Multi-center radiation dose survey with data feedback is a useful tool for the dose optimization of CT examinations

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Aims and objectives

Use of diagnostic reference level (DRL) is a method for evaluating whether the patient dose is unusually high or low for a particular medical imaging procedure [1]. Since 2008, we have been conducting prefecture-wide "Gunma radiation dose study (GRaD Study)", which estimated the DRL for each anatomical region by surveying radiation dose which was collected from hospitals/clinics in Gunma prefecture (state) with CT scanners. We previously reported that dose-length products (DLPs) were at comparable levels with DRLs previously reported from some countries, but the distribution of DLP had large variation and many outliers [2]. We suspected that lack of knowledge among radiological technologists on current standards of radiation exposure was considered to be one reason for this variation, and data feedback to each radiology department and education of radiological technologists may be necessary for optimization and reduction of patient dose from CT.

The aim of this study was to verify the usefulness in dose optimization of a prefecture-wide multi-center radiation dose survey followed by setting the DRL and providing data feedback.
Methods and materials

CT radiation dose survey

All 187 hospitals/clinics with CT scanners in Gunma prefecture were requested to report the data concerning vendor and model of the CT scanners, patient's age, anatomical scan region, number of scans, DLP and types of examination if other than routine for all patients who underwent CT during one month. The anatomical regions were divided into head (brain), face, neck, chest, upper abdomen, pelvis (lower abdomen) and coronary. Surveys of CT radiation dose were performed twice, in June 2011 (first survey) and June 2012 (second survey). This study was approved by the ethical committee of Gunma University Hospital, and informed consent from each patient was not necessary because this study was conducted under anonymity.

Data analyses

For the subjects of analysis, patients <15 years old and examination type other than routine were excluded. Since a scanner usually does not provide the DLP for each individual anatomical region when two or more anatomical regions are scanned in a single session, only examinations of one anatomical region were sampled for the evaluation of DRL and DLP. If the number of scans for chest, upper abdomen and pelvis were same, the examinations were sampled as whole body (chest to pelvis). When a region was scanned two or more times (for instance, non-enhanced and enhanced scans), the obtained DLP data were divided by the number of scans (we considered CT dose to be identical in non-enhanced and enhanced scans).

We chose to evaluate DLP instead of volume CT dose index (CTDIvol) because some CT scanners display maximum CTDIvol instead of mean CTDIvol, while the definition of DLP is identical in all CT scanners.

The DRL was defined as 25th and 75th percentile (Q1 and Q3) values (round off) of DLP [2].

Data feedback

After the first survey, DRLs estimated from the data of all hospitals/clinics along with the median and distribution of DLPs for each anatomical region for each CT scanner were sent to each hospital/clinic. On the individualized data sheets, data of the individual hospital/clinic was shown relative to that of other institutions, without showing the names of other institutions. Figs. 1-8 are the data sent.
One year later, a second survey was done in the same manner, and the results of each survey were analyzed. We asked 10 institutions with a particularly large change in radiation dose (5 institutions with large increase and 5 with large decrease) about evaluation of image quality after the change.

**Statistical analysis**

Mann-Whitney U-test and Mood test were employed for statistical analysis. The Mood test is a nonparametric test which tests a difference in distribution between two groups. A $P$ value of $<0.05$ was considered statistically significant. Statistical analyses were performed using R (ver. 3.0.1).
Fig. 1: Boxplot of the DLP in head for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 2: Boxplot of the DLP in face for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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**Fig. 3.** Boxplot of the DLP in neck for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 4: Boxplot of the DLP in chest for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 5: Boxplot of the DLP in upper abdomen for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).
Fig. 6: Boxplot of the DLP in pelvis for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 7: Boxplot of the DLP in whole body for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 8: Boxplot of the DLP in coronary for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Results

At the first survey, DRLs estimated from the data of all hospitals/clinics along with the median and distribution of DLPs for each anatomical region for each CT scanner were summarized (Figs. 1-8), and these were sent to each hospital/clinic. Table 1 shows estimated DRLs of DLP for each anatomical region in the first survey. 55 hospitals/clinics (29.4 % of all facilities; 62 CT scanners) provided CT data in both the first and second surveys. Fig. 9 is the brief summary of CT scanners of 55 hospitals/clinics. Table 2 and Fig. 10 show the results of DLPs for each anatomical region along with outliers.

