Robustness of local clinical DRLs for CT scanner examinations in a multicenter setting compared to the new Swiss national DRLs

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Authors: H. Brat\textsuperscript{1}, F. Zanca\textsuperscript{2}, D. Fournier\textsuperscript{1}, B. Rizk\textsuperscript{3}, J. Helal\textsuperscript{3}, N. Correia\textsuperscript{4}, J. Favre\textsuperscript{5}, P. Bosson\textsuperscript{6}, M. Eric\textsuperscript{7}, \textsuperscript{1}Institut de Radiologie de Sion Sion/CH, \textsuperscript{2}Palindromo Heverlee/BE, \textsuperscript{3}Centre d'Imagerie de Fribourg Fribourg/CH, \textsuperscript{4}Centre d'Imagerie de Lausanne-Epalinges Epalinges/CH, \textsuperscript{5}Centre d'Imagerie d'Onex Onex/CH, \textsuperscript{6}Centre d'Imagerie de Morges Morges/CH, \textsuperscript{7}Institut de Radiologie de Sion Sio/CH

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"Diagnostic reference level" (DRL):  

- introduced in 1996 by the International Commission on Radiological Protection (ICRP) (1),
- updated in 2017 with recommendations on DRLs in medical imaging and clarification issues related to definitions of the terms (2).

According to ICRP publication 135 (2):

- **National** DRLs (**NDRLs**) are representative of an entire country,
- **Local** DRLs (**LDRLs**) are representative of a few healthcare facilities in a local area. They consider faster local optimization processes than NDRLs and remain anatomy-based.

NDRLs and LDRLs are calculated as the third quartile of the median dose values of each CT modality.

- **Clinical** DRLs (**CDRLs**) define more specific dose levels according to the a specific clinical indication (example: a CT of the abdomen to exclude renal calculi will require a lower patient exposition than to characterize a kidney tumor).
- **Local Clinical** DRLs (**LCDRLs**) are representative of a few healthcare facilities in a local area for specific clinical indications.

LCDRLs are calculated as the third quartile of the median dose values of each CT scanner involved in the study.

The **purpose** of this multicenter prospective study was to estimate institutional dose levels based on clinical indication (LCDRLs) and compare it to the new Swiss NDRLs (3,4), while considering CT technology and protocol harmonization across scanners.

<table>
<thead>
<tr>
<th>SWISS NDRL</th>
<th>CTDI$_{vol}$ P50 (mGy)</th>
<th>CTDI$_{vol}$ P75 (mGy)</th>
<th>DLP P50 (mGy.cm)</th>
<th>DLP P75 (mGy.cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEST</td>
<td>6</td>
<td>7</td>
<td>210</td>
<td>250</td>
</tr>
<tr>
<td>ABDOMEN</td>
<td>10</td>
<td>11</td>
<td>470</td>
<td>540</td>
</tr>
</tbody>
</table>
Description of activity and work performed

5 imaging centers of the Swiss Groupe 3R (3R, Réseau Radiologique Romand) were involved in this study.

Study prerequisites

- A dose-team was set-up, with one radiologist and one technologist in each center, a CT field engineer, a physicist and team leader, aiming at standardizing protocols, optimizing dose while maintaining image quality and creating awareness and dissemination.

- Image quality was assessed using adapted European image quality guidelines (4) (Fig. 1 on page 7) and through an electronic image quality voting button in the dose tracking software used by the radiologists during their routine work (binary task, 0 = non-diagnostic image; 1 = diagnostic image).

- A protocol harmonization phase followed by an optimization phase were necessary for patient exposure standardization and adequate image quality per clinical indication:

  **Protocol Harmonization** (June 2015 - January 2016)

  - A clinical indication-based protocol map was defined by a senior radiologist with two categories of patients for each protocol according to body mass index (BMI<25 for non-overweight and BMI>25 for overweight patients).

  - In parallel, acquisition and reconstruction parameters were harmonized per clinical indication among 5 CT scanners (Philips). Specifically, the following parameters were used: detector configuration 64x0.625; rotation time 0.4, pitch 0.891-1.172; kVp 100-120; max mAs 64-217 depending on clinical indication; slice thickness 0.9 mm; reconstruction algorithm iDose level 4 (chest) or 3 (abdomen). Protocols were adapted to remain close to the Swiss P25 NDRL (5) for BMI<25 patients and the P75 NDRL for BMI>25 patients.

