Radiation protection of medical staff

John Le Heron a , *, Renato Padovani b , Ian Smith c , Renate Czarwinski a

a Radiation Safety & Monitoring Section, Division of Radiation, Transport and Waste Safety, International Atomic Energy Agency, Wagramer Strasse 5, P.O. Box 100, 1400 Vienna, Austria
b Medical Physics Department, University Hospital, Udine, Italy
c St Andrew’s Medical Institute, St Andrew’s War Memorial Hospital, Brisbane, Australia

ARTICLE INFO
Article history:
Received 14 June 2010
Accepted 15 June 2010

Keywords:
Radiation protection
Occupational exposure
Image-guided interventional procedures
Protective tools
Protective clothing
Monitoring

ABSTRACT
The continuing increase in the worldwide use of X-ray imaging has implications for radiation protection of medical staff. Much of the increased usage could be viewed as simply a workload issue with no particular new challenges. However, advances in technology and developments in techniques have seen an increase in the number of X-ray procedures in which medical personnel need to maintain close physical contact with the patient during radiation exposures. The complexity of many procedures means the potential for significant occupational exposure is high, and appropriate steps must be taken to ensure that actual occupational exposures are as low as reasonably achievable. Further attention to eye protection may be necessitated if a lowering of the dose limit for the lens of the eye is implemented in the near future.

Education and training in radiation protection as it applies to specific situations, established working procedures, availability and use of appropriate protective tools, and an effective monitoring programme are all essential elements in ensuring that medical personnel in X-ray imaging are adequately and acceptably protected.

© 2010 Elsevier Ireland Ltd. All rights reserved.

1. Introduction

The use of radiation in medical applications continues to increase worldwide. Latest UNSCEAR estimates suggest that there are about 4 billion X-ray examinations per year, worldwide [1]. All these procedures need to be performed by medical personnel with the accompanying potential for occupational radiation exposure. Does the increasing demand for X-ray imaging have implications for radiation protection of medical staff? The increasing usage could be viewed as simply a workload issue with no particular new challenges. However, there is also a change in the types of X-ray imaging procedures being performed and by whom – procedures requiring personnel to be close to the patient, and these procedures present a challenge to ensure appropriate radiation protection of medical staff.

The term X-ray imaging is used in this paper to cover both diagnostic radiology and image-guided interventional procedures. Occupational radiation protection is achieved by application of the three ICRP principles of justification, optimization and dose limitation [2]. In practice, to afford radiation protection for medical staff in X-ray imaging, it is the application of optimization and dose limitation that is arguably the most important. However, it should be recognized that the lack of rigorous application of the justification principle is resulting in the performance of significant numbers of unnecessary X-ray imaging examinations, and these add to occupational exposure.

This paper cannot cover all the aspects of radiation protection of medical staff, but instead focuses more on the challenges in the never ending story of occupational radiation protection, including a brief discussion of factors that determine the level of occupational exposure in X-ray imaging, the implications of recent trends in X-ray imaging for occupational radiation protection, and the basis for ensuring effective radiation protection of medical staff in the light of these new developments.

2. What determines the level of occupational exposure in X-ray imaging?

The level of occupational exposure associated with X-ray imaging procedures is highly variable and ranges from potentially negligible in the case of simple chest X-rays, to significant for complex interventional procedures. What are the reasons for this? From the occupational perspective, there are two “sources” of radiation exposure. Clearly the X-ray tube is the true source of radiation, but in practice there should be very few situations in which personnel have the potential to be directly exposed to the primary beam. This leaves the other “source”, which is the patient. Interac-
tion of the primary X-ray beam with the part of the patient's body being imaged produces scattered radiation, which emanates from the patient in all directions. So, in most cases, the main determinant for occupational exposure is proximity of personnel to the patient when exposures are being made. Furthermore, the level of scatter is determined largely by the dose to the patient, resulting in an important corollary that reducing the patient dose to the minimum necessary to achieve the required medical outcome also lowers potential occupational exposures. A common and useful maxim is that when personnel take care of the patient, they will also take care of their occupational exposure.

2.1. Working at some distance from the patient

For many situations, such as radiography, mammography and general CT, there is usually no need for personnel to be physically close to the patient. This provides two opportunities to afford good occupational radiation protection. First, being distant from the patient reduces the levels of scatter reaching personnel. Divergence of the scattered X-rays from the patient results in radiation intensities falling off rapidly with distance. This is the so-called "inverse square law" where, for example, a doubling of the distance results in a four-fold reduction in radiation intensity.

