Radiation safety for anaesthetists

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Key points

Anaesthetists regularly utilize ionizing radiation for diagnosis and interventions leading to significant levels of exposure.

Ionizing radiation can cause significant harm to patients and employees involved in its use.

The use of ionizing radiation is subject to statutory regulations enforceable under the Health and Safety Act.

All radiation exposure should be justified.

All radiation exposure should be as low as is practicable.

Anaesthetists are increasingly exposed to ionizing radiation while facilitating diagnosis and treatment in many settings. This can be as interventional practitioners, commonly in pain medicine, intensive care, and during vascular access procedures. A logical drive towards minimally invasive and safer interventions has led to an expansion in the use of fluoroscopy by a greater number of specialties including anaesthesia. In addition, better access to radiological services has increased to the point where X-rays can be performed in most clinical areas and CT scanning/fluoroscopy-guided interventions occur 24 h a day.

Unfortunately, this increase in exposure has not been paralleled by an increase in education about the safe use of ionizing radiation. It is important that anaesthetists do not rely on allied medical professionals to protect themselves and their patients from harm. When utilizing fluoroscopy, the anaesthetist should be aware of, and comply with the regulations surrounding the use of ionizing radiation and make the most effective use of the equipment to ensure exposure is kept as low as reasonably practicable (ALARP).

Radiobiology

Radiobiology links the physics of ionizing radiation to the biological impact of its interaction with living tissues. This is the basis for its therapeutic utilization but also harm.

Ionizing radiation consists of charged particles that influence the medium through which they pass by transfer of energy. Linear energy transfer (LET) is the term used to quantify this and is measured in kiloelectronvolts (keV) of energy transferred per micrometre (μm) of medium. X-rays and gamma rays used in radiotherapy have a relatively low LET compared with α-particles and neutrons generated by nuclear fission that have a high LET.

Radiation dosage is quantified using two SI units, Gray (Gy) and Sievert (Sv). Gray is a derived unit of absorbed radiation dose of ionizing radiation and is defined as the absorption of 1 J of ionizing radiation by 1 kg of matter. Sievert is a derived unit of dose equivalent radiation. In addition to representing the dose, the Sievert quantifies the biological effect of ionizing radiation by taking into account the energy of a particular radiation type when compared with gamma rays. Hence, 1 Sv is equal to 1 Gy multiplied by a weighting factor (Wg). In the case of X-ray, this factor is 1. Therefore, 1 Sv is equal to 1 Gy.

The action of ionizing radiation on tissues can either be direct or be indirect. Direct action is the predominant mechanism by which high LET radiation acts. Atoms and molecules become directly ionized or excited causing biological damage by a chain of physical and chemical events.

The predominant mechanism by which low LET radiation acts is indirect. Interaction between molecules and atoms and the radiation generates high energy electrons. These electrons collide with other molecules and produce free radicals. Free radicals then bring about biological damage through the disruption of DNA and the effect of this on cell fate (Fig. 1). 80% of the free radicals formed are derived from water, for example, water ions (H2O+) and hydroxyl radicals (OH-).

Cells undergoing the greatest rate of replication are the most vulnerable and so haemopoietic cells are affected first followed by reproductive and gastrointestinal cells, then nerve and muscle cells.

The clinical presentation of biological damage depends on its overall impact on an individual or their offspring. It varies with the temporal relationship to the radiation exposure and the dose delivered. Somatic effect refers to the effects of ionizing radiation on an individual. Genetic effect refers to the effects on their offspring as a result of mutations passed on via gametes. Such mutations increase the likelihood of congenital malformation or produce genomic instability leading to miscarriage or increased frequency of carcinogenesis. In utero exposure and its effects are similar but are considered somatic rather than genetic effects (Table 1).

Somatic effects can be acute or chronic. Acute effects present within hours, days, or...
weeks and are generally associated with exposure to high dose of radiation for a short duration. Chronic effects present over months or years and are generally associated with low doses of radiation over an extended period. High doses tend to cause cell death. If enough cells are involved, this leads to tissue and organ damage. Low doses tend to cause cell damage that either results in repair or carcinogenesis.

