high-pitch helical prospectively electrocardiogram (ECG)-triggered scanning. \(^1\)–\(^6\) Use of such methods has reduced the routine radiation dose for coronary CTA to levels similar to that of yearly natural background radiation levels. \(^7\)

The use of prospectively ECG-triggered or high-pitch helical acquisitions typically do not allow for complete evaluation of myocardial function because images are acquired during only a portion of the cardiac cycle, generally within mid-diastole to ensure minimal coronary motion. However, cardiac CT has the capability of providing reliable and reproducible quantification of left and right ventricular systolic functions and chamber volumes, when compared with other non-invasive cardiac imaging modalities. \(^8\)–\(^15\) Evaluation of left and right ventricular function has been shown to have important prognostic value in patients with coronary artery disease, acute coronary syndromes and pulmonary embolism. \(^16\)–\(^18\) It is conceivable that if information on myocardial function could be provided using cardiac CT without significant additional radiation expense, independently or at the time of coronary CTA, this might provide a useful and robust alternative means of determining accurate quantitative volumetric and functional data.
We evaluated the image quality and excess “radiation expense” associated with performing a dedicated cardiac CT acquisition with parameters tailored for the evaluation of myocardial thickening and left ventricular volumetric and functional assessment. This technique involves performing a dedicated low-dose scan for myocardial function. Appreciating that relatively large structures such as cardiac chambers and myocardial contours (as opposed to coronary arteries) allow for increased noise and lower spatial resolution demands, we allowed a lower uniform tube current setting and relied on thicker slice reconstructions akin to those used in cardiac MRI. Furthermore, since contrast attenuation is enhanced at lower tube voltages, which are closer to the k-edge of iodine, we utilized a low tube voltage of 80 kVp. This method was compared with the conventional approach of utilizing retrospective ECG gating with aggressive dose modulation down to 4% of the peak prescribed tube current (MinDose®; Siemens Healthcare, Forchheim, Germany) during systole for the simultaneous assessment of coronary arteries and myocardial function.

METHODS AND MATERIALS

Patient selection

This was a retrospective study that was approved by the PARTNERS institutional review board (Protocol no. 2013P002089), and informed consent was waived. A total of 26 patients were retrospectively identified from a selection of all clinically indicated coronary CTA examinations. These were divided into two groups (Groups I and II) based on different protocols for myocardial function acquisition.

Group I consisted of 13 consecutive patients who were referred for a clinically indicated cardiac CT scan for which assessment of both coronary anatomy and biventricular function was specifically requested. The majority of these patients had insufficient cardiac function assessment by echocardiography and had either a contraindication to cardiac MRI or could not tolerate and complete a cardiac MRI scan. Patients underwent first a prospectively triggered coronary CTA scan followed by a dedicated low-dose retrospectively ECG-gated scan for evaluation of left ventricular function. Parameters for the dedicated low-dose scan were a tube voltage of 80 kVp and reference tube current of 100 mA. A subset of Group I patients (seven patients) underwent the dedicated low-dose retrospectively ECG-gated scan 5–10 min after contrast administration in order to also assess for infarct based on the presence of abnormal late enhancement. These patients’ scans were included in the radiation dose comparative analyses but were not utilized in the image quality analyses described below, secondary to significant contrast clearance from the cardiac blood pool at the time of imaging.

These were matched with those of 13 control patients (Group II) who underwent a conventional retrospectively ECG-gated protocol based on body mass index (BMI; calculated as weight in kilograms per height in square metres), tube voltage (matched to that used for the Group I prospective coronary CTA) and mean heart rate. Tube voltage and current were per automatic tube potential selection (Siemens CARE kV and CARE Dose 4D; Siemens Healthcare). Aggressive tube current modulation was employed (Siemens MinDose). The window for dose modulation was scan specific and varied with heart rate and rhythm.

In both groups, a test bolus method was used to determine contrast agent timing prior to acquisition. All acquisitions were performed on a second-generation dual-source scanner console (Somatom® Definition Flash; Siemens Healthcare). All scans were performed as per standard of care as per routine clinical department protocols with direct physician supervision.

Estimation of radiation dose

The parameters related to patient effective radiation dose included the volume CT dose index and dose–length product (DLP), which were both obtained from the CT scan protocol for each study. The effective radiation dose was the product of the DLP and tissue-specific weighting factor for the chest.