The second factor is that structural shielding can be placed between the patient and personnel. For example, shielding may be incorporated into the wall and window of the control room barrier, resulting in negligible levels of scatter reaching personnel. Appropriate room design with shielding specification by a medical physicist or radiation protection expert (RPE) also should ensure that occupational exposure will be essentially zero for these X-ray imaging situations.

2.2. Working close to the patient

There are some situations, typically in fluoroscopic examinations and in image-guided interventional procedures, where it is necessary to maintain close physical contact with the patient when radiation is being used. Distance and structural shielding are not options, so what can be done for these personnel?

Scattered radiation can be attenuated by protective clothing worn by personnel, such as aprons, spectacles, and thyroid shields, and by protective tools, such as ceiling-suspended protective screens or table-mounted protective curtains or wheeled screens, which are able to be placed between the patient and personnel. Depending on its lead equivalence and the energy of the X-rays, an apron will attenuate 90% or more of the incident scattered radiation. Protective aprons come in different thicknesses and shapes, ranging from the simple front-only apron to a full coat: the former being effective only if the wearer is always facing the source of the scattered radiation.

The lens of the eye is highly radiation sensitive. For persons working close to the patient, doses to the eyes can become unacceptably high. Wearing protective eyewear, particularly those incorporating side protection, can reduce the dose to the eyes from scatter by 90%, but to achieve maximum effectiveness, careful consideration needs to be given to issues such as the placement of the viewing monitor to ensure the eyewear intercepts the scatter from the patient. It is likely that measures to protect the eyes will receive further attention if the dose limit for the lens of the eye is lowered.

3. Implications of recent trends in X-ray imaging for medical staff

In the area of radiography, including mammography, there has been a shift from film-based to digital systems. Patient doses remain broadly similar, but patient throughput for a given imaging room may have increased. Overall, the implications for occupational radiation protection have been minimal.

CT imaging has seen the advent of multi-detector CT scanners (MDCT). Again, depending on how well imaging protocols have been optimized, patient doses are broadly similar to their single slice antecedents and future trend are likely to lower patient doses as manufacturers continue to introduce more dose-saving features. Image acquisition is considerably faster and usage of CT is increasing, resulting in higher workloads in the CT room. This has often resulted in a need for increased structural shielding to maintain acceptable standards of occupational radiation protection.

New technologies and techniques have also allowed the performance of complex diagnostic and interventional procedures with the advantage of avoiding more risky surgical interventions in several cases. These procedures present several challenges for radiation protection of medical staff.

3.1. CT-fluoroscopy

CT-fluoroscopy facilitates the performance of biopsies by generating live tomographic images to better guide the intervention. However, as the interventionalist is very near to the patient, there is the potential for the hands to be exposed to the primary beam and hand doses of up to 0.6 mSv for a procedure lasting only 20 s have been reported [3]. Without protective measures, dose limits (see Table 1) for the hands could easily be exceeded.
4. Ensuring effective radiation protection of medical staff

A radiation protection programme (RPP) is one means of implementing occupational radiation protection by the adoption of appropriate management structures, policies, procedures and organizational arrangements. For medical staff in X-ray imaging, topics would include the need for local rules and procedures for personnel to follow, arrangements for the provision of personal protective equipment, a programme for education and training in radiation protection, arrangements for individual monitoring, and methods for periodically reviewing and auditing the performance of the RPP. The following sections describe aspects of two of these topics. Further details on RPPs can be found in the BSS [5], and IAEA SRS No 39 [6].

4.1. Radiation protection training

Education and training underpin the implementation of radiation protection in practice, and most countries have regulatory requirements for such training. In X-ray imaging, personnel need training not only in occupational radiation protection, but also in patient radiation protection as the latter can influence occupational exposure. Guidance has been published on what the training for medical staff should cover, such as by the European Commission [7]. Several resources for training are freely available, including IAEA material for diagnostic and interventional radiology and cardiology [8], and the MARTIR project (multimedia tool for training in interventional radiology) [9], which is particularly useful for distance learning purposes.

For the reasons noted previously, it is crucial that programmes for radiation protection training in hospital settings include those medical personnel who are outside the radiology department but who are involved in X-ray imaging procedures.

