Editorial

Radiation hazards for the patient in cardiological procedures

The radiation dose to both staff and patients in interventional cardiology and radiology procedures is high compared to diagnostic procedures, particularly in the cardiological techniques of percutaneous coronary intervention (PCI) and radiofrequency ablation as well as developing techniques such as direct myocardial revascularisation. In considering the potential harmful effects of radiation it is necessary to consider effects on the patients themselves as well as the staff performing the procedure. There is considerable experience relating to the exposure of staff and increasing awareness of the importance of radiation protection for the staff and patients. Regulations covering both groups have been in place for 10–15 years. The aim of this article is to review the radiation hazards to the patient and the radiation protection measures taken to ensure that the risk to the patient is kept as low as reasonably practicable. In addition it will review the newly implemented Ionising Radiation Regulations.

Radiation biology
There are two main biological effects of ionising radiation: deterministic and stochastic. Deterministic effects are those in which the number of cells lost in an organ or tissue is so great that there is a loss of tissue function. The harm will not occur below a threshold and above this the severity of the effect will increase with dose. Skin erythema and ulceration are examples of deterministic effects. Stochastic effects occur if an irradiated cell is modified rather than killed and then goes on to reproduce. The result may be the manifestation of a cancer after a prolonged and variable delay called the latent period. Stochastic effects do not appear to have a threshold and the probability of the effect occurring is related to the radiation dose. The International Commission for Radiation Protection (ICRP), an international professional body, produce recommendations which are the basis for the conceptual framework and key principles of radiation protection worldwide. The current international recommendations¹ (ICRP 60) lay out the principles of justification, optimisation, and limitation of all radiation exposures. While there are no specified dose limits for patients, the main principle is that all deterministic effects should be avoided while optimising radiation exposure to gain maximum diagnostic accuracy with minimum dose.

In most interventional procedures the doses are such that only stochastic effects need to be considered for radiation protection purposes, but recently a number of cases of skin erythema, necrosis and ulceration have been reported in the USA² and Europe.³ The case reports¹ published recently in this journal are two such examples. Unfortunately such problems generally come to light when reported by others and so there is usually little information about the procedure and radiation doses used to produce the damage as in the current reports. Nevertheless such cases serve as important examples of how things can go wrong.

Radiation dosimetry
The measurement of radiation and indicators of its effects are represented in a number of ways. Absorbed dose, unit gray (Gy), is a measure of the energy deposited in tissue. The quantity equivalent dose (ED), unit sievert (Sv), has been developed to allow an estimate of the risk of stochastic effects in a particular tissue taking into account the effect of different radiations. For diagnostic x rays these two quantities are numerically equal. The quantity effective dose unit, also the sievert, takes a weighted mean of the equivalent dose in each tissue allowing for the different tissue sensitivities, thus allowing the comparison of risks from exposure of completely different tissues. While absorbed dose in particular organs can be measured in tissue equivalent phantoms, absorbed dose in patients can only be extrapolated from other measurement values such as entrance skin dose and dose area product. Entrance skin doses (ESD) can be measured for individual patients using small tissue equivalent thermoluminescent detectors placed on the skin surface or indirectly using radiographic exposure factors and measured x ray tube characteristics. However, the risk to the patient from stochastic effects will depend not just on the ESD but also the volume of tissue irradiated and the sensitive organs irradiated. The dose area product (DAP) meter has been developed to give the product of the absorbed dose and the field area. Effective dose can be calculated from ESD or DAP readings (usually using computer systems) using extensive tabulated factors⁴ if the x ray beam characteristics and the projections used are known.

The radiation dose to an individual patient will vary considerably depending on the patient’s characteristics, distance from x ray source, tissues irradiated, and so forth. Even if these factors are known, there will be some uncertainty in the dose absorbed by the patient. The implementation of the current radiation protection regulations has taken place in the light of the complexities resulting from uncertainties concerning dose.

