Unit 3:
Radiation Doses and Effects
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Introduction

It is well known that high doses of radiation cause detrimental effects such as cancer, skin damage etc. The dose-risk relationship at the lower doses we are interested in are not certain and we therefore need to make assumptions. In order to quantify risk we also need to measure the radiation dose itself in a standardised manner.

The doses received from a mini “C” arm image intensifier in normal usage are generally low. However, we are required to consider the effects of accidental exposures that can be significant. This unit will discuss the concepts of radiation dose that we use and the units in which they are measured. We will look briefly at measurement of dose and quantification of risk. There will be a broad discussion of biological effects based on “low, medium and high” doses.

Learning outcomes

After your study of this unit you should be able to apply:

- The concepts of radiation dose used for protection of staff and patients
- The methods of measurement of dose and their limitations
- Understanding of the biological effects of ionising radiation at various doses.

References


National Protocol for patient dose measurements in diagnostic radiology. IPEM 1992. Published by NRPB.

Dose Concepts and Units

We normally talk about absorbed dose. This is a measure of the energy deposited by the radiation per unit mass of absorbing tissue. Absorbed Dose is measured in gray (Gy) (equivalent to joules per kilogram)

Some types of radiation do more damage than others for the same absorbed dose. For protection purposes therefore, we define the concept of equivalent dose, which is a measure of the biological damage from the radiation:

Equivalent Dose = Absorbed Dose X Radiation Weighting Factor (WR)

Equivalent Dose is measured in sievert (Sv) (also equivalent to joules per kilogram) Radiation Weighting Factor (WR) is a measure of the differing amounts of damage dose to tissue caused by different types of radiation:

(WR) = 1 for beta, gamma and X-rays.
(WR) = 20 for alphas

For our purposes therefore, Grays and Sieverts will have the same value as the Weighting factor for x-rays is 1. You will find doses expressed variously in Gy or Sv although these are large units and more likely to be found as milli- or micro- e.g. mGy or mSv.

Effective Dose (E) is defined because the probability of causing a stochastic effect as a result of an absorbed dose depends on the tissue irradiated. Some tissues are much more radiation sensitive than others so we have a series of Tissue Weighting factors (WT).

Effective dose therefore allows us to compare the detriment from irradiation of different areas of tissue and calculate the overall risk. Where more than one area is irradiated, we can add the contributions to give a total effective dose. Effective dose is the best overall measure of the risk from exposures to radiation and is used when considering either patient or staff doses. If you wear a radiation monitoring badge it will measure an estimate of effective dose as it is difficult to directly measure effective dose.

When patients are exposed to x-rays, the highest dose is to the skin where the x-rays enter the body. Entrance Surface Dose (ESD) was therefore defined in the national protocol for patient dose measurements in diagnostic radiology (the full scientific definition can be found in the IPEM National Protocol for dose measurement in diagnostic radiology!). Essentially it is a standardised measure of the dose to the patients skin where the x-rays enter. We need to take ESD into account as well as effective dose when considering patient exposure. It is normally expressed in mGy.

Dose-area product (DAP) is also defined in the national protocol for patient dose measurements in diagnostic radiology. It is usually expressed in Gy cm$^2$ (often it is in cGy cm$^2$ on instruments) and is a convenient way of measuring and comparing patient doses. It is possible that mini “C” arm image intensifiers could be fitted with DAP meters in the future.
Collective dose is used to express total doses for a selected population. It is the product of the sum of all the individual doses and the number of the sample taken. It is expressed in man Sv and is useful when comparing doses to groups of patients or populations and is often used in discussions in papers.

Screening time is often used on image intensifiers where no other means of measuring the dose is available. The screening time (dT) is displayed and needs to be reset at the beginning of each case.

**Measuring Patient Dose**

IRMER requires that we measure and record the dose to the patient for each examination. Most equipment is now fitted with dose measuring equipment but mini “C” arms are not generally suitable for fitting such equipment at present. In reality it is difficult to directly measure the patient dose and in most cases we use an indicator of dose. For work on extremities such as the hand or foot it is acceptable to record the screening time used; other exposure factors for extremity sites will not vary greatly from one patient to another. Also, screening time is a good indication of how well a procedure has gone i.e. a difficult case will take considerably more screening time than a simple one.

The screening time used should be recorded in the patient’s record along with a clinical evaluation of the procedure (see unit 1).

**Clinical Audit**

It is important to satisfy the Regulations (see unit 1) that periodic clinical audit of patients includes an evaluation of the role of the x-ray equipment. Examples are:

- Was the screening time reasonable for that type of procedure?
- Was the use of x-ray equipment essential?
- Can we reduce the screening time without detriment to the success of the procedure?
**Biological Effects of Radiation.**

**Definitions:**

Biological effects are classified as follows:

<table>
<thead>
<tr>
<th>Effect</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>Happen within a few days e.g. erythema.</td>
</tr>
<tr>
<td>Late</td>
<td>Happen some time later e.g. cancer induction.</td>
</tr>
<tr>
<td>Somatic</td>
<td>Affect only the irradiated person.</td>
</tr>
<tr>
<td>Genetic</td>
<td>Passed on to subsequent generations (genetic damage).</td>
</tr>
<tr>
<td>Stochastic</td>
<td>Probability of the effect occurring increases with dose e.g. cancer induction, genetic effects. Relationship assumed to be linear with dose and having no threshold. (see attached graphs).</td>
</tr>
<tr>
<td>Deterministic</td>
<td>The severity of the effect increases with dose but there may also be a threshold below which no effect is seen. e.g. cataracts, sterility. The relationship between dose and effect is assumed to be linear</td>
</tr>
</tbody>
</table>

With late effects it is often impossible to identify a radiation cause due to long lead times and other confounding factors such as natural occurrences etc. For this reason we try to minimise individual radiation exposures so as to reduce the overall lifetime risk.

