Updated review of CT effective doses in the literature

Poster No.: C-1602
Congress: ECR 2016
Type: Scientific Exhibit
Authors: C. Zhang, P. McLaughlin; Vancouver/CA
Keywords: Dosimetric comparison, Dosimetry, CT, Radioprotection / Radiation dose
DOI: 10.1594/ecr2016/C-1602

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR's endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.

As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method ist strictly prohibited.

You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys' fees, arising from or related to your use of these pages.

Please note: Links to movies, ppt slideshows and any other multimedia files are not available in the pdf version of presentations.

www.myESR.org
Aims and objectives

Amongst diagnostic radiological procedures utilizing ionizing radiation, computed tomography (CT) is a substantial and major contributor of cumulative effective dose (ED) to our patients.

Effective dose is the tool used by clinicians to compare and contrast the stochastic risk associated with exposure to ionizing radiation [1]. With the emergence of contemporary low-dose CT technology, tremendous decreases in ionizing radiation exposure have been achieved in the last decade [2-4]. These namely include (with inclusion of the approximate first year of clinical application) [4]:

1. **Automated exposure control** (2004): This allows efficient dose delivery by modulating the tube current to obtain patient-personalized scan protocols (i.e. in accordance to patient width and attenuation profile), replacing fixed tube current settings [5].
2. **Iterative reconstruction (IR) algorithms** (2010): Image noise is inherently the result of the reconstruction process. IR algorithms, which take into consideration various physical and scanner parameters, have been critical in preserving image quality even at low CT exposure [6].
3. **Combined analog-to-digital converter and photodiode layers in newer generation CT detectors** (2013): These allow for a lower photon detection threshold, translating into the ability of generating quality low-dose imaging [7].

Despite these technical advances, the latest comprehensive procedure-specific dose catalog, by Mettler et al. [8] includes data from the literature between 1980 and 2007. Therefore, **we sought to update the work that Mettler et al. conducted in 2008 in an effort to quantify the current trends in CT radiation exposure across multiple body parts.**
**Methods and materials**

**SEARCH**

A PubMed search from January 1\textsuperscript{st}, 2011 - December 31\textsuperscript{st}, 2014 inclusively of all studies whose focus was on lowering CT radiation was conducted.

**INCLUSION CRITERIA**

Search was limited to all clinical studies (clinical trials, comparative studies, evaluation studies, multicenter studies, observational studies, randomized controlled trials, and validation studies) in adult humans with search keywords "low dose CT" and "CT iterative reconstruction".

**EXCLUSION CRITERIA**

Excluded studies were those whose subjects were phantoms, whose focuses were on breast, vascular, head and spine imaging (excluded due to limited number of studies). Pediatric studies were excluded due to differences in proportions of radiosensitive organs in children [1]. Fluoroscopic, arteriographic, cone beam studies were excluded due to their differences in ED computation [1].

**DATA COLLECTED**

The remaining abstracts were first scanned to collect reported CT dose index (CTDI) in mGy, dose length product (DLP) in mGycm and effective dose (ED) in mSv. If these were not reported in the abstract, the full text article was then searched for those values, and if still none was found, the study was then excluded.

All results were entered and computed through an Excel Spreadsheet.

**SUB-GROUP ANALYSIS**

Due to different tissue-weighting factors, scan lengths, DLPs, amongst other factors, in addition to the goal of obtaining a representative clinical comparison, collected studies were subcategorized into whole body (chest/abdomen/pelvis), abdomen/pelvis, chest/lungs, cardiac or Kidney-Ureters-Bladder (KUB) for ED tabulation.

**EFFECTIVE DOSE (ED) CALCULATION & ANALYSIS**
Since ED is the widespread means of ionizing radiation detriment potential comparison utilized in clinical medicine, this was used as the final means of comparison between studies. When reported in the study, the mean ED was utilized.

Otherwise, conversion coefficients used to obtain ED from CTDI and DLP are those suggested in Huda et al.'s 2008 study [9]. Coefficient values from a single study were selected for purposes of conformity and standardization within our study. Huda et al.’s 2008 study took into consideration values stemming from various scanners and provided a comprehensive overall conversion coefficient for the entire body, therefore its values were applied [9]. Since parameters for cardiac scans were not included, a later study also by Huda et al. was utilized for cardiac-specific values [10].

