ICRP proposals for the application of effective dose in medicine

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ICRP
ICRP proposals for the application of effective dose

- Explanation of effective dose
- Health effects - use of LNT model
- Dosimetry - discontinuing use of equivalent dose for monitoring tissue reactions
- Occupational and public exposure
- Medical exposures – uncertainties and risks
Effective Dose

Attempt to have a dose quantity related to risk

- Uniform whole body dose with similar health detriment
- Sum of equivalent doses ($H_T$) to each radiosensitive tissue ($T$) multiplied by a tissue weighting factor ($w_T$) related to radiosensitivity

$$\text{Effective dose} = \sum w_T H_T$$
Organs at risk from radiation

Higher incidences of cancer can be differentiated for certain tissues

Head – low risk
Thorax – higher risk
Abdomen – higher risk

- Higher cancer risk
- Medium cancer risk
- Low cancer risk
- Gonads genetic effects
Effective Dose

- Effective dose has been developed as a dose quantity related to health detriment
- Calculated for reference persons using a set of male and female phantoms for ages from newborn to adult
- Not a scientific measure of dose, but a radiation protection quantity
The linear no-threshold model is used to calculate the probability of radiation induced cancer. The model assumes that the lifetime risk of cancer is directly proportional to the dose. This allows the summation of doses from all radiation exposure.
Scientific basis for the LNT Model
Extrapolation of dose - response data for the Japanese atomic bomb survivors

The “Gold Standard”
A-bomb Survivor dose data

Dose range we are interested in for medical imaging

We have to acknowledge that there are large uncertainties
Relative Risk per Gy for cancer excluding leukemia

INWORKS (UK, US, French combined cohorts)

Mortality Follow-up 1944-2005 N = 19,064

Richardson et al, BMJ 2015

► ERR per Gy = 0.48; 90% CI [0.20 – 0.79]
► No indication of non linearity

Note: The number of cancers in the lowest dose category (10,433 deaths) has not been annotated on this figure for reasons of legibility.

Acknowledgement to Laurier D Stockholm ICRP Committee 1
NCRP Commentary No. 27 analysed 29 studies

11 larger, stronger studies broadly supported an LNT model. 9 gave weak to moderate support to LNT. 9 provided no support or data were considered inconclusive.

Relative risk of colon cancer over restricted dose ranges

Linear trend still has borderline significance when cumulative doses above 100 mSv are excluded

Richardson et al. BMJ 2015

Acknowledgement to Laurier D Stockholm
ICRP Committee 1
System of Dosimetry for calculating effective dose

**Equivalent dose**

\[ H_T = \sum_R w_R D_{T,R} \]

- \( w_R \) = radiation weighting factor for Radiation R
- \( D_{T,R} \) = mean dose to tissue T from Radiation R

**Effective dose**

\[ E = \sum_T w_T H_T \]

- \( w_T \) = tissue weighting factor for tissue T

- Equivalent doses to internal organs (breast or thyroid) and effective dose (whole body) are expressed in Sv
- Provide dose quantities relating to stochastic effects
Proposal for reviewing use of equivalent dose

- The term equivalent dose is also used to describe dose to the skin, which is averaged over 1 cm\(^2\), and again is expressed in Sv in the current system.
- The skin dose is assessed in a very different way and relates to tissue reactions or deterministic effects.
- It is proposed that for dose limits relating to tissue reactions, **equivalent dose** should be replaced with **mean absorbed dose** in Gy.
Proposed system for dosimetry relating to effects

- Limits applying to tissue reactions, set in terms of absorbed dose (Gy).
- Limits applying to stochastic effects, set in terms of effective dose (Sv).
Sex-averaging in calculation of effective dose using ICRP reference phantoms

Radionuclide intake or external exposure

Male phantom doses $D_T^M$

Equivalent doses $H_T^M$

Female phantom doses $D_T^F$

Equivalent doses $H_T^F$

Sex average equivalent doses $H_T$

Effective dose $E$
Occupational and Public exposure
Use of effective dose

- **Prospective** - Assessments used for optimisation of radiological protection and to ensure that operations will be carried out within relevant dose constraints.

- **Retrospective** – Dose monitoring in planned exposure situations used to demonstrate that systems of protection have been implemented adequately and compliance with regulations.
Uses of collective effective dose

Occupational exposure:
- Determine optimum balance between larger exposures to a few workers and smaller exposures to a larger nos. of workers

Public exposures:
- Optimisation of planned, existing, or emergency exposures.
- Comparison of radiological impact of different sources of exposure.