Image analysis

Axial source CT images were transferred to a dedicated image processing workstation (OsiriX® MD v. 1.01; Pixmeo, Geneva, Switzerland) for blinded analysis. Slices were reconstructed as 8-mm-thick multplanar reformatted images in standard cardiac planes used in echocardiography (two-chamber, four-chamber, mid-cavity short axis and parasternal long axis) for evaluation of left ventricular function. Image quality was assessed with standard indices, including image noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). The signal intensity was defined as the attenuation value of the region of interest (ROI) in the left ventricular cavity. The image noise was derived from the standard deviation (SD) of the CT attenuation values in the ROI in the left ventricular cavity. The SNR was the signal intensity attenuation value divided by the SD. The CNR was defined as the difference between the attenuation value of the left ventricular cavity and the mean density of the left ventricular lateral wall, divided by the image noise. The measurements above were assessed in 10% phase increments for each group (0–90% of the cycle length interval).

In addition, a qualitative visual score was assessed by a reader with 8 years’ experience and dedicated fellowship training in cardiac CT and MRI (BBG) and an Adult Cardiovascular Medicine Core Cardiology Training (COCATS) Level 3 trained echocardiography reader with 4 years’ experience (MP), who were blinded to the acquisition protocol and scan parameters. This was performed for each myocardial segment (according to the American Heart Association (AHA) 17-segment model) in a total of 12 patients (6 in Group I with corresponding matched patients from Group II). Therefore, there were a total of 204 myocardial wall segments for which a qualitative score was determined. A visual score was determined on the basis of a three-point grading system (scores of 0–2) on both the end systolic and end diastolic frames. The visual score was based on the visibility of the endocardial border (Score 2, good visibility of endocardial border; Score 1, moderately or partly visible endocardial border; and Score 0, endocardial border barely visible or not visible).

Statistical analysis

Continuous data are presented as means ± SD or as medians with interquartile range (IQR). Categorical variables were expressed as numbers and percentages. Comparisons between groups were performed using paired t-test or Wilcoxon matched-pairs signed-ranks test for continuous variables and McNemar’s
test for categorical variables. Inter-rater agreement was analysed using the $k$-statistic measure. Comparison of image quality was carried out at a segmental level using Fisher’s exact test. For all analyses, a two-tailed $p < 0.05$ was required to reject the null hypothesis. All statistical analyses were performed using Stata® v. 13.1 (StataCorp LP, College Station, TX).

RESULTS

Baseline patient characteristics and total contrast dose were evenly distributed between the two groups and are shown in Table 1. The only significant differences between Groups I and II were the percentage of patients on $\beta$-blockers (38.5% vs 84.6%; $p = 0.030$), median heart rate variability (9 vs 3 beats per minute; $p = 0.030$) and contrast flow rate (5.3 vs 6.0 ml s$^{-1}$; $p = 0.007$).

Median total DLP was equivalent in Group I compared with Group II patients ($284 \pm 280$ mGy cm$^{-1}$). However, the total radiation exposure in Group I patients is a sum of the radiation exposure associated with the prospectively triggered coronary CTA for coronary acquisition and the dedicated function scan, which was a retrospective ECG-gated study (Table 2). Of note, the dedicated function scan alone was performed with a median DLP of 138 mGy cm$^{-1}$ (IQR, 116–203 mGy cm$^{-1}$).

Both SNR and CNR varied according to cardiac phase in patients of Group II, whereas these measures were more uniform across the cardiac cycle in patients of Group I (Figures 1 and 2). Interobserver agreement between the two readers was substantial for the visualization of endocardial border during systolic phases ($k = 0.69$) as well as end diastolic phases ($k = 0.73$). Qualitative image analysis of a total of 204 myocardial segments across 12 patients revealed no difference between groups in expert reader ability to visualize endocardial border during systolic phases; however, there was a significant difference in endocardial visualization at end diastole ($p < 0.001$) (Table 3).

DISCUSSION

Our work establishes that assessment of myocardial function could be performed at relatively low radiation exposures with a median DLP of 138 mGy cm$^{-1}$ in our cohort. Using a conventional chest weighting factor [$k = 0.014$ mSv (mGy cm$^{-1}$)], this equates to an effective radiation dose of roughly 1.9 mSv.\textsuperscript{19} However, recent literature has suggested that use of such a weighting factor significantly underestimates radiation exposure and that a more appropriate tissue weighting factor of 0.028 mSv (mGy cm$^{-1}$)\textsuperscript{1} be used.\textsuperscript{20-23} In this case, a dedicated CT function study can be performed with a median radiation expense of 3.8 mSv.