Ionising radiation regulations
Until 1 January 2000, UK radiation protection legislation was based upon a close interpretation of the 1977 ICRP⁵ recommendations. The Ionising Radiations Regulations 1985⁶ provided regulation for workers and members of the public and, of course, applied to the use of ionising radiation in medicine. The Ionising Radiation (Protection of Persons Undergoing Medical Examination or Treatment) Regulations 1988⁷ (POUMET) were designed to address the protection of the patient. The aim of POUMET was to ensure that individuals took responsibility for every medical exposure and that they were properly trained so that they understood the risk of the radiological examination, and were able to balance it against the patient benefit. This led to the definition of the terms “clinically directing” and “physically directing”; the person “clinically directing” the exposure would usually be a medical practitioner, while the individual “physically directing” the exposure would normally be a radiographer or an x ray technician. Those responsible for “clinically directing” an exposure, who were not already fully trained in radiation protection as demonstrated by professional qualification, were required to be trained in the “core of knowledge” defined in the legislation in addition to practical training.

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CT, computed tomographic; PCI percutaneous coronary intervention.

There are three specific steps that must be undertaken in conjunction with the three named “duty holders” in diagnostic radiology. These are identified. The employer must provide a framework for radiation protection through the provision of standard operating procedures. Each individual medical professional groups. The Royal College of Physicians has a working party which includes a cardiology representative and this will advise on training requirements for cardiology procedures. There will not be a “grandfather clause” for training under POPUMET, although previous theoretical training and practical experience demonstrated may be taken into consideration.

In another scenario a suitably qualified person (such as a radiologist and/or a radiographer acting as practitioner and/or operator) participating in the procedure with the cardiological specialist could undertake the justification and practical aspects of the exposure. The cardiologist would direct the procedure as a whole with the radiological elements of the procedure being the responsibility of these other trained clinical staff. This is likely to occur in a minority of situations only and it is important to clarify that if the cardiologist justifies and/or authorises the exposure (acting as a practitioner) or undertakes any of the practical aspects of the exposure such as using the footswitch, setting exposure factors or controlling the projections (acting as an operator) then he or she will require training in the use of ionising radiation. For example, if the cardiologist uses the footswitch, even if there is a radiographer present in the room, he or she will require adequate and appropriate training in the use of ionising radiation.

The roles of the referrer, practitioner, and operator in three typical clinical scenarios are shown in Table 1. One intracoronary radiation therapy (IRT) is a special and complex case and must be considered separately. It would normally require joint cooperation between cardiology,
radiation oncology, and medical physics departments. These arrangements are covered by the Medicines (Administration of Radioactive Substances) Act 1978 (MARS) and its amendment in 1995. These regulations are supervised by the administration of radioactive substances advisory committee (ARSAC) and staff involved in the use of radioactive substances in patients must be licensed by this committee.

**Clinical effects of radiation exposure**

There have been numerous publications that have estimated the radiation dose to patients having typical cardiological procedures. A summary of the results is presented in table 2. The dosimetric data are presented as effective dose, dose area product or entrance skin dose depending on the data source. The table illustrates that there is no consensus on the most appropriate dosimetric quantity. The variability of recorded doses is striking. This is likely to be explained by the large number of variable factors in recordings made in different institutions as well as the intrinsic difficulties of radiation dosimetry which is essentially an indirect technique. It should also be noted that different measurements such as the effective dose, the dose area product, and the skin dose do not always change in similar ways. In particular modern systems often use added copper filtration to reduce skin dose, but the reduction is not always reflected in the effective dose because of the higher effective energy of the x-ray beam.

These figures can be put into perspective by comparing the lifetime risk of cancer which has been estimated as approximately $5 \times 10^{-2}$ Sv$^{-1}$ or 1 in 20 000 per millisievert for adults in the 40–60 age group. This means that a percutaneous coronary intervention giving a patient dose of 14 mSv may add a 1 in 1400 risk of a cancer in an individual patient’s lifetime. With 25 000 percutaneous transluminal coronary angioplasty procedures being undertaken annually in the UK, this means that perhaps up to 20 patients per year will have a cancer caused by percutaneous coronary intervention at some future date. This is in addition to any immediate short term deterministic effects.