Medical exposure:
- Evaluating level of exposure in different countries and for deriving population doses per caput.
Medical exposures

- Stochastic risks vary according to the organs and tissues irradiated in different medical procedures.
- Measurable dose quantities cannot provide a meaningful indication of the relative health risks.
- Effective dose can be used for comparing doses from medical procedures in terms of health risk.
- Users should be aware of the uncertainties in any associated risk calculations.
Scientific basis for radiation standards

Problem with the LNT model

The “Gold Standard”
A-bomb Survivors

We are more uncertain of the dose response below 50-100 mSv

While low doses may be estimated with reasonable reliability, the associated cancer risk is uncertain.
Effective Dose

Effective Dose = \( \sum w_T H_T \)

\( H_T \) = Equivalent dose to tissue \( t \), \( w_T \) = tissue weighting factor

Tissues weighted according to sensitivity to ionising radiation

- **Higher cancer risk**
  - Bone marrow, Colon, lung, Stomach, Breast

- **Medium cancer risk**
  - Bladder, Oesophagus, Liver, Thyroid

- **Low cancer risk**
  - Brain, Salivary Glands, Remainder tissues

- **Gonads genetic effects**
Tissue Weighting factors
ICRP 103

Related to overall age- and sex- averaged detriment of \(7.2 \times 10^{-2} / \text{Sv}\) : rounded from relative detriment

<table>
<thead>
<tr>
<th>Tissue</th>
<th>(W_T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone-marrow, Colon, Lung, Stomach, Breast</td>
<td>0.12</td>
</tr>
<tr>
<td>Gonads</td>
<td>0.08</td>
</tr>
<tr>
<td>Bladder, Oesophagus, Liver, Thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>Bone surface, Skin, Brain, Salivary Glands</td>
<td>0.01</td>
</tr>
<tr>
<td>Remainder tissues*</td>
<td>0.12</td>
</tr>
</tbody>
</table>

*Remainder Tissues: Mean of doses to Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (♂), Small intestine, Spleen, Thymus, Uterus/cervix (♀).
Evaluation of effective dose

Generic values for a reference person

Effective doses for imaging examinations can be derived from measured quantities using coefficients:

- Entrance surface air kerma ($K_{a,e}$) or Kerma-area product ($P_{KA}$) for radiography and fluoroscopy
- Volume averaged CT dose index ($CTD_{vol}$) and dose length product (DLP) for computed tomography
- Administered activity for nuclear medicine

These provide straightforward tools with enough information about radiation exposure levels linked to detriment for making everyday decisions.
Calculation of Effective Dose

There are inherent uncertainties in the Monte Carlo computer calculations

- Organ shape and geometry ±40%
- Doses to organs within X-ray beam ±15%
- Doses to organs partially in X-ray beam ±40%
- Dose transit time curves for radionuclides in individual organs ±20%-60%
- Accuracy of effective dose is to nearest ±50% as a relative indicator of risk
Effective dose should only be quoted to:

One significant figure for values less than 1 mSv

Two significant figures for values above 1 mSv.
Decisions in medicine based on effective dose

Referral guidelines and justification of procedures

Justification is determined by the need for diagnostic information. Benefit for the patient should be balanced against potential risk from radiation exposure. Effective dose can provide sufficient information for the assessment. Clinicians should also take account of sex, age, medical risk of the disease, and life expectancy of the patient.

Choice of imaging technique

Effective dose enables straightforward comparisons of doses for procedures with different dose distributions.
Medical applications of effective dose

**Research studies:** Summing the doses that may accrue from procedures performed. (The age, sex and health of participants must also be taken into account)

**Optimisation of technique:** Where distribution of dose within body is different (e.g. selection of kV or filtration)

Relative changes take account of depths for sensitive organs.
Medical applications of effective dose

- **Reporting of unintended exposures:** Where the dose level is low, an assessment of detriment in terms of effective dose will usually be sufficient (up to 10s mSv)

- **Evaluating efficacy of imaging for health screening** for procedures that involve exposure of many organs within the trunk (N.B. not mammography) and for evaluating doses from dual x-ray absorption (DXA)

- **Doses to carers:** Incurred knowingly and willingly by individuals helping in the support and comfort of patients undergoing diagnosis or treatment
Communication of radiation dose / risk

Clinicians need language to describe radiation dose that reflects a broad perspective of risk

- Effective dose to a reference person can be used as an approximate indicator for risk communication
- Effective dose is a single dose value which can be used to compare different exposure scenarios
- Typical effective doses from common procedures can be included in the education and training of medical practitioners
Applications for which effective dose is not recommended

where measurable dose quantities: $K_{a,e}$ & KAP or $P_{KA}$ for radiography; CTDI$_{vol}$ & DLP for CT should be used.

