Patient Dose Estimation on Multi Detector-row CT from Abdomen for Adult and Abdomen-pelvis for Child Examinations

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Abstract

Many multi detector-row CT scanners are used clinically in Japan. Care must be taken because of the higher exposure of MDCT than single-slice CT due to the narrow slice separation of the former.

Various organ or tissue doses in the abdomen examination for an adult and abdomen-pelvis examination for a child were measured using anthropometric phantoms and TLDs, and their effective doses were evaluated according to ICRP60. For the adult abdomen scan, doses of organs located in the abdomen were around 20–30 mGy. The effective doses ranged from 7–13 mSv and averaged 8.4 mSv. The difference of effective doses between MDCT and single-slice CT was not substantial. For the child abdomen-pelvis scan, organ doses for organs located in the abdomen were around 10–20 mGy. The effective doses were 5–14 mSv. The child abdomen-pelvis scan doses varied greatly between facilities and devices.

It is necessary to search for the optimal dose in relation to the image quality when using MDCT.

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1. Introduction

Since multi detector-row computed tomography (MDCT) first appeared, its development and evolution have been remarkable. There were over 15000 CT scanners in Japan at the end of 2005; and about 2000, or 15%, were 4–32 detector row CT scanners. At present in Japan, 64–256 row CT scanners are being marketed. CT examinations have been pointed out as comparatively high dose examinations. The International Commission on Radiological Protection (ICRP) mentioned in their report No. 871) that “Absorbed doses in tissues from CT are among the highest observed in diagnostic radiology (i.e. 10–100 mGy). In view of a tendency to repeat the CT examination, these doses can often approach or exceed levels at which an increased cancer incidence has been directly observed in human population”. Initially, a dose reduction was expected by introducing MDCT. But this did not occur because a wide-range scanning became possible and the whole body scanning is done on occasion. And one more problem with CT is the incidental exposure of non-target organs.

In this study, various organ or tissue doses were measured at hospitals under routine scan parameters and estimated effective doses were obtained to examine the possibility for decreasing them by better understanding the current status of patient exposure. A disadvantage of using effective dose, however, is that identifying organs or tissues irradiated at higher doses is difficult because the numerical values of effective doses are generally lower than organ or tissue absorbed doses due to multiplying tissue weighting factors.

2. Materials and Methods

Dose evaluations were performed with several types of CT scanners namely Light Speed QX/i and Light Speed Ultra (General Electric Co., USA); Asteion and Aquillion (Toshiba Medical Systems Co., Otawara, Japan); and Sensation (Siemens AG, Erlangen, Germany). For the adult abdomen examination, two types of 4-detector row, one 8-detector row and three types of 16-detector row CT scanners were used. For the child abdomen-pelvis examination, three types of 16-detector row CT scanners were used. Measurements were performed under routine conditions in the hospital to which the CT belonged, but, for confirmation of the factors that related to the dose, two different scan conditions were tested for 4 and 8-detector row CT scanners in the adult abdomen examination. Then, these were randomly assigned the letters A to C for the 4-, D to E for the 8- and F to G for the 16-detector row scanners. Two types of anthropomorphic tissue-equivalent phantoms (Kyoto Kagaku, Kyoto, Japan) were used, representing an adult (height 164 cm, weight 54 kg) and a child (height 117 cm, weight 22 kg). Density of soft tissue, lung, and bone were 1.006, 0.30, and 1.24 g/cm³, and effective atomic numbers were 7.42, 7.77, and 9.14, respectively. The phantoms were sectioned transversely and each section was 2.5 cm thick from the crotch to the head, while the top of the head was 3 cm for adult and 5cm for child (Fig. 1).

The abdominal examination with the adult phantom was performed in a range of 21 cm from the diaphragm to a point near the ileum superior margin. The abdomen-pelvis examination with the child phantom was performed in a range of 25 cm from the diaphragm to
pelvic base. Scan parameters are shown in Tables 1 and 2. To compare the effect of pitch factor and mAs on patient dose, two scan conditions were used for the abdominal examination with scanner D.

Effective energy of CT X-ray beam was determined by measurement of the half value layer (HVL) according to the ImPACT method\(^2\). The X-ray tube was fixed at the bottom position in the stationary tube axial scan mode. The HVL of each CT apparatus was measured using a CT-10 CTDI chamber (length 10 cm, volume 2 ml) and AE132a exposure meter (Applied Engineering Inc., Tokyo, Japan). The chamber was extended beyond the couch top end. HVL measurements were done at the center of the gantry (at 0 cm), and ± 5 cm, 10 cm and 15 cm from the center.