In the upper abdomen, whole body, and coronary CT, significant decreases in DLP were observed between 2011 and 2012 surveys ($P<0.001$, respectively) (Table 2, Fig. 10). The median DLPs decreased by 16.6 %, 9.9% and 16.1%, respectively.

Mood statistics revealed that the distributions of DLP in the head, chest, pelvis and coronary CT were smaller in 2012 survey compared to 2011 survey ($P<0.001$, respectively, and $P=0.041$ for coronary CT), resulting in the smaller IQRs. IQRs were decreased by 25.0%, 11.3%, 38.8% and 6.9%, respectively (Table 2, Fig. 10).

We asked to 10 institutions with a particularly large change in radiation dose about the way of altering radiation dose and evaluation of image quality after the change. The main way of altering radiation dose was adjusting auto exposure control (AEC) settings or adjusting tube current. They also replied that the image quality, which was visually evaluated by the technicians and radiologists, was not impaired due to decreased radiation dose in any hospitals/clinics.
Fig. 1: Boxplot of the DLP in head for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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**Fig. 2.** Boxplot of the DLP in face for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 3: Boxplot of the DLP in neck for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 4: Boxplot of the DLP in chest for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 5: Boxplot of the DLP in upper abdomen for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Fig. 6: Boxplot of the DLP in pelvis for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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**Fig. 7.** Boxplot of the DLP in whole body for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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**Fig. 8.** Boxplot of the DLP in coronary for each CT scanner. The red box indicates the results from all CT scanners. The dotted lines indicate DRL. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR).

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Table 1. DRLs for each anatomical region in the first survey (CT dose data from 92 hospitals/clinics, 102 CT scanners; single to 320 detector row CT).

<table>
<thead>
<tr>
<th>Anatomical region</th>
<th>DRL (mGy cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25&lt;sup&gt;th&lt;/sup&gt; percentile</td>
</tr>
<tr>
<td>Head</td>
<td>810</td>
</tr>
<tr>
<td>Face</td>
<td>230</td>
</tr>
<tr>
<td>Neck</td>
<td>270</td>
</tr>
<tr>
<td>Chest</td>
<td>260</td>
</tr>
<tr>
<td>Upper abdomen</td>
<td>280</td>
</tr>
<tr>
<td>Pelvis</td>
<td>200</td>
</tr>
<tr>
<td>Whole body</td>
<td>660</td>
</tr>
<tr>
<td>Coronary</td>
<td>390</td>
</tr>
</tbody>
</table>

Table 1: DRLs for each anatomical region in the first survey (CT dose data from 92 hospitals/clinics, 102 CT scanners; single to 320 detector row CT).

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Fig. 9: Number of CT scanners according to vendors and number of CT acquisition channels.

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**Fig. 10:** Anatomical region-specific and survey-specific DLP for the 62 CT scanners. The lower whisker represents the 25th percentile (Q1) minus 1.5 times interquartile range (IQR) and the upper whisker represents the 75th percentile (Q3) plus 1.5 times IQR. The outlier was defined as the value above Q3+1.5*IQR, or below Q1-1.5*IQR (open circle, Q3+1.5*IQR or Q1-1.5*IQR; asterisk, Q3+3*IQR or Q1-3*IQR). * indicates Mann-Whitney U test, ** indicates Mood test, *** indicates significant difference with both statistical analyses.

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**Table 2.** DLPs for each anatomical region.