Acute exposure, especially to high LET radiation, affects the body in a pattern reflective of the dose and the relative sensitivity of the cell types. As the dose increases the impact on the haemopoietic system becomes more severe ranging from slight changes in blood count to immunosuppression and haemorrhage, then irreparable bone marrow destruction. Initial gastrointestinal (GI) upset becomes complete failure. At very high doses, there is central nervous system (CNS) failure with apnoea and cardiovascular collapse (Table 2).

Low LET such as X-ray and gamma rays at higher doses can produce cataracts (2 Gy), skin burns (3 Gy), sterility (4 Gy), and hair loss (5 Gy). Generally, such exposure occurs during radiotherapy. The higher dose exposures associated with significant probability of death would generally only occur in the healthcare setting as a result of occupational accidents or accidental overdose (Fig. 2).

Chronic radiation effects mirror those of chronic inflammation, namely fibrosis, atrophy, ulceration or stenosis, and occur as a result of direct exposure or loss of protective overlying structures (epidermis of mucosa). They may also present as cancer, most commonly acute or chronic myeloid leukaemia and solid tumours of the skin, bone, lung, thyroid, and breast (Table 3).

Finally, biological damage can be divided into manifestations which are dose-dependent, described as deterministic, and those independent of dose, described as stochastic. The increasing severity of haematological abnormality with increasing dose of radiation is an example of a deterministic effect, where the magnitude of damage is proportional to the dose. Commonly deterministic effects have a dose threshold whereupon sufficient cells are damaged to affect the integrity of a tissue or organ. The magnitude of a stochastic effect is independent of dose, although an increasing dose can increase the probability of occurrence. Carcinogenesis is an example of this. There is no threshold as these effects can occur with minimal exposure; only one cell need undergo neoplastic transformation to begin the development of cancer.1–3

**Regulations and safety**

The risk of diagnostic exposure has already been emphasized (Tables 1 and 2), but there is perhaps a misconception that fluoroscopy represents a relatively innocuous exposure. This is not the case and the risk therefore of injury is probably comparable with other
complications routinely presented during the consent process. There is also a not insignificant exposure to the physician. Generalizing about fluoroscopic radiation dosage is difficult because it can be influenced by many factors including the age, size, and body composition of the patient, the procedure and the technique, and experience of the physician, and also the beam magnification, distance of the patient from source and screening technique. An average quoted by the International Atomic Energy Agency (IAEA) is 30 mGy min$^{-1.4}$.

Taking pain procedures as an example, the average intervention (facet joint injections, caudal, lumbar epidurals, etc.) requires an exposure of between 13 and 80 s per patient.$^{5,6}$ This implies a dose of 6.5–40 mGy per patient. This is between half and four times the dose during an abdominal CT (lifetime cancer risk of 1 in 2000). The physician exposure outside the apron is 0.0134 mSv per patient.$^{5}$ This seems small but when taken in the context of a conservative eight patients per list, on two lists a week for 44 weeks per year the accumulative annual exposure is close to 1 CT abdomen per year. Beneath the lead apron, the dose is 0 mSv, emphasizing the need to wear protective clothing correctly.

With the potential magnitude of exposure and its biological consequence, there is a need for rationale and responsible use of ionizing radiation. There are two key regulations surrounding the use of ionizing radiation that are enforceable under the Health and Safety Act 1974. Failure to comply can result in prosecution under this act. The first Ionising Radiation Regulation 1999 (IRR99)$^{7}$ refers to conduct of a radiation employer and its employees while utilizing ionizing radiation. The second, the Ionising Radiation (Medical Exposure) Regulations 2000 (IRMER),$^{8}$ apply specifically to conduct during medical exposure in its various forms; those being medical diagnosis and treatment, occupational health surveillance, health screening programmes, research, and medic-legal procedures. The main aim of both regulations is to ensure that exposure to ionizing radiation is kept ALARP.

To achieve this, the legislation clearly prescribes the responsibilities of the individuals involved in the pathway to diagnostic or therapeutic exposure; provides a framework to justify exposure; and if justified outlines how this can be delivered with minimal hazard to the patient or employees.