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**Table 1** Scan parameters for abdomen examination with the adult phantom.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector row</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Tube voltage (kV)</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Tube current (mA)</td>
<td>200</td>
<td>270</td>
<td>250</td>
<td>270</td>
<td>320</td>
<td>400</td>
<td>250</td>
<td>320</td>
</tr>
<tr>
<td>Exposure time (s/r)</td>
<td>0.8</td>
<td>0.8</td>
<td>0.75</td>
<td>0.8</td>
<td>0.5</td>
<td>0.5</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Feed (mm/r)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>17.5</td>
<td>27</td>
<td>15</td>
<td>27.5</td>
<td>21</td>
</tr>
<tr>
<td>Beam width/Detector (mm)</td>
<td>5</td>
<td>2.5</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
<td>1</td>
<td>1.25</td>
<td>0.75</td>
</tr>
<tr>
<td>Beam width (mm)</td>
<td>20</td>
<td>10</td>
<td>12</td>
<td>20</td>
<td>20</td>
<td>16</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Pitch factor</td>
<td>0.75</td>
<td>1.5</td>
<td>1.25</td>
<td>0.875</td>
<td>1.35</td>
<td>0.9375</td>
<td>1.375</td>
<td>0.875</td>
</tr>
<tr>
<td>Effective mAs</td>
<td>213.3</td>
<td>144.0</td>
<td>150.0</td>
<td>246.9</td>
<td>118.5</td>
<td>213.3</td>
<td>145.5</td>
<td>182.9</td>
</tr>
</tbody>
</table>

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**Table 2** Scan parameters for abdomen-pelvis examination with the child phantom.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector row</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Tube voltage (kV)</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Tube current (mA)</td>
<td>150</td>
<td>200</td>
<td>110</td>
</tr>
<tr>
<td>Exposure time (s/r)</td>
<td>0.5</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Feed (mm/r)</td>
<td>15</td>
<td>27.5</td>
<td>12</td>
</tr>
<tr>
<td>Beam width/Detector (mm)</td>
<td>1</td>
<td>1.25</td>
<td>0.75</td>
</tr>
<tr>
<td>Beam width (mm)</td>
<td>16</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>Pitch factor</td>
<td>0.9375</td>
<td>1.375</td>
<td>1</td>
</tr>
<tr>
<td>Effective mAs</td>
<td>80</td>
<td>166.4</td>
<td>55</td>
</tr>
</tbody>
</table>

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Fig. 1 An adult and a child anthropomorphic phantom with an example section showing TLD setting points.
Where it proved difficult to determine the predominant X-ray quality in phantom measurements, energy calibration of dosimeters were done using the effective energy value estimated from an averaged HVL for the measured points of 0, 5, 10 and 15 cm.

Two kinds of glass-encapsulated thermoluminescence radiation dosimeters (TLDs), the UD-170A (BeO, diameter 2 mm, length 8 mm) and UD-110S (CaSO₄: Tm, diameter 2 mm, length 10 mm) (Panasonic Co., Oita, Japan) were used to measure organ and tissue doses in the phantoms. The effective atomic numbers of UD-170A and UD-110S were 7.6 and 14.4, respectively. The UD-170A TLD was used for dose measurement within the useful X-ray beam, while the UD-110S was used for measurement outside it. Annealing temperatures and time were 450°C, 60 min for the UD-170A and 400°C, 30 min for the UD-110S. At least 24 h after annealing, TLDs can be used for dosimetry. TLD dose measurements were evaluated using a commercial analyzer (UD-5160P, Panasonic Co., Japan) from the 48 hours right after CT X-ray irradiation, after waiting for the fading rate to become steady. Among TLDs tested, only those whose sensitivities fell within 7% of the mean were selected. The TLDs were calibrated with a tissue-equivalent phantom compared to an ionization chamber traceable to the Japanese National Standard at the Electro Technical Laboratory (AIST) in Tsukuba, Japan.

Dose measurements were made in organs and tissues for which weighting factors (wT) are provided in ICRP 60. Calculations concerning doses to bone marrow and to bone surfaces were based on the expression

\[ D = \left( \sum m_i d_i \right) / M \]  

where \( M \) is the weight of the whole red bone marrow, and \( m_i \) and \( d_i \) are the weight and exposure dose of the red bone marrow at measurement position \( r \), respectively.

