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

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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 of a non-uniform exposure in terms of an equivalent whole body exposure (ICRP, 1991)"[1].

Calculation of E: To calculate E[2-4], the absorbed doses to tissues and organs of the Reference Male and Reference Female phantoms must first be determined (**Fig.1**). This requires use of Monte Carlo simulation tools that accurately model the radiation exposure conditions[5-7]. The estimated doses to the *Reference Male* and *Reference Female* phantoms are averaged to obtain absorbed doses to tissues and organs of the *Reference Person*, and these values multiplied by a radiation weighting factor (w_R) of 1 (for x-rays) to obtain *equivalent doses*. Each equivalent dose is multiplied by the specified tissue weighting factor (w_T), and these values summed to calculate E.

Units: The fundamental measurable quantity of the amount of ionizing radiation absorbed in matter is *absorbed dose*. It measures the energy deposited in a specified mass of material and is expressed in Gray (1 Gy). Because w_R and w_T involve judgments regarding the biological detriment of a given absorbed dose, E is not a measurable quantity; its units are Sieverts (Sv).

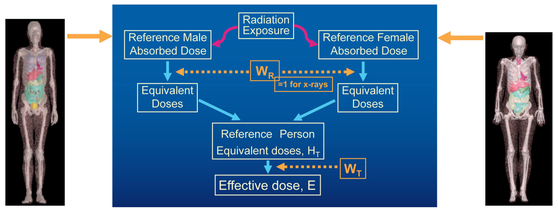

Figure 1: Diagram illustrating the determination of E, as specified in ICRP 103[4], and the ICRP Reference Male and Reference Female computational phantoms[8] defined in ICRP 110[9].

Tissue weighting factors (w_T) and their evolution over time: The ICRP has specified three sets of w_T (**Fig. 2**)[2-4], the most recent in 2007[4]. In each case, w_T were primarily based on data for the Japanese atomic bomb survivors and used data averaged over both genders and all ages. In all cases, the sum of the w_T over the specified set of sensitive tissues and organs equaled 1. However, the sets of specified tissues and organs, and methods used to determine w_T have changed over time. The most significant changes were in ICRP 60[3] where w_T additionally "took into account the severity of disease and years of life lost in determining total radiation detriment"[4(B20)] and in ICRP 103[4], where the risk of cancer incidence was used instead of the risk of cancer mortality, while continuing to account for "detriment."

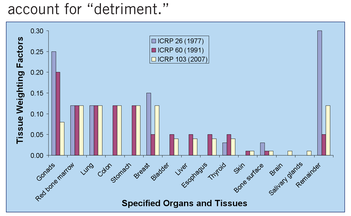

Figure 2: Evolution [10-11] of tissue weighting factors (w_T) specified by the ICRP[2-4]. Over time, 1) the relative importance of gonads was decreased; 2) the number of specified tissues increased, which caused the remainder weighting factor to decrease; and 3) the breast weighting factor was first decreased and then increased. In all cases, the sum of all specified w_T values equaled 1.

Select Quotations on How to Use E*

E is for use in occupational radiation protection:

103(B 135) "The tissue weighting factors, w_T, are sex-averaged and are for the assessment of effective dose for workers as well as members of the public, including children."

103(k) "The collective effective dose quantity is an instrument for optimisation, for comparing radiological technologies and protection procedures, predominantly in the context of occupational exposure."

103(B 251) "…the dosimetric models, conversion coefficients, and other parameters recommended by the Commission have been developed principally and primarily for planning and assessing normal occupational exposures, for planning for discharges into the environment and for generic assessments of doses. They are needed to demonstrate compliance with dose limits."

103(B 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 relevant for risk estimation:

103(101) "…effective dose…has enabled doses to be summed from whole and partial body exposure from external radiation of various types and from intakes of radionuclides."

103(340) "Effective dose can be of value for comparing the relative doses from different diagnostic procedures and for comparing the use of similar technologies and procedures in different hospitals and countries as well as the use of different technologies for the same medical examination, provided that the reference patient or patient populations are similar with regard to age and sex."

103(B 220) "The use of effective dose for assessing the exposure of patients has severe limitations that must be taken into account by medical professionals. Effective dose can be of value for comparing doses from different diagnostic procedures – and in a few special cases from therapeutic procedures – and for comparing the use of similar technologies and procedures in different hospitals and countries as well as using different technologies for the same medical examination…. For planning the exposure of patients and risk-benefit assessments, however, the equivalent dose or preferably the absorbed dose to irradiated tissues is the more relevant quantity. This is especially the case when risk estimates are intended."

Select Quotations on How NOT to Use E*

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

103(i) "Effective dose is calculated for a Reference Person and not for an individual."

103(B d) "The w_T values are age- and sex-averaged. Therefore E is not calculated for an individual but for a Reference Person…The new sex-specific computational models allow the calculation of male and female organ doses separately, from which the averaged equivalent organ doses are calculated. These are used for the calculation of E."

103(B h) "E is calculated on the basis of reference values for a Reference Person. The weighting factors are selected from a range of experimental and epidemiological data by judgement, and they apply to a population of all ages and both sexes."

103(81) "…nominal risk coefficients should be applied to whole populations and not to individuals."

103(157) "Effective dose is…not recommended… for detailed specific retrospective investigations of individual exposure and risk….Organ or tissue doses, not effective doses, are required for assessing the probability of cancer induction in exposed individuals."

103(340) "The age distributions for workers and the general population (for which the effective dose is derived) can be quite different from the overall age distribution for the patients undergoing medical procedures using ionising radiation… For these reasons, risk assessment for medical diagnosis… using ionising radiation is best evaluated using appropriate risk values for the individual tissues at risk and for the age and sex distribution of the individuals undergoing the medical procedures."

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

103(k) "Collective effective dose is not intended as a tool for epidemiological risk assessment, and it is inappropriate to use it in risk projections. …in particular, the calculation of the number of cancer deaths based on collective effective doses from trivial individual doses should be avoided."

103(66) "Because of this uncertainty on health effects at low doses, the Commission judges that it is not appropriate, for the purposes of public health planning, to calculate the hypothetical number of cases of cancer or heritable disease that might be associated with very small radiation doses received by large numbers of people over very long periods of time."

103(161) "Collective effective dose is an instrument for optimisation, 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 (e.g., when applying the [Linear-No-Threshold] LNT model) conceal large biological and statistical uncertainties. Specifically, the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided. Such computations based on collective effective dose were never intended, are biologically and statistically very uncertain, presuppose a number of caveats that tend not to be repeated when estimates are quoted out of context, and are an incorrect use of this protection quantity."

103(B h) "E should not be used for epidemiological studies."

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

The ICRP repeated these primary points many times and in many sections.

Section Number & Title	"E is for Reference Person"	"E is NOT for risk to an individual"	"E is NOT for epidemiology"
Executive Summary	1	2	2
2. Aims and Scope	1	2	2
3. Biological Aspects		1	1
4. Quantities Used	8	5	2
5. System of Protection	1		1
7. Medical Exposures		1	
Annex A		1+	
Annex B	26	8	8
Total	**37**	**20++**	**16**

\+ 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.

++ 9 additional unique statements that E is not for any one individual that did not specifically mention risk.

Conclusions

103(B 252) "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 particularly to effective dose. For the assessment and judgement of individual cases absorbed doses to organs or tissues should be used…"

References and Footnotes

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*Quotations are from IRCP Publication 103[4] with paragraph number given in parentheses.

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