CTDI was first converted into DLP by the equation: \[ \text{DLP} = \text{CTDI} \times \text{scan length} \], where the scan lengths utilized were:

- chest = 35 cm
- abdomen = 24 cm
- KUB = 24 cm
- pelvis = 20 cm
- cardiac = 16 cm [9]

ED was then obtained using the equation \[ \text{ED} = \text{DLP} \times 0.018 \text{ mSv/mGycm} \] for whole body (chest/abdomen/pelvis), abdomen/pelvis, chest/lungs and Kidney-Ureters-Bladder (KUB) [9].

For cardiac studies, an ED/DLP value of 0.026 mSv/mGycm was used, as that region is 30% more radiosensitive than chest [10].

The combined reported and calculated ED were subsequently averaged by body section.
Results

RESULTS

The above-outlined PubMed search methodology between 2011-2014 with keywords "low dose CT" and "CT iterative reconstruction" yielded a total of 537 and 167 studies respectively; many were repeated. Based upon the above exclusion criteria, a total of 168 studies were analyzed: 37 chest, 51 abdomen/pelvis, 7 chest/abdomen/pelvis, 65 cardiac, 8 KUB. The combined, reported and calculated, effective doses, along with their ranges, can be found in Table 1 on page 6.
Table 1: Adult Effective Doses for Various CT Procedures [3, 11-170]

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of Studies</th>
<th>Average Effective Dose (mSv)</th>
<th>Range of Effective Dose Reported in Literature (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest (Fig. 1)</td>
<td>37</td>
<td>2.41</td>
<td>0.15-9.0</td>
</tr>
<tr>
<td>Abdomen/Pelvis (Fig. 2)</td>
<td>51</td>
<td>5.10</td>
<td>0.52-29.2</td>
</tr>
<tr>
<td>Chest/Abdomen/Pelvis (Fig. 2)</td>
<td>7</td>
<td>10.91</td>
<td>6.7-17.1</td>
</tr>
<tr>
<td>Cardiac (Fig. 3)</td>
<td>65</td>
<td>3.39</td>
<td>0.06-12.1</td>
</tr>
<tr>
<td>KUB (Fig. 4)</td>
<td>8</td>
<td>1.99</td>
<td>0.48-4.2</td>
</tr>
</tbody>
</table>

Table 2: Comparison with Previous Comprehensive Review (Mettler et al.) [8] of Adult Effective Doses for Various CT Procedures

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Our Study (mSv)</th>
<th>Mettler et al’s (mSv)</th>
<th>Percent Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>2.41 (0.15-9.0)</td>
<td>7 (4.0-18.0)</td>
<td>65.6</td>
</tr>
<tr>
<td>Abdomen/Pelvis</td>
<td>5.10 (0.52-29.2)</td>
<td>14 (6.8-25)</td>
<td>63.6</td>
</tr>
<tr>
<td>Chest/Abdomen/Pelvis</td>
<td>10.91 (6.7-17.1)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cardiac</td>
<td>3.39 (0.06-12.1)</td>
<td>16 (5.0-32)</td>
<td>78.8</td>
</tr>
<tr>
<td>KUB</td>
<td>1.99 (0.48-4.2)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3: Journals with Highest Source of Study Articles

<table>
<thead>
<tr>
<th>Top 5 Radiology Journals (# of studies)</th>
<th>Top 5 Medical Journals</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Journal of Roentgenology (22)</td>
<td>19 studies within various journals; no single journal in prominence.</td>
</tr>
<tr>
<td>European Radiology (21)</td>
<td></td>
</tr>
<tr>
<td>Journal of Computer Assisted Tomography (17)</td>
<td></td>
</tr>
<tr>
<td>European Journal of Radiology (15)</td>
<td></td>
</tr>
<tr>
<td>The International Journal of Cardiovascular Imaging (13)</td>
<td></td>
</tr>
</tbody>
</table>
**Fig. 1:** Reformatted ultra-low-dose chest computed tomography (CT) coronal (A) and axial (B) in a 24 year old male patient to investigate a suspected nodular opacity at the lung base (arrow). - Pictured study: dose-length product (DLP) = 26 mGycm | effective dose (ED) = 0.52 mSv - Average CT chest ED reported in 2008: 7 mSv [8] - Average chest radiograph ED reported in 2008: 0.1 mSv [8]

