Differences in behavior of tube current modulation techniques between single- and dual-energy CT with a second-generation dual-source scanner

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Aims and objectives

A previous study compared radiation dose and image quality between single- and dual-energy CT for a given volumetric CT dose index [1]. However, to the best of our knowledge, there is no study published yet comparing behavior of tube current modulation (TCM) techniques between single- and dual-energy CT with a dual-source CT scanner.

This study investigated the differences in behavior of tube current modulation (TCM) techniques between single- and dual-energy CT with a second-generation dual-source CT scanner.
Methods and materials

1) CT scanner and TCM

In this study, a second-generation 128-section dual-source CT scanner SOMATOM Definition Flash (Siemens Healthcare, Erlangen, Germany) was used.

This scanner has an automatic exposure control system (CARE Dose4D). It can automatically modulate tube current by two ways according to the size and shape of the patient. First, the tube current is adjusted on the basis of localizer radiographs by comparing the patient to a "standard-sized" patient (70-80 kg for adult protocols). It is based on a "quality reference" milliampere-second (mAs) setting. Second, it is adjusted near-real time on the basis of a patient's angular attenuation profile [2].

2) Phantoms

Custom-made elliptical polymethyl methacrylate phantoms 180 × 260 mm (slim) and 260 × 380 mm (obese) in diameter were used (Fig. 1 on page 6). A commercially available 16-cm CT dose phantom can be inserted into these phantoms.

3) Dosimeter

A CT Dose Profiler (RTI Electronics, Mölndal, Sweden) equipped with 2 × 2 × 0.3-mm solid-state detector chip was used for measurement of absorbed dose (Fig. 2 on page 6). The photon energy dependence and angular response of the dosimeter are comparable with that of CT-SD60 (RTI Electronics), which found to be suitable for CT dosimetry applications [3]. The output signal of the detector probe was fed to an X-ray electrometer (Piranha, RTI Electronics) and dosimetry information stored on a laptop computer running Ocean software (RTI Electronics).

4) Acquisition parameters

After placing the phantoms in the isocenter of the CT scanner, localizer radiographs in the lateral and anteroposterior directions were obtained to facilitate the TCM operation. Then they were scanned with single- and dual-energy modes. TCM was activated in both energy modes, and quality reference mAs settings of 150, 300, 450, and 600 were selected for tube A. The combinations of tube voltage and quality reference mAs settings for tubes A and B used in this study are shown in Table 1. The other acquisition
parameters were as follows: a tube rotation time of 0.5 s (single-energy mode) or 0.33 s (dual-energy mode), a detector configuration of 128×0.6 mm, and a pitch of 0.6.

Table 1. Combinations of tube voltages and quality reference milliampere-second (mAs) settings used in this study

<table>
<thead>
<tr>
<th>Energy mode</th>
<th>Tube voltage (kV)</th>
<th>Quality reference mAs</th>
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<tbody>
<tr>
<td></td>
<td>tube A</td>
<td>tube B</td>
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<tr>
<td>Single-energy</td>
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<td>120</td>
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<tr>
<td>Dual-energy</td>
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</table>

5) Measurement of absorbed dose

The detector probe was inserted into the central holes of the phantoms so that the solid-state detector chip was located at the z center of the phantoms. After that, the phantoms were scanned three times over the full z extent for each tube voltage setting, and the dose value for each scan was obtained from the dosimeter. The dosimeter provides absorbed doses to air (air kermas).

6) Image reconstruction and evaluation of image noise

The phantoms were scanned three times over the full z extent for each tube voltage setting without inserting the detector probe. Then the images were reconstructed to slice thickness of 5 mm, displayed as contiguous images over the full z extent of the phantom using a B41f kernel, a scan field of view of 50 cm, and a display field of view of 28 cm. In the dual-energy mode, a fusion-weighted image-factor of 0.5 (corresponds to 50% of
their information from the 100 kV image and 50% from the Sn140 kV image) was selected to generate fusion-weighted images with 100 and Sn140 kV, and that of 0.3 (corresponds to 30% of their information from the 80 kV image and 70% from the Sn140 kV image) was selected to generate those with 80 and Sn140 kV.

Image noises were evaluated by measuring the standard deviation of CT numbers in four separate 204-mm\(^2\) circular regions of interest (Fig. 3 on page 7) in three sets of three central adjacent images of the phantoms for each tube voltage setting.