Doses at the positions used to calculate the bone marrow dose were also used to calculate the bone surface dose. Based on the assumption that the risk of osteosarcoma is proportional to the weight of mineralized bone, mean bone surface dose was calculated using the fraction of mineralized bone relative to the whole skeleton as the weighting factor. The weight of the whole red marrow and that of the mineralized bone for adults was assumed to be 764.7 g and 3700 g, respectively. For the child, the distribution of red bone marrow was derived from data of a child aged 5 years given in ICRP 70.

The effective dose, \( E \), could be calculated according to the ICRP 74 report with the expression

\[ E = w_{\text{breast}} H_{\text{breast,female}} + \sum w_T (H_{T,\text{male}} + H_{T,\text{female}}) / 2 \]

where \( w_T \) is the tissue weighting factor recommended by ICRP 60 which represents the relative contribution of the organ or tissue, \( T \), to the total of damage caused by irradiation. \( H_T \) is the equivalent dose of an organ or a tissue, \( T \). The radiation weighting factor \( w_R \) used to calculate the equivalent dose could be assumed to be 1, since X-rays were being dealt with.

Surface doses were measured at the front, right side, back and left side of the body at the center of the axis direction of the scan area.
Fifteen TLDs in close contact with each other were used for each measurement point, and were about 3 cm in width. The surface dose was obtained by averaging the 15 measured values. Exposure skin areas, calculated on the basis that the body was an elliptical cylinder, were 12.5% for the adult abdomen examination and 27.4% for the child abdomen-pelvic examination.

3. Results
All scans were done with 120 kV. The average effective energy was estimated to range from 56 keV to 75 keV for the different scanners. Measurement results for organ and tissue doses as well as the effective doses calculated with formula 2 are shown in Tables 3 and 4 for abdomen and abdomen-pelvis examinations, respectively.

Figure 2-a shows dose distribution in the ab-
The dose varied among scanners and the variation was about three-fold. To show the effect of mAs and pitch factor on exposure dose, Fig. 2b shows normalized dose to 100 effective mAs dose calculated from data in Fig. 2a. Figure 3a shows the dose distribution at the vertebrae, which are on the central axis of the body for the abdomen-pelvis scan. Figure 3b shows normalized dose to 100 effective mAs calculated from Fig. 3a. In Fig. 3a, scans were done in the low-dose mode except for scanner G. The difference among scanners in the normalized dose distribution was small.

In Table 5, estimated X-ray effective energies of the used CTs are shown.

4. Discussion

Dose measurements of various organs and tissues from CT examinations were done for adult abdomen and child abdomen-pelvis using representative MDCT models in Japan. There are some problems in evaluating effective dose in medical exposure, but it is a convenient quantity to use for comparison with other exposures and therefore effective doses have been calculated. Measurements were performed under the conditions used in a routine
examination in each hospital. As shown in Tables 1 and 2, scanning parameters differed significantly among scanners. The scan area was assumed to be constant. Recommended values of the manufacturer were adopted in many cases for the scan parameters. Scanners A and B, and scanners D and E were the same CT model but varied in their scan parameters.

Table 3 shows the organ or tissue doses from the abdomen examination for the adult phantom. And it also shows the effective doses and averaged body surface doses. High dose organs were the colon, the stomach and the liver, naturally. So the category “Remainders” included many organs used in the calculation of the effective doses because they are located in the abdomen. Figure 2a shows dose distribution in order of the organ positions from head to hip. Distance between organs was not considered in the analysis. The dose differences were about three times depending on CT scanners. Figure 2b data were normalized from Fig. 2a values for 100-effective mAs. In Fig. 2b, good conformity was observed for scanners A and B or scanners D and E to each other. The dose difference among scanners after normalization was less than two-fold. It
seemed that geometrical difference, collimation of the device and a difference in the X-ray beam quality influence this. The effective dose ranged from 7–13 mSv and their average was 8.4 mSv. The skin surface dose had an average of 23.3 mGy in a range of 19–30 mGy. The effective dose for scanner E was about 4 mSv. If the exposure with this dose was met with clinical necessity, it was a reasonable value. Actually, scan parameters of D and E were used properly with the clinical necessity.

