Prospective Electrocardiogram-Gated Axial 64-Detector Computed Tomographic Angiography vs Retrospective Gated Helical Technique to Assess Coronary Artery Bypass Graft Anastomosis – Comparison of Image Quality and Patient Radiation Dose –

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Background: In the present study the effective dose and image quality at distal anastomoses were retrospectively compared between prospective electrocardiogram (ECG)-gated axial and retrospective ECG-gated helical techniques on 64-detector computed tomographic (CT) angiography following coronary artery bypass graft surgery.

Methods and Results: Following bypass surgery, 52 patients with a heart rate <65 beats/min underwent CT angiography: 26 patients each with prospective and retrospective ECG gating techniques. The effective dose was compared between the 2 groups using a 4-point scale (4, excellent; 1, poor) to grade the quality of curved multiplanar reformation images at distal anastomoses. Patient characteristics of the 2 groups were well matched, and the same CT scan parameters were used for both, except for the interval between surgery and CT examination, tube current, and image noise index. Image quality scores did not differ significantly (3.26±0.95 vs 3.35±0.87; P=0.63), but the effective dose was significantly lower in the prospective (7.3±1.8 mSv) than in the retrospective gating group (23.6±4.5 mSv) (P<0.0001).

Conclusions: Following bypass surgery, 64-detector CT angiography using prospective ECG gating is superior to retrospective gating in limiting the radiation dose and maintaining the image quality of distal anastomoses. (Circ J 2010; 74: 735–740)

Key Words: Computed tomographic angiography; Coronary artery bypass graft anastomosis; Image quality; Prospective electrocardiogram gating axial technique; Radiation dose
the effective dose and lifetime attributable cancer risk compared with the standard technique, especially for women and younger patients, maintains diagnostic image quality, and is recommended whenever possible.  

Prospective ECG gating on coronary angiography using 64-detector CT has been introduced to further reduce patient radiation exposure and is used in combination with step-and-shoot axial data acquisition, an incrementally moving table, improved image reconstruction algorithm, and multiphase reconstruction.  

For wide detector coverage (64×0.625-mm collimation), the table is stationary during image acquisition and then moved to the next location without irradiation for the next scan, which is initiated by the subsequent cardiac cycle. The effective pitch is 1.0 with this technique and 0.16–0.24 with the retrospective gated helical technique. Furthermore, with prospective gating, the X-ray beam is turned on for a brief predetermined diastolic window and turned off during the rest of the cardiac cycle. Compared with the retrospective technique, studies with prospective gating have reported reductions in effective dose of 77–83%.  

Image quality is reported either better than
equivalent to  that of retrospective gating.

Multidetector CT assessment of coronary artery bypass grafts and anastomoses following surgery is expected to be a noninvasive alternative to selective bypass graft angiography, the current gold standard for evaluating graft patency and stenosis. Compared with native coronary arteries, grafts are characterized by less cardiac motion, larger luminal diameter, and less calcification, all factors that contribute to reliable assessment of bypass grafts by multidetector CT.  

Most studies have reported almost 100% accuracy in detecting bypass occlusion, but clinically it may be reasonable in most cases to assess the presence of coronary stenosis in the course of the bypass graft or at the anastomotic site, as well as in the native coronary artery system, in addition to evaluating graft patency. However, this is more difficult because of the smaller caliber of these vessels, the presence of artifacts from metal clips, and often, pronounced coronary calcification. Recent studies using 16-detector CT show high sensitivity (96–100%) and specificity (93–100%) for detecting significant stenosis as well as obstruction of bypass grafts.  

Detection of significant stenosis of bypass grafts is also high using 64-detector CT, with sensitivity of 98–100% and specificity of 89–99%. Thus, although assessment of native coronary arteries remains difficult in patients after bypass surgery, 16- or 64-detector CT is increasingly being used as a noninvasive means of evaluating graft patency and stenosis, especially distal anastomosis, and is replacing invasive angiography at some institutions unless percutaneous intervention is mandatory. Nevertheless, the wider scan coverage required to assess the entire heart and graft course by multidetector CT exposes patients to a much higher radiation dose (approximately twice) than does coronary CT angiography. CT angiography by 64-detector CT with prospective ECG gating may be a feasible alternative following bypass surgery to reduce patient radiation dose and maintain sufficient diagnostic image quality.