Fig. 2: Ultra-low-dose abdominal computed tomography (CT) with oral contrast in 24-year-old female with suspected appendicitis. Coronal image (A) demonstrates a normal appendix (arrow). Sagittal reconstruction (B) shows that the osseous and soft tissue structures in lumbar spine are well depicted. - Pictured study: dose-length product (DLP) = 35 mGycm | effective dose (ED) = 0.56 mSv - Average CT abdomen ED reported in 2008: 8 mSv [8] - Average abdominal radiograph ED reported in 2008: 0.7 mSv [8]

Fig. 3: Ultra-low-dose functional coronary CTA in a 30 year old female with chest pain and atrial fibrillation. Reconstruction of coronary vessels throughout cardiac cycle shown: curved planar reformatted images, demonstrating no plaque in the right coronary artery (RCA) (A) and in the left anterior descending (LAD) (B). - Pictured study: dose-length product (DLP) = 50 mGycm | effective dose (ED) = 1 mSv - Average coronary angiography ED reported in 2008: 16 mSv [8] - Average chest CT ED reported in 2008: 7 mSv [8]


Fig. 4: Ultra-low-dose, noncontrast, abdominal computed tomography (CT) in a 22 year old female scheduled to undergo shock wave lithotripsy for a known left intrarenal
calculus, where the nonobstructing calculus is clearly demonstrated (arrows). - Pictured study: dose-length product (DLP) = 27 mGycm | effective dose (ED) = 0.4 mSv - Average CT abdomen ED reported in 2008: 8 mSv [8] - Average abdominal radiograph ED reported in 2008: 0.7 mSv [8]

Conclusion

DISCUSSION

The results that have been gathered in this study (Table 1 on page 16) are a representative sample which illustrate the significant and unanimous decreases in radiation doses used in various CT procedures achieved in the past 3-4 years (2011-2014): **63.6-78.8% reductions in ED observed for every body part** (see Fig. 1 on page 13, Fig. 2 on page 13, Fig. 3 on page 14, Fig. 4 on page 15 for examples of low dose images). The latter is in comparison to the last procedure-specific comprehensive review completed in 2008 by Mettler et al. [8] (please see Table 2 on page 16 for comparative values). Technological improvements in CT scanners have majorly contributed to this reduction in radiation doses. Despite the clinical significance of ED, the vast majority of these studies have been published in radiology specific journals where only 19 out of the total 168 studies have been published in various non-radiology journals, typically specialty-specific ones (e.g. cardiology, hepatology) (Table 3 on page 16).

The precise values of this study are to be used with caution. They are obtained from studies with variable levels of quality and quantity, utilizing different sets of references and targeted towards measuring various clinical entities, although all with a purpose of assessing CT radiation dose reductions in the clinical setting. Numerous averaged coefficient factors (ED/DLP) exist, of which the most recent include works by Huda et al. and Deak et al. [1, 9, 10, 171]. However it is not rare to see the higher expressed value of the range to be the double of the lower one (e.g. ED/DLP ranging from 0.0145 - 0.033 mSv/mGycm for CT chest alone) [171]. This can be explained by the various older scanner models which were used to obtain those values, but also by sex differences being compounded into a single value: conversion factors for women phantoms are 76% higher for chest due to higher radiosensitivity of the breast tissue [1]. Or for instance, coefficient factors can be up to 33% lower when comparing current International Commission of Radiological Protection (ICRP) 103 to the outdated ICRP 60 values [1]. In sum, all of these can explain the large variations in ED that can be observed in the current study.

LIMITATIONS

Furthermore, ED in of itself has many limitations, despite being the clinically referenced tool to represent the stochastic effects of ionizing radiation for potential detriment and cancer risk [8]. For instance, there is a relative uncertainty of +/- 40% associated with a reference patient where the variation for each patient is even greater [172]. In the end, effective dose is not a precise value and should be used for indicative purposes, however,
as illustrated in this study, its unanimous decrease in all bodily locations coupled with technological advances indisputably communicates that lower CT radiation dosages per procedure have recently been required clinically.