**Low Dose Effects <100mSv effective dose**

These effects are usually invisible; normally a slightly increased risk of late effects e.g. general cancers and leukaemia. However it is impossible to determine individuals having radiation induced effects from those with natural incidence.

Latent periods can be 5 to 30 years making causes difficult to identify precisely. The exact relationship between dose and risk is unknown at low doses.

**Moderate Dose Effects 100mSv to 1Sv effective dose**

The effects are similar to those for low doses but with a higher risk. The dose – risk relationship appears to be linear. Also some non-stochastic effects may be seen e.g. transient erythema, cataracts.

Germinal cell damage may occur leading to a temporary depression of blood cell count and sterility. There is a risk of infection until the white cell levels recover.
**Assumed Dose/Effect Relation for Stochastic Effects**

The graphs show the assumed dose risk relationships: linear with no threshold for initiation of stochastic effects and linear with some threshold for the severity of deterministic effects.
High Dose Effects >1Sv effective dose

These effects are more severe and often fatal. Early effects dominate although late effects are likely after surviving high doses. Permanent damage occurs to germinal tissues, bone marrow is destroyed, and there is a high susceptibility to infection and disease. Symptoms of radiation sickness are seen: sickness, nausea, vomiting and diarrhoea. Permanent skin damage occurs with hair loss, bleeding gums and nails.

Above 5 Sv gastro-intestinal death occurs due to death of the gut tissue – villi die. Death is usually through infection.

Above 10 Sv survival is impossible.

At 20Sv death occurs due to damage to the brain and central nervous system.

Examples of deterministic effects

The lens of the eye is a sensitive organ and measurable opacity can be seen at doses as low as 300 mSv. Actual impairment of vision is unlikely below 1.5 Sv.

Skin erythema can be caused by doses in the region of 2 Sv with serious skin damage at about 10 times this value. Fluoroscopic procedures can give significant doses to the skin (measured as Entrance Surface Dose). This must be taken into account when restricting exposure times during patient procedures on a mini C arm even though doses are generally low. (See Unit 4 for factors affecting radiation dose).

Exposure to ionising radiation during pregnancy

Advice has been published by the Health Protection Agency (HPA), the purpose of which is:

- To prevent inadvertent exposure during diagnostic procedures before the pregnancy is declared.
- To reduce the exposure to the foetus when diagnostic radiology is clinically indicated.
- To avoid anxiety and unnecessary action if exposure does occur.

The advice considers the risk to the foetus/embryo of death, malformation, mental impairment, cancer and genetic damage.

Restrictions are not normally required when a woman of reproductive capacity presents for a diagnostic examination unless the primary beam irradiates the pelvic area (NRPB 1998).

However, it is important to provide reassurance to the patient as about 1 in 10 births is abnormal in some way and a radiation exposure may be blamed whether justifiably or not. It is therefore
advisable to provide e.g. lead rubber protection for the pelvic region for patients who are known to be pregnant, and for any women of reproductive capacity if they request it.

Dose Limits for Occupational Exposures from Ionising Radiations Regulations 1999

<table>
<thead>
<tr>
<th>Category</th>
<th>Whole Body Effective Dose (mSv)</th>
<th>Skin Equivalent Dose (mSv) (average over 1 cm²)</th>
<th>Hands Feet Forearms Ankles (mSv)</th>
<th>Eye Lens (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employees aged over 18 years</td>
<td>20</td>
<td>500</td>
<td>500</td>
<td>150</td>
</tr>
<tr>
<td>Trainees aged 16 - 18 years</td>
<td>6</td>
<td>150</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Any other person</td>
<td>1</td>
<td>50</td>
<td>50</td>
<td>15</td>
</tr>
</tbody>
</table>

Additional Notes:
Excludes doses “knowingly and willingly” received by comforters and carers.

Tissue Weighting Factors WT for Effective Dose from ICRP 60

<table>
<thead>
<tr>
<th>0.01</th>
<th>0.05</th>
<th>0.12</th>
<th>0.2</th>
</tr>
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<tbody>
<tr>
<td>Skin</td>
<td>Bladder</td>
<td>Red bone marrow</td>
<td>Gonads</td>
</tr>
<tr>
<td>Bone surfaces</td>
<td>Breast</td>
<td>Colon</td>
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<tr>
<td></td>
<td>Liver</td>
<td>Lung</td>
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<td></td>
<td>Oesophagus</td>
<td>Stomach</td>
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<td></td>
<td>Thyroid</td>
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<td></td>
<td>Remainder</td>
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Conclusion

You should now understand the different types of radiation exposures and dose concepts. This should allow you to apply them in your field of work.