There are three individuals identified, the referrer, the practitioner, and the operator. The referrer is a registered medical practitioner, dental practitioner, or other healthcare professional entitled in accordance with the employer’s procedures to refer an individual for medical exposure to a practitioner. Their duties under the regulations are to supply the practitioner with sufficient medical data relevant to the medical exposure requested, to enable them to decide whether there is sufficient net benefit. This is our principal role as anaesthetists, even when we are performing interventions. The practitioner is a registered medical practitioner, dental practitioner, or other healthcare professional entitled in accordance with the employer’s procedures to take responsibility for an individual exposure. They are responsible for the justification of exposure. The operator is a person who is entitled in accordance with the employers procedures to carry out the practical aspects and has responsibility for this. Practitioners are usually radiologists and operators radiographers. However, in theatre, radiographers can take on both roles while providing fluoroscopy.

The significant risk of radiation exposure means that justification cannot be emphasized enough. No exposure is trivial. IRMER sets out clauses for medical exposure to ensure it is justified. First, no exposure should occur without authorization by a practitioner or operator. Secondly, the exposure has to be justified by the practitioner (or operator) as showing sufficient net benefit having given appropriate weight to:

- the specific objective of the exposure and the characteristics of the individual involved.
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- the total potential diagnostic or therapeutic benefit to the individual and benefits to society of the exposure;
- the individual detriment that the exposure may cause;
- the efficacy, benefit, and risk of available alternative techniques having the same objective but involving no or less exposure to ionizing radiation.

To paraphrase, we should be clear as to the objectives of imaging; what question are we asking? Is there any benefit to answering that question in terms of alteration of management or improved efficacy or safety of a procedure? Does the evidence for the efficacy of the procedure generally and for a specific individual justify the exposure? And are there alternative procedures or imaging techniques which use less or no X-ray? These are questions anaesthetists should answer before requesting exposure for diagnostic or therapeutic purposes.

Once an exposure is justified, the regulations keep this as low as possible for the patient and employees by setting out clear responsibilities for the employer and employees. Summarizing those components relevant to non-radiology employees; generally, every radiation employer should:

- take all reasonable and necessary steps to restrict exposure of employees and other persons;
- provide personal protective equipment appropriate for the work and take all reasonable steps to ensure that it is properly used or applied and provide appropriate storage when it is not being used.

With respect to pregnant or breastfeeding employees, every employer should:

- ensure that the conditions of exposure are such that once notified of pregnancy (in writing) the equivalent dose to the fetus is unlikely to exceed 1 mSv during the remainder of the pregnancy (UK average annual background radiation dose=2.2 mSv);
- for breastfeeding employees, ensure the conditions of exposure are restricted so as to prevent significant bodily contamination.

An employee engaged in work with ionizing radiation should:

- not knowingly expose one’s self or any other person to an extent greater than is necessary;
- make full use of personal protective equipment provided, report any defects in the equipment, and take reasonable steps to ensure it is stored appropriately when not in use.

The practical implications of these regulations for an anaesthetist are that they should:

- avoid entering areas unnecessarily where ionizing radiation is in use, and protect others from the same;
- always wear personal protective equipment provided (>3.5 mm lead apron and thyroid shield) and take responsibility for storing it correctly after use;
- if pregnant inform their employer immediately;
- when performing procedures utilizing fluoroscopy, be aware of measures used to minimize the dose of radiation used.

Measures that should be used to minimize exposure include:

- a comprehensive knowledge of the anatomy and the optimal and safe technique to achieve the treatment goal;
- pulsed rather than continuous screening;
- use of the lowest exposure, as long as the image is adequate;
- avoidance of magnification (reducing the field of view by a factor of 2 increases the dose rate by a factor of 4);
- moving the source as close to the object as possible reducing the need for magnification and reducing scatter;
- laser cross-light to ensure intensifier is correctly positioned before exposure;
- beam collimation (reducing the size of the beam and its divergence improving image quality with less energy and reducing exposure area).

Summary

Exposure to ionizing radiation is associated with significant potential harm to the patient and employees involved in its use, and also their subsequent offspring. Its use therefore for diagnostic and therapeutic purposes requires impeccable justification and once justified, exposure should be as low as is practicable. Anaesthetists have a responsibility in both these areas.

Declaration of interest

None declared.

References

7. The Ionising Radiation Regulations, 1999
8. The Ionising Radiation (Medical Exposure) Regulations, 2000

Please see multiple choice questions 17–20.