Effect of patient habitus on organ radiation dose and image quality for chest computed tomography: a phantom study

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Purpose

Dramatic increases in the use of Computed Tomography (CT) in the evaluation of cardiac and thoracic disease, has led to a corresponding increase in medical and public concern regarding the potential for adverse health outcomes due to the radiation exposure [1]. It is important to keep the radiation As Low As Reasonably Achievable in light of the ALARA principle.

As radiation exposure is proportional to object size, larger patients are of special concern particularly in light of the global obesity epidemic [2].

The radiation exposure associated with a CT examination depends on the protocol applied and is stratified to patient parameters such as body mass index (BMI), bodyweight or body dimensions such as anterio-posterior diameter or chest wall composition [3].

Although a larger radiation exposure will result in higher surface (skin) dose, it is unclear whether it also results in larger organ dose in larger patients. Therefore, it is important to study the amount of radiation dose actually absorbed by large patients - is the "organ dose" (center and surface of the body) comparable between patients of different sizes when maintaining the same image quality (image noise)?

*The purpose of this study was to investigate the effect of patient size on absorbed dose and image quality.*
Methods and Materials

Phantoms

1. An anthropomorphic adult chest phantom (QRM GmBH, Germany) was used for this study. The phantom consists of a replaceable central muscle attenuation insert surrounded by two air cavities representing lungs. The lungs were filled with cork in order to simulate heterogeneous lung attenuation. Dosimetry recording positions were located both in the periphery and in the central insert of this phantom.

2. A commercially available step-contrast insert containing nodules varying in diameter (15, 8, 6, 4 and 2 mm) and contrast (-100, -75, -50 and -25 HU) replaced the central insert when qualitative evaluation was required.

3. Expansion rings of variable circumference and fat attenuation were used to simulate different body habitus. These also contain peripheral dosimetry recording positions (Fig. 1 on page).

CT Scans

Volume CT scans were performed on a Toshiba Acquilion One (Toshiba Medical Systems, Otawara, Japan) unit using 320x0.5mm detector configuration.

Study parameters

1. The chest phantom was configured in four sizes as determined by the mean thoracic diameter (average of lateral and antero-posterior diameters): S-25, M-30, L-35 and LL-52.5 mm)

2. Four different tube potentials were used; 80, 100, 120 and 135 kV.

3. The tube current was adjusted to maintain a constant image noise of 30 HU in the center of the phantom at a reconstruction slice thickness of 5 mm x 2.5 mm. As the maximum achievable tube current was 580mA, the largest phantom size (52.5mm) could not be scanned at 80 kV due to inadequate photon flux.

The scan parameters are given in Table 1. The scans for the dose measurements were performed with the blank muscle insert in the centre of the phantom while the scans for the image quality assessment were performed with the step-contrast insert.

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<th>Size(mm)</th>
<th>Tube Current (mA)</th>
<th>Gantry Rotation (s)</th>
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<tr>
<td>LL (52.5)</td>
<td>- 580 240 150</td>
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Table 1. Scan parameters.

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<tr>
<td>S</td>
<td>60</td>
<td>25</td>
<td>15</td>
<td>10</td>
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Evaluation

Dose Measurements: These were performed with the muscle insert in place. A 10-mm pencil ion chamber (Radcal, CA, USA) was placed in the peripheral and central locations within the phantom. Four repeat measurements were carried out at each position, for each scan configuration for precision. This resulted in a total of 4 phantom sizes x 4 tube potentials x 5 positions x 4 repetitions = 320 measurements. The dose values were compared amongst the different phantom sizes at each kV. A CTDI value was calculated based on the measured values at the center and the periphery using the following equation:

Image Quality: Qualitative image quality assessment was performed by 3 independent readers who were presented with anonymized images read in random order. For a given nodule size in the step-contrast insert, the reader chose the maximum contrast level at which it was detectable. This resulted in a total of 3 readers x 4 phantom sizes x 4 tube potentials x 3 repetitions x 2 slice thicknesses = 288 measurements. The contrast values were converted to a 5 point numerical score that ranged from 0 = Not Visible to 4 = Clearly Visible at -25 HU. In averaging the scores, variable weights were given to nodules according to their sizes ranging from 1 = 15 mm to 5 = 2 mm. Reader studies were performed on two different clinically-utilized slice thickness reconstructions, 5 and 3 mm. Each image was presented three times to each reader to determine intra- and inter-reader reproducibility. The scores over all nodule sizes were averaged for each kV and phantom size.
Fig. 1: (A) The anthropomorphic chest phantom with different sized fat attenuation rings and the lung cavities filled with cork. (B) The step-contrast insert containing nodules varying in diameter (15, 8, 6, 4 and 2 mm) and contrast (-100, -75, -50 and -25 HU). (C) The scanning and dosimetry setup within the CT gantry.

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Results

1) At any kV, larger phantoms require a higher CTDI in order to maintain the same image noise in the centre. When averaged over all kVs, the CTDI for the LL phantom was 314%, 661% and 1680% higher compared to L, M and S phantoms, respectively (Fig. 2 on page 7).

2) When averaged over all kVs, the LL phantom required 97%, 246% and 591% increase in central dose (Fig. 3 on page 7) compared to 408%, 842% and 2244% increase in peripheral dose (Fig. 4 on page 8) for the L, M and S phantoms, respectively. Consequently, larger phantoms have a significant increase in the peripheral : central dose ratio over the smaller configurations (Fig. 5 on page 9).

3) At any phantom size, the radiation dose required to maintain the same image noise increases with decreasing tube voltage (Fig. 2 on page 7 / Fig. 3 on page 7 / Fig. 4 on page 8).

4) Despite the same target image noise for each phantom size, the qualitative image quality varies amongst the different configurations (Fig. 6 on page 10). The average image score assigned by Reader 1 shows that at both slice thicknesses, the largest phantom size received the lowest image quality score. In addition, for smaller sizes, lower tube voltages were preferred (Fig. 7 on page 11).
Fig. 2: The relationship between calculated CTDI, tube potential and phantom size.

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Fig. 3: The relationship between measured central dose, tube potential and phantom size.

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Fig. 4: The relationship between measured peripheral dose, tube potential and phantom size.

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Fig. 5: The relationship between calculated Central: Peripheral dose ratio, tube potential and phantom size.

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Fig. 6: Representative images at 120 kV at 5 mm slice thickness.

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Fig. 7: Qualitative image quality scores for 5 mm (left) and 3 mm (right) slice thickness reconstructions.

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Conclusion

1) Radiation dose required to maintain the same image noise is dependent on patient size. Larger patients require a higher CTDI compared to smaller patients.

2) The dose increase is disproportionately higher at the periphery resulting in increased peripheral:central dose ratios in larger patients. This is especially of concern for female patients due to the presence of radio-sensitive breast tissue.

3) Despite the same target image noise, the qualitative image quality in larger patients is lower than small patients.
References


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