  - Each protocol was mapped into a dose monitoring system (DoseWatch®, GE Healthcare) to the RadLex playbook.

  **Protocol Optimization** (January 2016 - January 2017)

  - Optimization methodology was based on a 12% step-wise mAs reduction for all protocols with continuous diagnostic-based image quality assessment.
• After 50 examinations of the same indication without negative voting, an
additional 12% of dose reduction was applied. After 50 examinations of the
same indication without negative voting, an additional 12% of dose reduction
was applied.

• In case of 3 negative voting's for one type of protocol, confirmed by a
second reader, dose was increased back by 12% to reach previous
accepted dose level, representing the "right dose for the right diagnosis".

• In parallel, phantom tests were performed to identify the lower dose limit for
low contrast liver lesions by a task-based quantification of image quality (6).

**Study data collection**

Following data were automatically retrieved with DoseWatch® for each series: DLP, CTDIvol, protocol name, protocol scan parameters, anatomical region, center name, RadLex coding, patient age and gender, date of scan, series number. Short scans obtained to determine the peak time for contrast injection were excluded as acquisitions. Use of collected CT data was approved by the Institutional Review Board (Medical Ethics Committee).

Minimum, maximum, median, 25th percentile (P25) and 75th percentile (P75) values were calculated for CTDIvol and DLP quantities for each clinical indication and anatomical region in order to:

- Compare typical anatomy-based institutional dose levels to NDRLs (7)
- Compare clinical indication-based institutional dose levels to NDRLs (7)
- Compare clinical indication-based institutional dose levels to anatomy-based
dose levels.

**Study population**

From February 2017 to June 2018, 6368 CT chest and abdomen series were
prospectively collected, representing 70% of chest and abdomen examinations and the
11 most recurrent clinical indications (Fig. 2 on page 7):

- 53.5% were female and 46.5% male.
- Mean age was 59.7 years (range 1-101).
• 5310 (83.4%) were CT of the abdomen, 44.1% with BMI < 25 and 55.9% with BMI > 25.

• 1058 (16.6%) were CT of the chest, 46.3% with BMI < 25 and 53.7% with BMI > 25.

Statistical analyses (statistical software Prism 7 (GraphPad))

• The Mann Whitney tests were used to assess statistically significant differences among two unpaired groups.

• The Wilcoxon test was used to compare one group to a hypothetical value.

• The Kruskall-Wallis test was used to assess statistical difference among clinical indications dose levels and anatomy-based dose levels.

A p-value < 0.05 was considered statistically significant.

Results

Comparison of anatomy-based institutional dose levels to NDRLs

Median CTDIvol and DLP values of our study population are presented in Table format (Fig. 3 on page 8) and boxplots (Fig. 4 on page 9).

• The institutional median CTDIvol for chest and abdomen examinations was significantly lower than the P75 and P50 NDRL.

• For chest examinations, the institutional median DLP was significantly lower than the P75 NDRL, but not significantly different from P50 NDRL, indicating that this might represent the lowest limit for chest.

• For abdomen examinations, the institutional median DLP was always statistically lower than the P75 NDRL and P50 NDRL.

Comparison of indication-based institutional dose levels to NDRLs

Fig. 5 on page 9 shows the boxplots of CTDIvol dose levels based on clinical indications respect to NDRLs.
• The median CTDIvol of all chest examinations indications was statistically significantly lower than the P75 and P50 NDRL (p<0.0001).

• The median CTDIvol of all abdomen examinations indications was significantly lower than the P75 NDRL and the P50 NDRL (p<0.0001), indicating that for these new DRL levels there is still margin of optimization.

Fig. 6 on page 10 shows the boxplots of DLP dose levels based on clinical indications respect to NRDLs.

• The median DLP of all chest indications was statistically significantly lower than the P75 NDRL (p<0.0001).

• For abdomen examinations, the median DLP per clinical indication was significantly lower than P75 NDRL and P50 NDRL for all clinical indications (p<0.0001).