<table>
<thead>
<tr>
<th>Anatomical region</th>
<th>year</th>
<th>CT scanner</th>
<th>CT scanning</th>
<th>DLP (mGy cm)</th>
<th>Statistical analyses **&lt;br&gt;(P value)</th>
<th>Mann Whitney U</th>
<th>Mood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>2011</td>
<td>61</td>
<td>4,927</td>
<td>800 950 1,387 587</td>
<td>0.186 &lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>5,029</td>
<td></td>
<td>822 989 1,262 440</td>
<td>0.761 0.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face</td>
<td>2011</td>
<td>23</td>
<td>404</td>
<td>206 313 402 195</td>
<td>0.021 0.089</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>472</td>
<td></td>
<td>189 300 419 230</td>
<td>0.076 0.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>2011</td>
<td>28</td>
<td>387</td>
<td>266 415 616 350</td>
<td>0.450 &lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>321</td>
<td></td>
<td>323 440 677 354</td>
<td>0.450 &lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>2011</td>
<td>54</td>
<td>3,040</td>
<td>251 372 544 293</td>
<td>0.450 &lt;0.001</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>2012</td>
<td>3,143</td>
<td></td>
<td>259 371 519 260</td>
<td>0.450 &lt;0.001</td>
<td></td>
<td></td>
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<tr>
<td>Upper abdomen</td>
<td>2011</td>
<td>39</td>
<td>1,776</td>
<td>280 434 694 414</td>
<td>&lt;0.001 0.062</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>2012</td>
<td>1,594</td>
<td></td>
<td>255 362 589 335</td>
<td>&lt;0.001 0.062</td>
<td></td>
<td></td>
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<tr>
<td>Pelvis</td>
<td>2011</td>
<td>29</td>
<td>181</td>
<td>108 345 556 448</td>
<td>0.086 &lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>164</td>
<td></td>
<td>258 365 531 274</td>
<td>0.086 &lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole body</td>
<td>2011</td>
<td>44</td>
<td>1,541</td>
<td>718 1,010 1,558 840</td>
<td>&lt;0.001 0.412</td>
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<tr>
<td></td>
<td>2012</td>
<td>1,816</td>
<td></td>
<td>674 910 1,343 670</td>
<td>&lt;0.001 0.412</td>
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<tr>
<td>Coronary</td>
<td>2011</td>
<td>15</td>
<td>543</td>
<td>353 722 1,165 812</td>
<td>&lt;0.001 0.412</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>2012</td>
<td>545</td>
<td></td>
<td>275 606 1,031 756</td>
<td>&lt;0.001 0.412</td>
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</table>

* IQR: interquartile range
** The Mann-Whitney U test was for evaluating the difference in median of DLP, and Mood test was for the distribution.
Conclusion

We have shown that feedback of DRLs and DLP distribution data for each CT system derived from our CT dose survey led to optimization and reduction of radiation dose for head, upper abdomen, pelvis, whole body and coronary. This was supported by reductions of median of DLP and by the reduction of distribution of DLPs, which were also indicated by the reduction of IQRs.

It has been reported that optimization of CT acquisition protocol and a reduction of CT radiation dose delivered to patients by 30% was achieved by radiological staff training [3]. This is more effective than the results of our study. However, it is not realistic to hope to enroll all radiologists and radiological technologists in the 187 hospitals/clinics in Gunma prefecture in training programs and adequately cover the necessary material within a reasonable amount of time. Our method of simply making competent radiologists and radiological technologists aware of how high or low DLP is in each CT system was surprisingly effective considering the limited resources involved, and at the same time appropriate DRLs could be evaluated.

Limitations

1. All CT vendors and CT models were analyzed together. Consequently, only DLP was analyzed for radiation dose optimization and reduction, and image quality was not objectively analyzed. In CT examinations, it is important to consider the balance between CT image quality and radiation dose.

2. We compared the data of only 29.4% of facilities in Gunma prefecture. We did succeed in evaluating 42.5% of hospitals with more than 100 beds, which is where most of the scans were performed. Only radiologists or radiologic technologists who were interested in quality improvement of their radiology department responded to these surveys.
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