Because we believe few clinical data have been reported regarding patient radiation dose or image quality using this technique, we compared the effective dose and image quality at distal anastomoses on CT angiography using 64-detector CT with the prospective axial gating and retrospective helical gating techniques for follow-up of patients after bypass surgery.  

Methods

Study Population

We retrospectively evaluated 52 consecutive asymptomatic patients (38 men, 14 women; mean age 65.5±10.1 years, range, 41 to 85 years) with a mean heart rate (HR) less than 65 beats/min just before examination and no arrhythmia who underwent CT angiography by 64-detector CT between July 2007 and September 2008 following coronary artery bypass graft surgery. We obtained written informed consent from all the enrolled patients. Unless contraindicated, 90 min before examination, patients with a baseline HR higher than 60 beats/min were orally administered a β-blocker (Seloken; Astra Zeneca, Tokyo, Japan; 1 mg/kg of body weight) to lower their HR. Until prospective gating axial scan software (SnapShot Pulse; GE Healthcare, Milwaukee, WI, USA) was introduced at Tokyo Women’s Medical University Medical Center East in January 2008, in patients with a mean HR less than 65 beats/min, we routinely performed retrospective gated helical scan with peak tube current during 70–80% of the R-R interval using ECG modulation. After the software was introduced, the institutional protocol called for only those patients with a variable HR, defined as standard deviation (SD) of 5 beats/min or more, to undergo retrospective gated helical scan in the same way; those patients whose HR varied less than 5 beats/min underwent prospective gated axial scan with radiation exposure during only 70–80% of the R-R interval. Patients with HR of 65 beats/min or higher before examination underwent standard retrospective gated helical scan and were excluded from the present study because we planned to compare both scan techniques under similar conditions. Finally, 26 patients (18 men, 8 women; mean age 64.7±9.0 years) underwent prospective gated axial scan and the other 26 patients (20 men, 6 women; mean age 66.2±11.2 years) had a retrospective gated helical scan.

CT Scan Technique

All examinations were performed with a 64-detector CT scanner (LightSpeed VCT; GE Healthcare, Milwaukee, WI, USA) with rotation time, 350 ms; collimation, 64×0.625 mm; tube voltage, 120 kV. The scan sequence included a scout scanogram, low-dose axial scan, test-bolus scan, and actual CT angiography. We performed the low-dose axial scan to determine the coverage range for the actual scan that included the entire heart and graft course. All patients were sublingually administered 0.3 mg of nitroglycerin (Nitropen; Nippon Kayaku, Tokyo, Japan) just before acquisition of noncontrast localization images. The test bolus was tracked in the ascending aorta at the level of the pulmonary trunk every 2 s after intravenous administration of 10 ml iopamidol (Iopamiron; Bayer HealthCare, Osaka, Japan) with an iodine concentration of 350 mg I/ml followed by 15 ml saline bolus at the same injection rate during the actual scan. Thereafter, CT angiography was performed after administration of the contrast medium with the delay calculated during the test-bolus scan. Specifically, a bolus of the contrast medium at a dose of 0.9 ml/kg body weight was injected for 15 s and followed by bolus injection of 30 ml saline at the same rate.

We performed prospective gated CT angiography with step-and-shoot axial scanning direction, and tube current of 500 mA for patients with body mass index (BMI) less than 30 or 700 (or 800) mA for those with BMI of 30 or more, and an imaging window covering 70–80% of the R-R interval, which we determined by adding the padding time calculated from the pre-examination HR and HR variability (HRV) to

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the center of 75%. Specifically, we used our previous original data to determine the predictive padding time for covering 70–80% of the R-R interval and the absolute time of HRV, and thus added these values to determine the actual padding time according to the mean pre-examination HR (Table 1). Data were acquired with a 40-mm axial scan (64×0.625-mm collimation) with the table stationary. Next, the table was moved 35 mm to allow a 5-mm overlap for the next step. Retrospective gated CT angiography was performed with helical scanning direction, 0.16–0.22 pitch, and ECG tube current modulation with 500–750 mA peak tube current determined empirically from BMI during 70–80% of the R-R interval and minimal tube current of 80% reduction during the rest of the cardiac cycle.