CONCLUSION

In conclusion, with percent reductions between 60-80% in every subgroup analysis, it is undeniable that the necessary CT radiation dose in the clinical setting has drastically decreased. It is our hopes that this comprehensive review can preliminarily become the new reference material upon which clinicians refer to when facing decisions involving ionizing radiation, as in the interim, multiple-source and dual-energy CT [6], amongst many others, continue paving the way towards lower and lower radiation doses.
Fig. 1: Reformatted ultra-low-dose chest computed tomography (CT) coronal (A) and axial (B) in a 24 year old male patient to investigate a suspected nodular opacity at the lung base (arrow). - Pictured study: dose-length product (DLP) = 26 mGy/cm | effective dose (ED) = 0.52 mSv - Average CT chest ED reported in 2008: 7 mSv [8] - Average chest radiograph ED reported in 2008: 0.1 mSv [8]

Fig. 2: Ultra-low-dose abdominal computed tomography (CT) with oral contrast in 24-year-old female with suspected appendicitis. Coronal image (A) demonstrates a normal appendix (arrow). Sagittal reconstruction (B) shows that the osseous and soft tissue structures in lumbar spine are well depicted. - Pictured study: dose-length product (DLP) = 35 mGycm | effective dose (ED) = 0.56 mSv - Average CT abdomen ED reported in 2008: 8 mSv [8] - Average abdominal radiograph ED reported in 2008: 0.7 mSv [8]
**Fig. 3:** Ultra-low-dose functional coronary CTA in a 30 year old female with chest pain and atrial fibrillation. Reconstruction of coronary vessels throughout cardiac cycle shown: curved planar reformatted images, demonstrating no plaque in the right coronary artery (RCA) (A) and in the left anterior descending (LAD) (B). - Pictured study: dose-length product (DLP) = 50 mGycm | effective dose (ED) = 1 mSv - Average coronary angiography ED reported in 2008: 16 mSv [8] - Average chest CT ED reported in 2008: 7 mSv [8]


**Fig. 4:** Ultra-low-dose, noncontrast, abdominal computed tomography (CT) in a 22 year old female scheduled to undergo shock wave lithotripsy for a known left intrarenal
calculus, where the nonobstructing calculus is clearly demonstrated (arrows). - Pictured study: dose-length product (DLP) = 27 mGycm | effective dose (ED) = 0.4 mSv - Average CT abdomen ED reported in 2008: 8 mSv [8] - Average abdominal radiograph ED reported in 2008: 0.7 mSv [8]


<table>
<thead>
<tr>
<th>Table 1: Adult Effective Doses for Various CT Procedures (3, 11-170)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Studies</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Chest (Fig. 1)</td>
</tr>
<tr>
<td>Abdomen/Pelvis (Fig. 2)</td>
</tr>
<tr>
<td>Chest/Abdomen/Pelvis (Fig. 2)</td>
</tr>
<tr>
<td>Cardiac (Fig. 3)</td>
</tr>
<tr>
<td>KUB (Fig. 4)</td>
</tr>
</tbody>
</table>

Table 1: Adult Effective Doses for Various CT Procedures [3, 11-170]

© Department of Radiology, Vancouver General Hospital, University of British Columbia, Vancouver, Canada

<table>
<thead>
<tr>
<th>Table 2: Comparison with Previous Comprehensive Review (Mettler et al) (8) of Adult Effective Doses for Various CT Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Our Study (mSv)</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Chest</td>
</tr>
<tr>
<td>Abdomen/Pelvis</td>
</tr>
<tr>
<td>Chest/Abdomen/Pelvis</td>
</tr>
<tr>
<td>Cardiac</td>
</tr>
<tr>
<td>KUB</td>
</tr>
</tbody>
</table>

Table 2: Comparison with Previous Comprehensive Review (Mettler et al.) [8] of Adult Effective Doses for Various CT Procedures

© Department of Radiology, Vancouver General Hospital, University of British Columbia, Vancouver, Canada
### Table 3: Journals with Highest Source of Study Articles

<table>
<thead>
<tr>
<th>Top 5 Radiology Journals (# of studies)</th>
<th>Top 5 Medical Journals</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Journal of Roentgenology (22)</td>
<td>19 studies within various journals; no single journal in prominence.</td>
</tr>
<tr>
<td>European Radiology (21)</td>
<td></td>
</tr>
<tr>
<td>Journal of Computer Assisted Tomography (17)</td>
<td></td>
</tr>
<tr>
<td>European Journal of Radiology (15)</td>
<td></td>
</tr>
<tr>
<td>The International Journal of Cardiovascular Imaging (13)</td>
<td></td>
</tr>
</tbody>
</table>
References


151. Neroladaki A, Botsikas D, Boudabbous S, Becker CD, Montet X. Computed tomography of the chest with model-based iterative reconstruction using a radiation


172. Martin C. Effective dose: how should it be applied to medical exposures? The British journal of radiology. 2014.