7) Statistical analysis

Statistical analyses of absorbed dose and image noise comparisons were performed with paired t-test or Tukey's honestly significant difference (HSD) test using IBM SPSS Statistics 19 software (IBM Corp., Armonk, NY, USA). A significant difference was defined by a p value of \# 0.05.
Images for this section:

**Fig. 1:** Slim (right) and obese (left) elliptical polymethyl methacrylate phantoms

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Fig. 2: CT Dose Profiler and Piranha Electrometer manufactured by RTI Electronics
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Fig. 3: Measurement points of image noise in axial images. Circles drawn in the images show the positions of noise measurement. (a) slim phantom; (b) obese phantom

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Results

1) Slim phantom

The results of absorbed doses and image noises with single- and dual-energy modes are shown in Fig. 4 on page 11 and Fig. 5 on page 11, respectively.

Although the absorbed dose increased as the quality reference mAs setting increased, the increasing trends were different among three tube voltage settings. The absorbed doses of 80 and Sn140 kV were low compared to other two tube voltage settings. Although the absorbed doses were almost the same between 120 kV and 100 and Sn140 kV at the quality reference mAs settings of 150, 300, and 450, that of 100 and Sn140 kV was significantly lower than that of 120 kV at the quality reference mAs setting of 600 (p<0.001, paired t-test).

The image noise decreased as the quality reference mAs setting increased, and the image noises of 80 and Sn140 kV were significantly higher than those of other two tube voltage settings (p<0.001, Tukey's test).

2) Obese phantom

The results of absorbed doses and image noises with single- and dual-energy modes are shown in Fig. 6 on page 12 and Fig. 7 on page 13, respectively.

The increasing trends of absorbed doses were different among three tube voltage settings. The increase in the absorbed dose reached a plateau as the quality reference mAs setting of 300, 450, or 600 was selected with 100 and Sn140 kV. As a result, the difference of image noise was less than 3 HU among all four quality reference mAs settings with 100 and Sn140 kV.

The decreasing trends of image noises were similar between 120 kV and 80 and Sn140 kV. However, the image noises of 80 and Sn140 kV were significantly higher than those of 120 kV at all four quality reference mAs settings (p<0.01, paired t-test).

Appendix, Clinical images
Fig. 8 on page 14 and Fig. 9 on page 15 are clinical images scanned with single-(120 kV) and dual-energy (100 and Sn140 kV) modes. In both energy modes, the quality reference mAs setting of 450 was selected for tube A. In the dual-energy mode, the quality reference mAs setting for tube B was automatically selected on the basis of localizer radiographs. When a patient with a body mass index (BMI) of 22.4 kg/m$^2$ was scanned, single- and dual-energy modes provided almost the same image noise level (see Fig. 8 on page 14). When an obese patient with a BMI of 36.1 kg/m$^2$ was scanned, however, the single-energy mode provided lower image noise level than the dual-energy mode (see Fig. 9 on page 15). These tendencies are the same with the results obtained from this study.
**Fig. 4:** Results of absorbed doses as a function of quality reference mAs setting when the slim phantom was scanned

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Fig. 5: Results of image noises as a function of quality reference mAs setting when the slim phantom was scanned

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**Fig. 6:** Results of absorbed doses as a function of quality reference mAs setting when the obese phantom was scanned

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Fig. 7: Results of image noises as a function of quality reference mAs setting when the obese phantom was scanned

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**Fig. 8:** Images acquired from a 66-year-old man with a body mass index of 21.1 kg/m². (a) single-energy non-contrast image with volumetric CT dose index of 14.93 mGy; (b) dual-energy contrast image with volumetric CT dose index of 18.91 mGy

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**Fig. 9:** Images acquired from a 46-year-old woman with a body mass index of 36.1 kg/m². (a) single-energy non-contrast image with volumetric CT dose index of 31.17 mGy; (b) dual-energy contrast image with volumetric CT dose index of 24.21 mGy

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Conclusion

When TCM was applied, the tube voltage setting of 80 and Sn140 kV provided low absorbed doses and high image noise level compared to the tube voltage settings of 120 kV and 100 and Sn140 kV under the same quality reference mAs setting. This is thought the TCM used in this study is not based on the approach to modulate the tube current to keep the image noise constant [2]. When the obese phantom was scanned with 100 and Sn140 kV, the increase in the absorbed dose and the decrease in the image noise reached plateaus as the quality reference mAs setting of 300, 450, or 600 was selected. This is thought the tube current of the low tube voltage side (100 kV) reached the upper limit.

When the TCM is activated, it is important to be aware that the quality reference mAs setting and the size of the patients undergoing CT examination determine the image quality and the radiation dose [2]. In addition, our study showed that the energy mode and the tube voltage setting also affect the image quality and the radiation dose. For obese patients, a higher tube voltage setting is generally more appropriate [1]. The same goes for the dual-energy CT, and it is impossible to prevent the tube current of low tube voltage side from reaching the upper limit when the quality reference mAs setting is increased.

In conclusion, the combination of TCM and dual-energy mode is unsuitable for obese patients in the second-generation dual-source CT scanner because it has a tendency to provide images with higher image noise level than the combination of TCM and single-energy mode.
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