**Radiation protection in practice**

All UK hospitals must have a structure to implement and monitor radiation protection measures. There must be a qualified medical physics expert, normally the radiation protection adviser, to advise the hospital management and to produce detailed work instructions—‘local rules’—which ensure that doses to staff and members of the public are as low as reasonably practicable. The individual departmental manager or director should have a radiation protection supervisor whose responsibility it is to ensure that the local rules are adhered to. The radiological procedure is expected to be carried out with attention to the ALARA principle (“as low as reasonably achievable”) and in accordance with accepted diagnostic practice. As such, the final decision on radiation dose rests with the clinician in charge of the procedure. Following the recommendations of ICRP 60, the IR(ME)R 1999 do, however, require constraints or “diagnostic reference levels” which are produced either locally or possibly nationally. These are dose levels that should not normally be exceeded, but if they are they should be reviewed by the employer and action taken where appropriate.

All procedures will have to be based on written protocols. It will be necessary for these protocols to allow adequate flexibility for the proper conduct of procedures, but they will be based on fundamental principles that are accepted as the basis of good practice. The IR(ME)R 2000 have a subsidiary clause which allows until 1 January 2001 for these written protocols to be established.

The more stringent requirements for training will need the development and implementation of new training programmes. Such programmes do not exist at this early stage, but it is likely that they will be developed locally. The training given will need to conform to both the legal regulations and the professional guidance that will be given by the Royal Colleges. The regulations are very new and at present there has been insufficient time for the new courses to be implemented; this will need to take place in the next few months.

A major part of radiation protection is the keeping of adequate records. Monitoring badges for staff are well accepted but it is only just becoming commonplace for radiation doses to patients (usually dose–area product, DAP) to be routinely recorded. The new regulations do not require that every medical exposure is individually recorded, but in each individual medical exposure there must be proper documentation of the justification, authorisation, and practical aspects (the equivalent of radiology requests and reports). In addition to this, regular detailed clinical audit is required which will allow assessment of untoward incidents and will allow the comparison of one x-ray machine with another or one x-ray department or operator with another. Records of departmental doses (local “diagnostic reference levels”) should be kept in sufficient detail to allow reconstruction of a patient dose in the case of an incident that requires investigation. An incident involving an excessive radiation dose will need to be reported to the appropriate health department if there has been a procedural failure or the Health and Safety Executive if equipment has failed or malfunctioned. Up to date records of all equipment must be kept.

### Table 2 Review of recent literature giving mean patient doses for cardiac angiography techniques

<table>
<thead>
<tr>
<th>Reference</th>
<th>Coronary angiography</th>
<th>PTCA/PCI</th>
<th>Ablation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose (mSv)</td>
<td>DAP (Gy cm$^2$)</td>
<td>ESD (mGy)</td>
</tr>
<tr>
<td>Betsou et al 1998</td>
<td>29</td>
<td>5.6</td>
<td>30.4</td>
</tr>
<tr>
<td>Broadhead et al 1997</td>
<td>2174</td>
<td>94</td>
<td>57.8</td>
</tr>
<tr>
<td>Room A</td>
<td>126</td>
<td>4.6</td>
<td>23.4</td>
</tr>
<tr>
<td>Room B</td>
<td>90</td>
<td>3.1</td>
<td>14</td>
</tr>
<tr>
<td>Leung and Martin 1996</td>
<td>288</td>
<td>66.5</td>
<td>45</td>
</tr>
<tr>
<td>Zorzetto 1999</td>
<td>3.0–5.7</td>
<td>20–40</td>
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<tr>
<td>Coulden and Readman 1993</td>
<td></td>
<td></td>
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<tr>
<td>Pattie et al 1993</td>
<td>39</td>
<td>55.9</td>
<td>35</td>
</tr>
<tr>
<td>Pattee et al 1995</td>
<td>23</td>
<td>39</td>
<td>55.9</td>
</tr>
<tr>
<td>Zorzetto et al</td>
<td>1999</td>
<td>135</td>
<td>180</td>
</tr>
<tr>
<td>Hwang et al 1998</td>
<td>24</td>
<td>135</td>
<td>180</td>
</tr>
<tr>
<td>Rosenthal et al 1998</td>
<td>1993</td>
<td>18</td>
<td></td>
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<tr>
<td>Park et al 1996</td>
<td>18</td>
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</tbody>
</table>