### Image Postprocessing and Evaluation

After scanning, we calculated the distance of scan coverage in the cranio-caudal direction, reconstructed the axial images at the cardiac phases of 70%, 75%, and 80% of the R-R interval, and transferred the reformatted images to a workstation (Advantage Workstation version 4.3; GE Healthcare) for postprocessing. Experienced radiology technologists selected the best cardiac phase and used Card IQ Xpress software to create volume-rendering images that included the entire heart and course of the bypass graft and curved multiplanar reformation (CPR) images that included the entire graft course, especially the distal anastomoses. Four cardiovascular radiologists who knew the numbers and sites of the anastomoses of the grafts but were blinded to other patient information arranged the images randomly and, in consensus, evaluated image quality at the distal anastomoses of the patent grafts on the CPR images in the workstation. Graft occlusion was defined as absence of contrast medium along the course of the graft, through the anastomosis to the native distal artery, or to the next graft and the native distal artery in sequential anastomosis, and we excluded such cases from image quality evaluation. In sequential anastomosis, each of several distal anastomoses of 1 graft was counted as several grafts.

In addition, we placed 3 circular regions of interest (ROIs) measuring 50 mm² in the ascending aorta on the reformatted

<table>
<thead>
<tr>
<th>HR (beats/min)</th>
<th>Predicted PT (ms)</th>
<th>Absolute time of HR variability (ms)</th>
<th>Actual PT (ms)</th>
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<tr>
<td>&lt;45</td>
<td>70</td>
<td>34</td>
<td>104</td>
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<td>45–49</td>
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<td>60–64</td>
<td>48</td>
<td>18</td>
<td>66</td>
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PT, padding time; HR, heart rate. The PT is determined by adding the predicted PT for covering 70–80% of the R-R interval and the absolute time of HR variability according to the mean pre-examination HR.

**Table 1.**

**Figure.** Curved multiplanar reformation images revealing distal bypass graft anastomotic sites in 4 patients illustrate the semiquantitative 4-point scoring of image quality. (A) Excellent vessel opacification, no motion artifacts or noise-related blurring, and no structural discontinuity (score 4). (B) Good vessel opacification, minor motion artifacts, and no structural discontinuity (score 3). (C) Fair vessel opacification, some motion artifacts, and minimal structural discontinuity (score 2). (D) Poor vessel opacification and marked noise-related blurring, resulting in absence of diagnostic information (score 1).
axial image, 1 cm above the upper margin of the Valsalva sinus, and calculated the average of the SD of the CT value within the 3 ROIs as an index of the image noise of the CT angiography.

**Image Quality**
We used a 4-point scale to grade the quality of the CT angiographic images at the distal anastomosis on the CPR image: 4, excellent image quality, absence of motion artifacts or noise-related blurring, excellent vessel opacification, no structural discontinuity (Figure A); 3, good image quality, minor motion artifacts or noise-related blurring, good vessel opacification, no structural discontinuity (Figure B); 2, fair image quality, some motion artifacts or noise-related blurring, fair vessel opacification, minimal structural discontinuity (Figure C); and 1, poor image quality, marked motion artifacts or noise-related blurring, poor vessel opacification, or prominent structural discontinuity, resulting in absence of diagnostic information (Figure D). Scores of 4 to 2 were considered diagnostic. Distal anastomoses totally overlapped by a surgical clip or calcification were regarded as unassessable and excluded from the evaluation, because the image quality of those anastomoses would not depend on the difference between the 2 CT scan techniques. For distal anastomoses with a metallic artifact caused by surgical clips, we assessed image quality at a location unaffected by the artifact and as near the anastomotic site as possible.

**Radiation Dose**
We used the recorded dose–length product (DLP, measured in mGy·cm) displayed on the dose report on the CT scanner to reasonably approximate the effective dose (E) using the equation: \( E = \kappa \cdot \text{DLP} \), where \( \kappa \) is equal to 0.017 mSv·mGy\(^{-1} \)·cm\(^{-1} \). This value is applicable for chest examinations and is the average between male and female models.

