Use of Effective Dose in Medical Imaging: What the International Commission on Radiological Imaging Says NOT to Do

JA Christner, PhD, JM Koller, Jr, PhD, GM Sturchio, PhD, S Leng, PhD, L Yu, PhD, JG Fletcher, MD and CH McCollough, PhD
ICT Clinical Innovation Center, Department of Radiology and Division of Preventative, Occupational, and Aerospace Medicine, Department of Medicine

Mayo Clinic, Rochester, MN

Purpose
To describe the concept and operational definitions for Effective Dose (E), as developed by the International Commission on Radiological Protection (ICRP), in particular noting that in the context of medical imaging, the ICRP strongly discourages use of E for quantifying patient dose, assessing patient risk or performing epidemiological studies.

Definition and Determination of E

ICRP definition of E: “Effective dose is a calculated quantity that reflects the radiation detriment from nonuniform exposure in terms of an equivalent whole body exposure (ICRP, 1991).”

Calculation of E: To calculate $E$, the absorbed doses to tissues and organs of the Reference Male and Reference Female phantoms must first be determined ($E_{\text{RM}, \text{RF}}$). This requires use of Monte Carlo simulation tools that accurately model the radiation exposure conditions.

The estimated doses to the Reference Male and Reference Female phantoms are averaged to obtain absorbed dose to tissues and organs of the Reference Person, and these values multiplied by a radiation weighting factor ($w_T$) of 1 (for $x$-rays) to obtain an equivalent dose ($E$). Each equivalent dose is multiplied by the specified tissue weighting factor ($w_T$), and these values summed to calculate $E$.

The fundamental measurable quantity of the amount of ionizing radiation absorbed in matter is absorbed dose. It measures the energy deposited in a material as a result of ionization. Dose is used to determine the radiation exposure of the public, including children.

Units: The SI unit of absorbed dose is the Gray (Gy). The SI unit of equivalent dose is the Sievert (Sv). These units are based on the same definition of the amount of ionizing radiation absorbed in matter, but the absorbed dose unit is weighted to consider the different radiobiological effects of different types of ionizing radiation.

Calculation of E:
$E = \sum (x_i \times w_T)$

where:
- $x_i$ is the absorbed dose to tissue $i$
- $w_T$ is the tissue weighting factor for tissue $i$

Note: The ICRP defined $w_T$ values differ over time. The most significant changes were in the breast weighting factor being first decreased and then increased. In all cases, the sum of all specified $w_T$ values equals 1.

E is NOT for use in occupational radiation protection:

103B 15”) “The tissue weighting factors, $w_T$, are not averaged and are for the assessment of effective dose for as well as members of the public, including children.”

103B 25)” “...the dosimetric models, conversion coefficients, and other parameters used in the procedures... are radiobiologically and statistically appropriate for the purpose of averaging over age, sex and populations to determine the radiation protection.”

103B 10)” “Effective dose... has been implemented into legislation and regulations in many countries worldwide. It has been shown to provide a practicable approach to the management and limitation of radiation risk in relation to both occupational exposures and exposures of the general public.”

E can be used in medicine to compare diagnostic exams but otherwise is not suitable for risk estimation:

103B101)” “Effective dose is used to show... from whole and partial body exposure from external radiation of various types to different body regions.”

103B340)” Effective dose can be used to compare the relative radiation from different diagnostic procedures and for comparing the use of similar diagnostic procedures in different hospitals and countries as well as the use of different technologies for the same medical examination, to determine the radiation protection of patients or natural populations, as well as for epidemiological studies, for comparing the rate of cancer induction in exposed individuals.”

E is NOT for use with reference to any one individual:

103B10)” “Effective dose is calculated for a Reference Person and not for an individual.”

103B 27)” “E should not be used for epidemiological studies, and it is inappropriate to use it in risk projections. This is because it does not reflect the true biological significance of the individual’s absorbed dose to the individual’s tissues or organs.”

103B44)” “The assumption is made in the calculation of effective dose... (for which the effective dose is derived) can be quite different from the overall age distribution for the patients undergoing medical procedures.”

103B 128)” “...nominal risk coefficients should be applied to whole body exposure, and not to individuals.”

103B 163)” “Effective dose is NOT for use with reference to any one individual.”

References and Footnotes

Table 1. How many times did ICRP 103 say it?

<table>
<thead>
<tr>
<th>Section Number</th>
<th>Title</th>
<th>“E is for Reference Person”</th>
<th>“E is NOT for risk to an Individual”</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Aims and Scope</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Executives Summary</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Annex A</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Annex B</td>
<td>26</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td>20</td>
<td>16</td>
</tr>
</tbody>
</table>

The main topic of Annex A is how the ICRP averaged over age, sex and populations to determine the radiation and tissue weighting factors. In addition, there is a direct statement that E is NOT for risk to an individual.

E is NOT for use with reference to any one individual:

103B10)” “Effective dose is calculated for a Reference Person and not for an individual.”

103B 27)” “E should not be used for epidemiological studies.”

103B11)” “Collective effective dose is an instrument for optimization, for comparing radiological technologies and protection procedures. Collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections. This is because - the assumptions implicit in the calculation of collective effective dose... (for which the collective effective dose is derived) can be quite different from the overall age distribution for the patients undergoing medical procedures.”

E is NOT to be used for estimating potential numbers of cancers from small doses in a large population:

103B10)” “Collective effective dose is not intended as a tool for epidemiological risk assessment.”

103B 25)” “In conclusion, the reference models and their parameter values... should NOT be used for individual risk estimates or for epidemiological studies. This limitation of usage applies based on collective effective dose were never intended, are biologically and statistically very inaccurate, presuppose a number of factors that are not realistic when estimates are quoted out of context, and are an incorrect use of this protection quantity.”