Image quality of endocardial borders for detection of systolic wall thickening was essentially identical between both groups, and there was more consistent image quality across all cardiac

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### Table 1. Patient characteristics and scan parameters

<table>
<thead>
<tr>
<th>Baseline characteristics</th>
<th>Group I</th>
<th>Group II</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Age (years), mean ($\pm$ SD)</td>
<td>51.6 ($\pm$17.7)</td>
<td>51.8 ($\pm$14.2)</td>
<td>0.980</td>
</tr>
<tr>
<td>Males, $n$ (%)</td>
<td>7 (53.9)</td>
<td>8 (61.5)</td>
<td>0.660</td>
</tr>
<tr>
<td>Body mass index (kg m$^{-2}$), mean ($\pm$SD)</td>
<td>27.4 ($\pm$5.0)</td>
<td>27.4 ($\pm$4.2)</td>
<td>0.920</td>
</tr>
<tr>
<td>HR (beats per minute), mean ($\pm$SD)</td>
<td>65.5 ($\pm$10.7)</td>
<td>63.9 ($\pm$11.5)</td>
<td>0.350</td>
</tr>
<tr>
<td>HR variability (beats per minute), median (IQR)</td>
<td>9 (7–23)</td>
<td>3 (1–6)</td>
<td>0.030</td>
</tr>
<tr>
<td>Sinus rhythm, $n$ (%)</td>
<td>9 (69.2)</td>
<td>11 (84.6)</td>
<td>0.320</td>
</tr>
<tr>
<td>Use of $\beta$ blockers, $n$ (%)</td>
<td>5 (38.5)</td>
<td>11 (84.6)</td>
<td>0.030</td>
</tr>
<tr>
<td>Contrast volume (cc), mean ($\pm$SD)</td>
<td>93.6 ($\pm$13.9)</td>
<td>95.1 ($\pm$19.8)</td>
<td>0.810</td>
</tr>
<tr>
<td>Contrast flow rate (cc s$^{-1}$), mean ($\pm$SD)</td>
<td>5.3 ($\pm$0.8)</td>
<td>6.0 ($\pm$0.8)</td>
<td>0.007</td>
</tr>
<tr>
<td>Tube potential (for the first scan), mean ($\pm$SD)</td>
<td>101.5 ($\pm$15.2)</td>
<td>103.1 ($\pm$13.8)</td>
<td>0.340</td>
</tr>
<tr>
<td>Left ventricular ejection fraction (%), median (IQR)</td>
<td>60 (49–64)</td>
<td>65 (52–70)</td>
<td>0.160</td>
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</tbody>
</table>

HR, heart rate; IQR, interquartile range; SD, standard deviation.

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### Table 2. Radiation exposure: dose-length product (DLP) (mGy cm$^{-1}$)

<table>
<thead>
<tr>
<th></th>
<th>Group I</th>
<th>Group II</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial scan, median (IQR)</td>
<td>150 (113–215)</td>
<td>280 (236–564)</td>
<td>0.003</td>
</tr>
<tr>
<td>Dedicated function scan, median (IQR)</td>
<td>138 (116–203)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Total exposure, median (IQR)</td>
<td>284 (251–369)</td>
<td>280 (236–564)</td>
<td>0.600</td>
</tr>
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IQR, interquartile range.

Initial scan for Group I was a prospectively triggered acquisition for coronary evaluation, while for Group II it was retrospective with tube current modulation.

N/A refers to the fact that only Group I subjects underwent a subsequent dedicated function scan.
phases using our tailored protocol. Also, of note, the total contrast dose did not differ between the two groups. Although we utilized a dual-source 128-slice CT scanner, low-dose retrospectively ECG-gated protocol could be employed using essentially any multidetector CT scanner.

Our study does have some limitations. Our sample size is small, and we relied on retrospectively selected patients. However, we controlled for other factors affecting image quality and radiation dose, including heart rate and BMI using a matched control group. Furthermore, the purpose of this preliminary study was to evaluate the feasibility, radiation expense and image quality of a dedicated and tailored protocol for acquiring functional data with cardiac CT. Therefore, it serves as a basis for further studies utilizing such an approach for ascertainment of myocardial function.

Clinically, there are several potential applications of performing a dedicated low-dose cardiac function acquisition. These include evaluating response to therapy in patients with heart failure who often have devices such as intracardiac defibrillators and cardiac resynchronization devices. Furthermore, these patients may not be able to lie flat and effectively cooperate with breathing instructions for cardiac MRI. Also, a low radiation and contrast dose cardiac CT could be used to serially monitor patients who undergo potentially cardiotoxic chemotherapy, which has been traditionally performed with cardiac blood pool imaging using 99mTc at higher estimated effective radiation dose.24 In addition, this modality can be employed in any scenario where echocardiography is not adequate (e.g. owing to poor acoustic windows) and in cases where cardiac MRI is either not available or not suitable (e.g. pacemaker implantation and claustrophobia).

Further studies will be required to validate our findings in a larger cohort of patients and for assessment of this approach in specific clinical scenarios. However, for now, this simple protocol may provide us with a viable, low “radiation expense” alternative imaging modality for myocardial function evaluation.

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REFERENCES