**Comparison of institutional clinical indication-based dose levels to institutional anatomy-based dose levels**

When comparing the dose levels of each clinical indication with the dose levels of the corresponding anatomical region, we observe that there was no significant difference for chest examinations, while for the abdomen there was a significant difference for colonography and diverticulitis only (Fig. 7 on page 10). However, these results don't take into account BMI distribution, which could represent a significant impact.
**Fig. 1:** Image Quality Assessment

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<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>Protocol name</th>
<th>Number of series per BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BMI &lt; 25</td>
</tr>
<tr>
<td><strong>Chest</strong></td>
<td>Emphysema</td>
<td>147</td>
</tr>
<tr>
<td></td>
<td>Pulmonary Embolism</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>Pneumonia</td>
<td>178</td>
</tr>
<tr>
<td><strong>Abdomen</strong></td>
<td>Appendicitis</td>
<td>249</td>
</tr>
<tr>
<td></td>
<td>CT colonography</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Diverticulitis</td>
<td>541</td>
</tr>
<tr>
<td></td>
<td>Kidney Stones</td>
<td>501</td>
</tr>
<tr>
<td></td>
<td>Liver</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>Pancreas</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td>Renal Tumor</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Renal Infection</td>
<td>150</td>
</tr>
<tr>
<td><strong>Total number of series</strong></td>
<td></td>
<td>6368</td>
</tr>
</tbody>
</table>

**Fig. 2:** Table 1: Study data per protocol and stratified per BMI.

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**Fig. 3: Table 2 : Institutional dose levels**

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<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>Institutional Median CTDvol (P25-P75)</th>
<th>p-value to P50 NDRL (6 mGy)</th>
<th>p-value to P75 NDRL (7 mGy)</th>
<th>Institutional Median DLP (P25-P75)</th>
<th>p-value to P50 NDRL (210 mGy.cm)</th>
<th>p-value to P75 NDRL (250 mGy.cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>5.0** (3.6-6.7)</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>6.9** (5.3-9.2)</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td></td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
</tbody>
</table>

NDRLs represents National DRL; * indicates a p-value <0.05 (significant); ** indicates a value significantly lower than the P75 NDRL; * indicates a value significantly lower than the P50 NDRL.

**Fig. 4: Boxplots of CTDvol and DLP values per anatomical region for chest and abdomen examinations.**

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**Fig. 5:** Institutional CTDIvol dose levels based on clinical indication.

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**Fig. 6:** Institutional DLP dose levels based on clinical indication.

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<table>
<thead>
<tr>
<th>Anatomical region</th>
<th>Clinical Indication</th>
<th>Median CTDIvol (mGy)</th>
<th>p-value to “Chest”</th>
<th>p-value to P75 (7 mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>Emphysema</td>
<td>4.9</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Pneumonia</td>
<td>4.8</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Pulmonary Embolism</td>
<td>5.1</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Abdomen</td>
<td>Appendicitis</td>
<td>6.7</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>CT Colonography</td>
<td>4.9</td>
<td>&lt;0.001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Diverticulitis</td>
<td>7.3</td>
<td>&lt;0.001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Kidney Stones</td>
<td>6.8</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Liver Tumor</td>
<td>6.9</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Pancreas Tumor</td>
<td>6.9</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Renal Infection</td>
<td>7.5</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Renal Tumor</td>
<td>6.6</td>
<td>&gt;0.05</td>
<td>&lt;0.0001*</td>
</tr>
</tbody>
</table>

**Fig. 7**: Comparison between optimized clinical indication dose levels and anatomy-based dose levels

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Conclusion and recommendations

This study showed that our institutional dose levels remain significantly lower than the new Swiss NDRls published in 2018, indicating that our quality project on harmonization and optimization of CT scanner acquisition protocols has allowed a dose optimization in line with the ALARA principle.

When considering CT scanner optimized protocols based on clinical indication, the difference with respect to the dose metrics corresponding to anatomical region protocols are not significant for chest and significantly different only for specific indications in abdomen. Including patient habitus would possibly give different results.
Personal/organisational information

Hugues Brat, MD

Institut de Radiologie de Sion

Rue du Scex, 2

CH-1950 Sion, Switzerland

Mail: hugues.brat@groupe3r.ch
References