The average effective dose and skin dose for the adult abdominal scan using the step and shutting scan method of the single helical scanner were 10.5 mSv and 27.0 mGy, respectively. On the other hand, the doses by a single-slice helical CT scanner were 8.8 mSv and 22.5 mGy, respectively. In comparison with these, no dose reduction was seen in effective dose and skin dose either. Nicholas et al. estimated effective dose from MDCT with a method based on energy imparted. They gave the effective doses for a new born, 1-, 5-, 10-, and 15-year old child, and an adult abdomen examination. Comparing the values of the effective doses in the present research with the value of a 15-year old child by Nicholas et al. showed that the former value was higher than the latter for almost all the scanners, assuming that an averaged Japanese adult size was comparable to a 15-year old European or American. The difference in the evaluation methods had the most influence; however, the scanning mAs of this study tended to be comparatively higher than that of Nicholas et al.

For children, abdomen-pelvis scans are done more commonly than only abdominal examinations. Table 2 shows parameters of the abdomen-pelvis scan for the child phantom. The parameter set which reduced the effective tube current was prepared for the scanner and chosen for scanners F and H. This effective tube current was 30–40% of that used for adult abdominal scan. Scanner G reduced tube current about 20% from that used for the adult phantom scan. Table 4 shows the doses of organs and tissues. The doses of scanners F and H were much reduced compared to scanner G. The dose could be reduced mechanically; however, it was not sure whether the doses of scanners F and H were optimized or not because the image qualities were not evaluated. The skin dose in Table 4 was the mean of four places—front, right side, left side and back of the phantom including the upper ileum. In comparison with skin dose and organ doses, skin dose of scanner F was bigger than that of the other scanners. This reflected a difference of qualities of the X-ray beam of three scanners (cf. Table 5). Figure 3a plots dose in the vertebrae which are at the center of the X-axis of the phantom. Figure 3b shows normalized dose to 100 effective mAs calculated from Fig. 3a. In Fig. 3b, vertebrae dose of scanner G was about 1.5–2 times that of scanners F and H. Dose difference of the normalized values were small in the three scanners. It seemed that geometrical difference and collimation of the scanner influenced this.

Scanner F showed a high dose all over in comparison with scanners G, and H in Fig. 2b. There was a different tendency in Fig. 3b. Because Fig. 2 showed organ doses which were averaged doses of many measured points, they were influenced by various kinds of conditions and these had additive effects. Figure 3b showed the comparison of the value of a single measured point. As Brenner et al. pointed
out, dose optimization is expected more for infant examinations. However, some physicians are of the opinion that the image quality is not always enough for a clinical diagnosis with the reduced dose. This is a basic problem of dose optimization in medical uses.

One of the problems in evaluating effective dose in medical exposure is the large difference between effective dose and organ or tissue doses because almost all of the organs or tissues given WT are in the abdomen area. For example, in a head scan, it is not rare that there is a 10-fold numerical difference between brain dose and effective dose⁠⁠¹¹⁠. In this study, abdomen or abdomen-pelvis irradiation was the subject, and numerical values of organ doses of organs in the abdomen were twice the effective dose. Effective dose is a useful and well-researched measure for comparing the range of patient doses. A disadvantage of using effective dose, however, is that identifying organs or tissues irradiated at higher doses is difficult because of the lower values of the effective dose. The dose optimization that pays attention to individual doses of the organs or tissues is necessary because the organ or tissue that shows a high dose might not be noticed when only the effective dose is paid attention to.

5. Conclusion

The exposure doses of various organs or tissues in the abdomen examination for the adult and abdomen-pelvis examination for the child were measured using anthropomorphic phantoms and TLDs, and the effective doses were evaluated. The effective doses were calculated according to ICRP60.

1) In the adult abdomen scan, doses for organs located in abdomen were around 20 mGy. The effective doses were 7–13 mSv, and 8.44 mSv on average. There was no significant transformation in effective dose of abdomen examination by scanners which were operated using the step and shutting scan method or the single helical scanner which is an earlier type of MDCT.

2) The child abdomen-pelvis scan doses varied greatly between facilities and scanners used. The doses to organs which were in the abdomen ranged from 10–20 mGy and effective doses were 5–14 mSv.

MDCT has a wide choice of scan parameters and its application is possible for various kinds of image making. On the other hand, however, doses to the patient varied with scan parameters greatly, too. It is necessary to search for the optimal dose in relation to the image quality.

Acknowledgments

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