Radiation dose and physical image quality in 128-section dual-source CT coronary angiography: a phantom study

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Purpose

To measure organ-absorbed doses and evaluate the physical image quality when CT coronary angiographies (CTCAs) were performed using 128-section CT equipped with dual X-ray sources (DS) applying high-pitch spiral (HPS), step-and-shoot (SAS) and low-pitch spiral (LPS) modes in order to confirm which mode should be applied regularly.
Methods and Materials

1. CT system and phantom

A 128-section DSCT SOMATOM Definition Flash (Siemens Healthcare, Erlangen, Germany) was used in this study.

For dose evaluation, we used the RAN-110 (Phantom Laboratory, Salem, NY) anthropomorphic female thoracic phantom onto which two breast sections were mounted (figure 1 on page 7).

To evaluate the physical image qualities of CT scanners, we used the Catphan 600 calibration phantom (Phantom Laboratory).

2. Dosimeters and dose calibration

Radiophotoluminescent glass dosimeters (RPLDs; GD-302M; Chiyoda Technol, Tokyo, Japan) were used to estimate the radiation dose absorbed by the organs. The RPLDs were annealed at 400°C for 30 min prior to each exposure. After each exposure, the RPLDs were further heated to 70°C for 30 min and were read using a FGD-1000 reader (Chiyoda Technol) in accordance with the manufacturer's recommended protocol.

3. Measurement of organ-absorbed dose

After obtaining localization radiographs, we placed 48 RPLDs at locations that corresponded to the breast (six RPLDs), heart (eight RPLDs), lung (eight RPLDs), red bone marrow within the ribs, sternum and thoracic vertebrae (six, two and four RPLDs, respectively), thymus (two RPLDs) and skin (12 RPLDs). Two RPLDs were used to measure background radiation.

Thereafter, prospective electrocardiogram (ECG)-triggered HPS mode (Flash Spiral Cardio, Siemens Healthcare), prospective ECG-triggered SAS mode (Flash Sequence Cardio, Siemens Healthcare) and retrospective ECG-gated LPS mode were applied at a fixed heart rate of 60 beats per minute (bpm). Exposure parameters (indicated in table 1) were chosen according to those used in our institution. ECG monitor demo mode function was used to simulate an arbitrary heart rate of 60 bpm. Each measurement was performed four times to reduce random errors.
Subsequently, the absorbed dose for each organ was calculated by multiplying the calibrated mean dose values obtained from the reader by the mass energy coefficient ratio of each organ to air (reference 23). For thymus, we used the coefficient of lymph nodes.

Table 1. Acquisition parameters for evaluating absorbed doses and physical image quality.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acquisition mode</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HPS</td>
<td>SAS</td>
<td>LPS</td>
<td></td>
</tr>
<tr>
<td>Collimation (mm)</td>
<td>128×0.6</td>
<td>128×0.6</td>
<td>128×0.6</td>
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</tr>
<tr>
<td>kV</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td></td>
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<tr>
<td>Pitch factor</td>
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<td>N/A</td>
<td>0.17:1</td>
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</tr>
<tr>
<td>mAs</td>
<td>340</td>
<td>340</td>
<td>340</td>
<td></td>
</tr>
<tr>
<td>Rotation time (s)</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>Scan range (mm)</td>
<td>153</td>
<td>172</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>Padding window (%)</td>
<td>N/A</td>
<td>35-85</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Scan duration (s)</td>
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<td>7.0</td>
<td>8.0</td>
<td></td>
</tr>
</tbody>
</table>

4. Measurement of noise power spectrum (NPS)

Noise properties in each acquisition mode were evaluated using the reconstructed images of CTP486 (image uniformity module), which were scanned at the isocenter by measuring NPS. All images were reconstructed with a displayed field of view (DFOV) of 220 mm, a slice thickness of 0.75 mm and reconstruction kernel of B35f (HeartView medium). Exposure parameters were the same as those indicated in table 1.

To calculate NPS, the central 256 × 150 pixels in the reconstructed images were used. One-dimensional NPS was calculated using the Fourier transform of one-dimensional noise profiles obtained by the numerical slit scanning technique (reference 24). To improve the accuracy of NPS data, an average NPS was calculated using three different CT images.

5. Measurement of in-plane modulation transfer function (MTF)

In-plane spatial resolution of each acquisition mode was evaluated using the reconstructed images of CTP528 (point source bead module), which were scanned
at the isocenter by measuring in-plane MTF. To avoid aliasing errors, images were reconstructed so that the bead was located at the center of the images with a DFOV of 50 mm (sampling pitch was 0.098 mm), a slice thickness of 3.0 mm and a reconstruction kernel of B35f (HeartView medium). Exposure parameters were the same as those indicated in table 1.

To calculate the in-plane MTF, a slit with a height of 40 pixels (1 × 40 pixels) was used to obtain one-dimensional profiles that were equivalent to line spread functions (LSFs). Subsequently, the in-plane MTF was calculated by one-dimensional Fourier transformation of the LSFs. To improve the accuracy of MTF data, the average MTF was calculated using three different CT images.