**Statistical Analysis**
All data were expressed as mean±SD. We performed statistical analysis using StatView for Windows (version 5.0; SAS Institute, Cary, NC, USA). From the ECG data obtained during the scan, we calculated mean HR and HRV as the SD of the CT value in the ascending aorta as an index of image noise, patient age, BMI, mean HR or HRV during the scan, but they differed significantly (P<0.05) for the interval between bypass surgery and CT angiography examination (prospective group: P=0.03) for the interval between bypass surgery and CT angiography examination (prospective group: 1,027.7±1,686.7 [5–3,234] days; retrospective group: 1,869.6±1,899.4 [6–4,902] days) (Table 2).

**Results**

**Patients Characteristics**
Patients in the prospective gating axial and retrospective gating helical scan groups did not differ significantly in sex, age, BMI, mean HR or HRV during the scan, but they differed significantly (P=0.03) for the interval between bypass surgery and CT angiography examination (prospective group: 1,027.7±1,686.7 [5–3,234] days; retrospective group: 1,869.6±1,899.4 [6–4,902] days) (Table 2).

**Assessed Bypass Grafs and Anastomoses**
We excluded 9 occluded grafts from the image quality assessment, so we evaluated 55 grafts in the prospective gating group (24 left internal thoracic artery [LITA], 11 right internal thoracic artery [RITA], 5 radial artery [RA], 5 right gastroepiploic artery [RGEA], and 10 saphenous vein [SV] grafts) and 53 grafts in the retrospective group (24 LITA, 12 RITA, 1 RA, 8 RGEA, and 8 SV grafts). We excluded 6 sites (4.7%) of distal anastomoses that were totally overlapped by a surgical clip (5) or calcification (1). Finally, we assessed image quality for 65 sites, from 52 arterial and 13 venous grafts, in the prospective group and 56 sites, from 46 arterial and 10 venous grafts, in the retrospective gating group.

**Image Quality Score**
In the prospective gating group, image quality of the distal anastomoses was graded 4 in 35.4% of the total sites, 3 in 53.8%, 2 in 9.2%, and 1 in 1.5%; in the retrospective gating group, image quality was graded 4 in 51.8% of the total sites, 3 in 35.7%, and 2 in 12.5%. Thus, the rate of diagnostic image quality was 98.5% in the prospective group and 100% in the retrospective group. In the prospective group, only 1 site, at the anastomosis of the LITA to the distal left anterior descending artery, was not diagnostic 7 days after bypass surgery because of marked image noise from pericardial effusion. Image quality scores at the distal anastomosis did not differ significantly between groups (3.26±0.95 vs 3.35±0.87; P=0.63) (Table 3).

**CT Scan Parameters and Effective Dose**
Mean BMI and z-axis scan coverage were not significantly different between the 2 groups, and tube voltage was identical. However, peak tube current was significantly lower in the prospective gating group (588.4±107.1 mA) than in the retrospective gating group (687.7±44.6 mA) by 14.4% (P=0.04); scan time was significantly longer in the prospective group (13.5±1.8 s) than in the retrospective gating group (12.2±2.2 s) by 9.6% (P=0.01); the index of image noise was significantly higher in the prospective group (27.5±6.4 HU) by

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**Table 2. Patient Characteristics**

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<thead>
<tr>
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<th>PGA (n=26)</th>
<th>RGH (n=26)</th>
<th>P value</th>
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<tbody>
<tr>
<td>Male sex</td>
<td>18 (69.2)</td>
<td>20 (76.9)</td>
<td>0.53</td>
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<tr>
<td>Age (years)</td>
<td>64.7±9.0</td>
<td>66.2±11.2</td>
<td>0.47</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>24.9±3.3</td>
<td>23.9±5.0</td>
<td>0.83</td>
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<tr>
<td>Mean HR (beats/min)</td>
<td>54.1±5.1</td>
<td>57.5±4.4</td>
<td>0.35</td>
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<tr>
<td>HRV (beats/min)</td>
<td>0.9±0.4</td>
<td>2.2±4.5</td>
<td>0.68</td>
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<tr>
<td>Days after CABG surgery</td>
<td>1,027.7±1,686.7</td>
<td>1,869.6±1,899.4</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Data are mean±standard deviation (SD) or number (%) of patients.
PGA, prospective gating axial; RGH, retrospective gating helical; BMI, body mass index; HRV, HR variability; CABG, coronary artery bypass graft. Other abbreviation see in Table 1.
Prospective ECG-Gated Axial CT Angiography for CABG