PTCA, percutaneous transluminal coronary angioplasty; PCI, percutaneous coronary intervention; ED, effective dose; DAP, dose area product; ESD, entrance skin dose; M male; F female.
It is also a requirement for the employer to keep accessible and up to date records of all practitioners and operators together with details of the nature of their training and the date the training was completed.

The responsibilities for compliance with these new regulations will ultimately lie with the employer, commonly a hospital trust in the National Health Service. The statutory legal instruments, supported by advice and protocols from the professional bodies which set out best practice, must be ultimately implemented by the employer. The new regulations will be interpreted variably at local levels, but each employer will ultimately be required to comply with these regulations in terms of training, protocols, record keeping, audit, and supervision.

Cardiological procedures

Interventional cardiology procedures are often difficult and stressful for the clinician who must keep many technical and clinical aspects in mind simultaneously. Coupled to this is the notion that the patient’s cardiological condition carries a substantial threat compared to the radiation dose that is often ignored or considered negligible. There is also a factor of technical challenge associated with such procedures, namely that “success is everything” and the concept of discontinuing a procedure is seen a failure, even if in the patient’s overall best interests. It is not surprising therefore that on occasions some overenthusiastic operators continue procedures for very long periods with prolonged screening times. It may be difficult for a radiographer or other staff member to remind the clinician of the radiation hazards and, if there is no radiographer present, then the difficulties are compounded.

Much radiation protection is common sense. The x ray beam obeys the inverse square law and, as such, will deliver extremely high skin doses if the patient is not kept in the isocentre but is allowed to lie close to the x ray tube. Proper collimation of the beam is essential. Steep cranial or caudal angulations are sometimes clinically indicated but they deliver much higher doses; they should only be used where necessary. The use of a single projection for a prolonged procedure will concentrate the radiation on one skin entry point, therefore projections should be varied whenever possible. Asking the patient to take a breath in will not only improve the image but will also decrease the radiation dose; of course, there will be difficult situations where an inspiration is not possible but there are many occasions where it is. If a patient has previous films and these are not possible. Asking the patient to take a breath in will not only improve the image but will also decrease the radiation dose; of course, there will be difficult situations where an inspiration is not possible but there are many occasions where it is. If a patient has previous films and these are not reviewed then repeat studies could cause unnecessary radiation dose. Perhaps the most obvious but a nevertheless common mistake is related to the use of the screening pedal. If this is controlled by the cardiologist performing the procedure there is a risk of exposure being continued unnecessarily when the operator is not looking at the screen or is performing some non-essential manoeuvre such as watching an unchanging inflated balloon. Sometimes screening is also unnecessarily continued when projections are being changed.

The equipment used is a major variable. Modern digital systems with radiation limiting technology such as improved beam filtration or pulsed fluoroscopy can substantially reduce radiation dose. Upgrading an old unit can in itself be a major radiation reducing action.

Finally, although it has not been mentioned in this article, we should consider the whole issue of informed consent. It may soon be time to mention the risks from radiation exposure along with all the other risks of the intervention.

Conclusions

Radiation protection is often seen as a dry and dull topic, but it is becoming increasingly important particularly in interventional cardiology. All hospitals and cardiology departments have a legal duty to comply fully with the new regulations but it goes much further than this. Clinical governance requires that high standards of clinical practice are maintained by the responsible medical staff together with the hospital administration. The new regulations may require staff to change long standing practices and perhaps redirect resources to better control, monitoring, and audit of radiation exposures as well as more rigorous training in the use of ionising radiation.

Britain has traditionally maintained high standards of radiation protection practice. In times of changing clinical practice and professional regulation we must ensure that this high standard is maintained.

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References