Simple measures for records without any adjustment:

- Comparison of doses for similar techniques and setting DRLs
- Recording patient dose information in reports:
  Patient exposure for medical radiological procedures, as required by EURATOM 59/2013
- Tracking of patient doses: Calculations of organ and effective dose can aid summation of doses and understanding of potential risks for individual patients.
Applications for which effective dose is not recommended

Assessment of doses where only one organ is exposed
Doses from mammography of the breast, or imaging procedures involving radioiodine uptake by the thyroid should be quoted in terms of estimates of absorbed dose to the organ or tissue exposed
Variation of incidence of solid cancer with sex and age at exposure

Tables of lifetime attributable risks of incidence of solid cancers from uniform whole body exposures
Variation of cancer incidence with sex and age at exposure

Tables of lifetime attributable risks of cancer incidence from exposures of sensitive organs are included in report

Examples of how risk varies with sex and age at exposure
Risks of cancer from x-ray examinations

Lifetime risk of cancer incidence per unit effective dose for some x-ray examinations as a function of age at exposure and sex. These curves show the range of values for different exams.

- Risk estimate could be 3 times higher or lower than a calculation based on organ doses for an individual.
- It would be within about ±50% for adults between 25 and 65.
Effective Dose and Risk

The estimates of cancer risk derived from effective dose are not accurate – approximate indicator

- Numerical risk estimates are rough and are not adjusted for difference due to sex and age-at-exposure
Dose ranges and terminology for describing risks from medical procedures for adult patients age 30 y - 39 y

<table>
<thead>
<tr>
<th>Effective dose (mSv)</th>
<th>Risk of cancer</th>
<th>Risk term</th>
<th>Examples of medical radiation procedures within different dose categories&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.1</td>
<td>No direct evidence</td>
<td>Negligible</td>
<td>Radiographs of chest, femur, shoulder limbs, neck, and teeth.</td>
</tr>
<tr>
<td>0.1–1</td>
<td>No direct evidence</td>
<td>Minimal</td>
<td>Radiographs of spine, abdomen, pelvis, head and cervical spine.</td>
</tr>
<tr>
<td>1–10</td>
<td>No direct evidence</td>
<td>Very low</td>
<td>Barium meals, CT scans of head, chest, abdomen, and pelvis, barium enemas, cardiac angiography, interventional radiology;</td>
</tr>
<tr>
<td>10–100</td>
<td>10&lt;sup&gt;-3&lt;/sup&gt; – 10&lt;sup&gt;-2&lt;/sup&gt; based on LNT model&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low</td>
<td>CT scans of chest, abdomen, and pelvis, double CT scans for contrast enhancement, interventional radiology.</td>
</tr>
<tr>
<td>100s</td>
<td>&gt;10&lt;sup&gt;-2&lt;/sup&gt; from epidemiology&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Moderate</td>
<td>Multiple procedures and follow-up studies.</td>
</tr>
</tbody>
</table>

<sup>a</sup> Risk bands are lifetime detriment adjusted incidence to nearest order of magnitude.

<sup>b</sup> Effective doses based on UK for diagnostic procedures and ICRP (2010) for interventional radiology.
Effective dose gives a single dose quantity related to risk

- Mean absorbed dose should be used for tissue doses in relation to tissue reactions
- Effective dose is a useful indicator for level of harm from a dose received, but has inherent uncertainties
- Generic values of effective dose can be used in medical referral guidelines and justification, but the age, sex and health of the patient should be taken into account
Effective dose can be used in evaluating detriment in research studies, incident reporting, doses to carers.

Effective dose provides the best option for quantifying dose in explanations to clinicians and the public.

Measured quantities are preferred for comparing patient doses for similar techniques, setting DRLs, recording patient dose data in reports, or tracking patient doses.

Organ dose should be used where exposure is predominantly to one organ.

Risks should be described in general terms.
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Any questions?