Table 3. Image Quality Scores

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<th></th>
<th>PGA (n=65)</th>
<th>RGH (n=56)</th>
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<tbody>
<tr>
<td>4 (excellent)</td>
<td>23 (35.4)</td>
<td>29 (51.8)</td>
</tr>
<tr>
<td>3 (good)</td>
<td>35 (53.8)</td>
<td>20 (35.7)</td>
</tr>
<tr>
<td>2 (fair)</td>
<td>6 (9.2)</td>
<td>7 (12.5)</td>
</tr>
<tr>
<td>1 (poor)</td>
<td>1 (1.5)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Total image quality score*</td>
<td>3.26±0.95</td>
<td>3.35±0.87</td>
</tr>
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</table>

Data are mean±SD or number (%) of anastomotic sites. *P=0.63.

Abbreviations see in Table 2.

Note. We excluded from the image quality evaluation, 6 sites (4.7%) where the distal anastomoses were totally overlapped by surgical clips (5 sites) or calcification (1 site) because the image quality of those anastomoses would not depend on the difference between the 2 computed tomographic scan techniques.

12.4% (P=0.04); and the effective dose was significantly lower in the prospective group (7.3±1.8 mSv) than in the retrospective group (23.6±4.5 mSv) (P<0.0001). Thus, prospective gated axial scanning reduced the effective dose of CT angiography by approximately 69% compared with retrospective gated helical scanning (Table 4).

**Discussion**

This retrospective study showed that when using CT angiography for follow-up after coronary artery bypass graft surgery, prospective ECG-gated axial scanning is superior to retrospective gating helical scan in reducing the effective radiation dose (approximately 69%) and maintaining sufficient image quality for diagnosis. Certainly, this dose reduction may be partly attributable to the significantly lower peak tube current used in the prospective scan; z-axis scan coverage was not significantly different between the 2 groups. However, Earls et al also reported a much lower mean effective dose for CT angiography after bypass surgery using 64-detector CT with prospective gating (6.4±2.3 mSv) than with retrospective gating (30.8±4.8 mSv), but they found a significantly higher tube current with prospective gating than retrospective gating. Because it limits the cardiac phase of radiation exposure and has a higher effective pitch, the prospective gated axial scan is significantly superior to the retrospective scan in reducing dose.

Although higher BMI can increase image noise, defined as the SD of the CT value measured in the ascending aorta, on coronary CT angiography, we observed no significant difference in BMI between our 2 study groups. Therefore, image noise on CT angiography in this study was more likely increased by the significantly lower tube current used in the prospective gating than in the retrospective group. The use of BMI-adapted scanning parameters, including tube current and voltage, may lead to more optimal dose reduction with maintenance of sufficient signal-to-noise ratio (SNR) on prospective gated axial CT angiography. Even increasing the tube current to some extent, the prospective method is superior to the retrospective method in improving image quality while significantly reducing dose.

The interval between bypass surgery and CT angiography examination was significantly shorter in the prospective group than in the retrospective group; in particular, 12 patients underwent the examination within 2 weeks after bypass surgery in the former group and 4 patients in the latter. Thus, postoperative collection of pleural and/or pericardial effusion enhanced image noise in the prospective group. Image quality was diagnostic in 98.5% of the prospective group and 100% in the retrospective group; marked image noise from pericardial effusion precluded early postoperative diagnosis at only 1 site in the former group. We believe tube current should be adequately increased to maintain sufficient SNR in the early postoperative period, and prospective gated axial scanning may be crucial to prevent a marked increase of radiation dose.