6. Measurement of slice sensitivity profile (SSP) and z-axis MTF

The slice width and z-axis spatial resolution of each acquisition mode were evaluated using reconstructed images of CTP528 (point source bead module), which were scanned at the isocenter by measuring SSP and z-axis MTF. Images were reconstructed with a slice thickness of 3.0 mm, a reconstruction interval of 0.3 mm (equal to the sampling pitch) to avoid aliasing errors, a DFOV of 50 mm and a reconstruction kernel of B35f (HeartView medium). The reconstructed location was adjusted so that the bead was located at the center of the images. Exposure parameters were the same as those indicated in table 1.

To calculate SSP, an oval region of interest, which had a diameter of 25 pixels (approximately 2.4 mm), was put over the center of the images and the z-axis profile was obtained. Subsequently, the full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of each mode were calculated using an interpolation method.

The obtained z-axis profiles were equivalent to LSF values. Therefore, the z-axis MTF was calculated by one-dimensional Fourier transformation of LSF values. To improve the accuracy of MTF data, the average MTF was calculated using three different CT images.

7. Evaluation of artifact

The amount of artifact in the images for each acquisition mode was subjectively evaluated using the reconstructed images of CTP528 (high-resolution module with 21 line pair per cm gauge), which were scanned at the isocenter. All images were reconstructed with a DFOV of 220 mm, a slice thickness of 0.75 mm and reconstruction kernel of B35f (HeartView medium). Exposure parameters were the same as those indicated in table 1.

8. Software
Evaluation of the physical image quality was performed using ImageJ (National Institutes of Health, Bethesda, MD) and Excel 2010 (Microsoft, Redmond, WA).
Images for this section:

**Fig. 0:** The anthropomorphic female thoracic phantom used in this study. The entire phantom was cut into thin transverse sections with grids of holes for placing small dosimeters.

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Results

1. Organ-absorbed dose

Figure 1 on page 10 indicates the differences in absorbed doses for each organ according to HPS, SAS and LPS modes at a fixed heart rate of 60 bpm. The highest absorbed dose was observed for the heart: 10.0, 96.1 and 195.7 mGy with HPS, SAS and LPS modes, respectively. The doses absorbed by the breast were approximately half of those absorbed by the heart: 5.0, 38.4 and 92.0 mGy with HPS, SAS and LPS modes, respectively.

2. NPS

Figure 2 on page 10 indicates the results of NPS measurement with the three acquisition modes. NPS values with the LPS mode were superior to those with the HPS and SAS modes. NPS values with the SAS mode were slightly superior to those with the HPS mode.

3. In-plane MTF

Figure 3 on page 11 indicates results of in-plane MTF measurement with the three acquisition modes. MTF with the LPS mode was slightly superior to that with the HPS mode. MTF values less than 0.6 cycles/mm with the SAS mode were inferior to those with the HPS and LPS modes, but MTF values greater than 0.7 cycles/mm with the SAS mode were superior to those with the HPS and LPS modes. The values for 50% MTF were 0.41, 0.36 and 0.42; and the values for 10% MTF were 0.73, 0.80 and 0.77 with HPS, SAS and LPS modes, respectively.

4. SSP and z-axis MTF

Figure 4 on page 12 indicates the results of SSP measurement with the three acquisition modes. The FWHM values were 3.57, 3.41 and 3.41 mm; and the FWTM values were 9.61, 4.68 and 7.23 mm with HPS, SAS and LPS modes, respectively. The error margin around the nominal value of slice thickness (3.0 mm) for FWHM was 18.9, 13.5 and 13.8% with HPS, SAS and LPS modes, respectively.

Figure 5 on page 13 indicates the results of the z-axis MTF measurement with the three acquisition modes. The z-axis MTF for the SAS mode was superior to that with the LPS mode, which in turn was superior to that with the HPS mode. The values for 50%
MTF were 0.13, 0.16 and 0.14; and the values for 10% MTF were 0.22, 0.26 and 0.25 with HPS, SAS and LPS modes, respectively.

5. Artifact

Figure 6 on page 14 indicates the reconstructed images of CTP528 (high-resolution module with 21 line pair per cm gauge) which were scanned at the isocenter. The amount of artifact in the reconstructed image with the HPS mode was larger than that with the other two acquisition modes.
Fig. 0: The comparison of organ-absorbed doses between the three acquisition modes at an assumed heart rate of 60 beats per minute.

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**Fig. 0:** Noise power spectrum results for the three acquisition modes. Each graph was drawn by simply calculating the average between 12 points.

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**Fig. 0:** In-plane modulation transfer function results for the three acquisition modes.

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**Fig. 0:** Slice sensitivity profile results for the three acquisition modes.

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**Fig. 0:** Z-axis modulation transfer function results for the three acquisition modes.

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Fig. 0: Reconstructed images used for evaluation of the amount of artifact: (a) High-pitch spiral mode; (b) Step-and-shoot mode; (c) low-pitch spiral mode.

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Conclusion

When three acquisition modes of CTCAs are applied using 128-section DSCT, the HPS mode has the advantage of small absorbed dose but the disadvantage of inferior image quality. The LPS mode results in a high absorbed dose of approximately 200 mGy for the heart. The absorbed radiation dose for the SAS mode is considerably low compared to that for the LPS mode even when the maximum X-ray is exposed during wide R-R range, which includes systole and diastole phases, with the SAS mode. When the SAS mode is compared to the LPS mode, there are advantages and disadvantages in both acquisition modes regarding image quality.

Therefore, the SAS mode should be applied to patients with stable sinus rhythm first because of its low absorbed dose and superior image quality.
References


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