Influence of BMI on clinical DRLs for CT examinations: a prospective multicenter study after protocol harmonization and optimization.

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Background/introduction

A. "Diagnostic reference level" (DRL): Definitions

• introduced in 1996 by the International Commission on Radiological Protection (ICRP) (1),
• updated in 2017 regarding 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 needed image quality for 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 a study.

B. Current initiatives

• The European Society of Radiology (ESR) has recently started a European prospective study, named EUCLID (European study on Clinical DRLs), among EuroSafe Imaging Stars to develop a set of CDRLs based on clinical indication rather than anatomical location. These CDRLs are intended to help reducing large variations in dose levels for the same type of examinations.
• Also, the American College of Radiology (ACR) tried to go one step further in the definition of DRLs by introducing patient size (3).
C. DRLs: Remaining Limitations

DRLs for adults have been confined to representative standard patient:

- the DRL is defined as the 75th percentile of the mean doses for a sample of patients close to the standard size, typically 70 kg or, in some countries, 60-70 kg.

However, larger fractions of patients are currently non-standard, as it can be seen from the data presented in this study, where overweight patients are not outliers, but a large part of the population.

D. This multicenter prospective study aims at contributing to the definition of local clinical DRLs (LCDRLs) for chest and abdomen examinations in CT, while considering influence of patient BMI and comparing them to the recently published updated Swiss DRLs (4).
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 8) 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 in order to compare clinical indication-based institutional dose levels to NDRLs according to BMI class (7).

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 8):

- 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))

- Mann Whitney tests were used to assess statistically significant differences among two unpaired groups.
- Wilcoxon test was used to compare one group to a hypothetical value.
- Kolmogorov-Smirnov test was performed for each clinical indication to assess the skewness of the BMI distribution.

A p-value < 0.05 was considered statistically significant.

Results

Fig. 3 on page 9 and Fig. 4 on page 10 show the boxplots of CTDI_{vol} (left) and DLP (right) metrics grouped per clinical indication and stratified per BMI class for chest and abdomen examinations.

Fig. 3 on page 9 presents chest institutional dose levels based on clinical indication:

- The difference in dose metrics among the clinical indications is limited in each BMI class.
- The median CTDI_{vol} of all chest examinations indications was statistically significantly lower than the P75 NDRL for all BMI classes (p<0.0001).
- The median CTDI_{vol} was significantly lower than the P50 NDRL for the BMI<25 class indications only (p<0.0001).
- For the BMI>25 indications, the median CTDI_{vol} was not significantly different than the P50 NDRL for emphysema (p= 0.17) and significantly higher for pneumonia and pulmonary embolism (p<0.0001).
- The median DLP of all chest indications was statistically significantly lower than the P75 NDRL for all BMI classes, except for BMI > 25 pneumonia indication for which it was higher (p<0.0001).
- The median DLP was significantly lower than the P50 NDRL for the BMI<25 class indications only (p<0.0001).
- For the BMI>25 indications, the median DLP was significantly higher than the P50 NDRL for all indications (p<0.0001).
Fig. 4 on page 10 presents abdomen institutional dose levels based on clinical indication:

- There is a large variation in dose metrics within each BMI class, with the lowest dose for colonography and the highest for renal infection.

- For all clinical indications and BMI classes, the median CTDI_{vol} was significantly lower than the P75 NDRL and the P50 NDRL (p<0.0001), except for renal infection BMI>25, for which it was not significantly different (p=0.27).

- The median DLP per clinical indication was significantly lower than P75 NDRL and P50 NDRL for all clinical indications and BMI classes, except for appendicitis (p=0.95), diverticulitis and renal infection BMI>25 for which it was not significantly different (p=0.06).

Largest variations are observed in the BMI>25 class. The Kolmogorov-Smirnov test indicated that the BMI distribution was skewed to the right for each clinical indication, with a skewness value ranging 0.6 to 1.1 per abdominal examinations (0.4 to 0.7 for chest examinations), with long tails of BMI values larger than 30.
**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>
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<td></td>
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<td>BMI &lt; 25</td>
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<td><strong>Chest</strong></td>
<td>Emphysema</td>
<td>147</td>
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<td><strong>Abdomen</strong></td>
<td>Appendicitis</td>
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<td></td>
<td>Diverticulitis</td>
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<td>Renal Infection</td>
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<tr>
<td><strong>Total number of series</strong></td>
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</tr>
</tbody>
</table>

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

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**Fig. 3:** Chest institutional CTDIvol (left) and DLP (right) based on clinical indication and BMI class.

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**Fig. 4:** Abdomen institutional CTDIvol (left) and DLP (right) based on clinical indication and BMI class.

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Conclusion and recommendations

This prospective multicenter study on > 6'000 examinations shows:

- BMI>25 patients are not outliers anymore (>50% of study population).
- Large dose metrics variations between the BMI<25 and BMI>25 groups, for chest and abdomen examinations.
- Influence of clinical indication on dose metrics is more important in abdomen than in chest examinations.
- Current limitation of adult DRL definition, confined to representative standard patient.

In this respect, addressing clinical indication and patient BMI is very relevant when defining clinical DRLs for CT examinations.

Recommendation:

Given the importance of dose metrics variations between non-overweight and overweight populations, a simple BMI stratification (<25 and >25) allows a more realistic standardization when defining CDRL and/or LCDRLs.
Personal/organisational information

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References