A substantial number of scanned grafts were not fully assessable (up to 22%) in a study that used 16-detector CT. Reasons for nonassessability other than prominent image noise include cardiac motion, respiratory artifacts, poor opacification, and the presence of surgical clips. However, increased temporal and spatial resolution, which reduces acquisition time, has improved the rate of fully assessable scanned grafts, including distal anastomoses, using 64-detector CT; 87–100% of grafts have been reported assessable using 64-detector CT and 78–100% for 16-detector CT. In our study, using 64-detector CT, no motion artifacts were detected in the prospective group; only 2, at anastomotic sites, were noted in the retrospective group, and these were still diagnostic, with image quality grades of 2 and 3. In addition, in each group, the stair-step artifact was noted at only 1 anastomotic site, with image quality graded as 2. Whereas a significant inverse correlation between mean HR and image quality has been observed with 16-detector CT, with 64-detector CT coronary angiography, lower HRV (<2.7 beats/min as the SD of the mean HR during scanning) was described as strongly associated with optimal image quality. Our good results regarding motion and stair-step artifacts with 64-detector CT can be explained by the sufficiently low HRV in both groups, specifically 0.9±0.4 beats/min for the prospective gating group and 2.2±4.5 beats/min for the retrospective group. Furthermore, recent rapid advances in X-ray tube technology permit reduced image noise with higher tube power for 64-detector CT than for 16-detector CT.

Venous grafts are generally larger in diameter and have better image quality at distal anastomoses than arterial grafts. In our study, the demography of bypass grafts assessed and the administration of contrast medium with dose adjustment for patient body weight were comparable between the 2 groups. Therefore, we believe that with optimal patient selection and scan protocol, prospective ECG-gated axial scanning is useful for follow-up of patients after coronary artery bypass surgery, markedly reducing the radiation dose and providing image quality comparable to that obtained using retrospective ECG-gated helical scanning on 64-detector CT angiography.

**Study Limitations**

First, selection of our study population may have been biased.

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Table 4. Computed Tomographic Scan Parameters and Effective Dose

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<th>PGA</th>
<th>RGH</th>
<th>P value</th>
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<tr>
<td>Tube voltage (kV)</td>
<td>120</td>
<td>120</td>
<td>NA</td>
</tr>
<tr>
<td>Tube current (mA)</td>
<td>588.4±107.1</td>
<td>687.7±44.6</td>
<td>0.04</td>
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<tr>
<td>z-axis coverage (mm)</td>
<td>230.2±31.0</td>
<td>233.9±29.9</td>
<td>0.80</td>
</tr>
<tr>
<td>Scan time (s)</td>
<td>13.5±1.8</td>
<td>12.2±2.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Image noise (HU)</td>
<td>27.5±6.4</td>
<td>24.1±4.9</td>
<td>0.04</td>
</tr>
<tr>
<td>Effective dose (mSv)</td>
<td>7.3±1.8</td>
<td>23.6±4.5</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Data are mean±SD. NA, not applicable. Other abbreviations see in Table 2.
We consecutively selected patients to compare the 2 scan techniques under similar conditions, but not for the same cohort. However, the 2 resultant groups were relatively well matched, for example, in age, sex, BMI, HR, HRV, and z-axis scan coverage. Second, although metallic artifacts from surgical vascular clips can obscure distal anastomoses and cause major issues on CT angiography assessment following bypass surgery, we did not evaluate metallic artifacts, because they precluded comparison of image quality between the 2 CT scan methods using the respective cohorts under equivalent conditions. Third, our system for scoring image quality is, by nature, subjective, although it has been used by other investigators of cardiac CT image quality. Fourth, we did not correlate the imaging findings to the definitive results using a reference modality such as CCA. Finally, additional studies using larger patient populations in a prospective manner are needed to assess diagnostic accuracy and image quality to prove the clinical feasibility of prospective gated axial scan for CT angiography examination.

Conclusion

For patient follow-up after coronary artery bypass surgery, prospective ECG-gated axial scan is superior to retrospective ECG-gated helical scan in limiting the effective radiation dose and maintaining image quality at distal anastomoses on CT angiography using 64-detector CT.

Acknowledgments

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References