4.2. Monitoring of occupational exposure in X-ray imaging

Occupational exposure is subject to dose limits as given in Table 1, established to ensure that the risks arising from occupational exposure are not unacceptable [2]. The dose limit expressed as effective dose addresses cancers and hereditary effects, while the other dose limits (in terms of equivalent dose) are to prevent radiation effects in particular tissues or areas of the body. In addition, the application of the principle of optimization of protection should ensure that occupational doses to medical staff in X-ray imaging are as low as reasonably achievable (ALARA principle), and typically well below the dose limits.

The purpose of individual radiation monitoring is to ensure the dose limits are not exceeded. Further, through regular review, the results of individual monitoring are used to assess the effectiveness of strategies for optimization. It is always hoped that the monitoring results confirm that good practice is taking place.

Estimates of effective dose and equivalent dose can be made using appropriately designed and calibrated dosimeters, such as those provided by an accredited individual monitoring service, worn by medical personnel when performing X-ray imaging. It is important that personal dosimeters are worn correctly. In X-ray imaging this can become complicated, depending on the roles of the person being monitored and whether they are sometimes or even always wearing protective clothing. If a person is normally distant from the patient and is being protected by structural shielding, then wearing a single dosimeter on the front of the torso, between the shoulders and the waist, would normally suffice. However, if a person is working close to the patient during imaging and is wearing a protective apron, then a single dosimeter worn under the apron will provide a good estimate of exposure to the shielded parts of the body, but will underestimate exposure to the organs and tissue outside the apron. In these cases, as dose to the eyes is often of most concern, it is recommended that two dosimeters are worn, one under the apron and the other outside the apron, often at shoulder or collar level. The results of the two dosimeters can be combined to give a better estimate of effective dose, as well as providing an estimate for the dose to the eyes.

In some cases in X-ray imaging, monitoring of the fingers and hands may be indicated. This requires special dosimeters, such as ring or bracelet dosimeters. It is important to position the dosimeter in the position most likely to receive the highest exposure. This may not be the dominant hand. In all cases of individual monitoring, specific advice from a medical physicist or RPE should be obtained. One of the practical difficulties in individual monitoring is ensuring that monitored personnel actually always wear their dosimeters when working with radiation. Incomplete compliance means that a person’s occupational exposure is underestimated and, if this lack of compliance with monitoring is widespread, then doses to that occupational group as a whole would also be underestimated. The reality is that many medical personnel do not always wear their

### Table 1

Recommended dose limits for occupational exposure in X-ray imaging (adapted from ICRP[2]).

<table>
<thead>
<tr>
<th>Dose quantity</th>
<th>Occupational dose limit*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective dose</td>
<td>20 mSv per year averaged over 5 consecutive years (100 mSv in 5 years), and 50 mSv in any single year</td>
</tr>
<tr>
<td>Equivalent dose in:</td>
<td></td>
</tr>
<tr>
<td>Lens of the eyeab</td>
<td>150 mSv in a year</td>
</tr>
<tr>
<td>Skinbc</td>
<td>500 mSv in a year</td>
</tr>
<tr>
<td>Hands and feet</td>
<td>500 mSv in a year</td>
</tr>
</tbody>
</table>

* Dose limits can be different in national regulations.

b This limit is currently being reviewed by an ICRP Task Group.

c Averaged over 1 cm² of the most highly irradiated area of the skin.
dosimeters, for a variety of reasons that range from simple negligence to deliberate avoidance to ensure that monitored results remain below the threshold for administrative or regulatory investigation. It is important that monitoring is not viewed negatively, but rather as a means for adding value to occupational radiation protection by confirming good practice when this is the case, and for improvement through corrective actions when problems are identified.

Developments in individual dosimetry may help solve the monitoring compliance issue. For example, technology is being developed that utilises compact personal electronic monitoring devices that wirelessly connect to a base station. Multiple devices can be monitored simultaneously, so all staff involved in a complex imaging procedure can monitor their doses and dose rates in real-time and use this information to modify their practice if indicated. Future technology may even negate the need for dosimeters or devices to be worn by personnel. It is feasible that a person's location in a room can be monitored in real-time, and their real-time occupational exposure calculated from the real-time knowledge of the X-ray equipment and how it is being used.

4.3. Current occupational doses to medical staff

There is a large number of publications giving occupational doses per given procedure in X-ray imaging in a given facility, and others that estimate likely annual doses. UNSCEAR provides a comprehensive source of information on occupational doses worldwide, and in its 2010 report (covering the period 2002–2006) it concludes that over 80% of general and CT radiographers did not receive measurable doses [1], confirming that for personnel who are protected by structural shielding, doses are very low. The report notes that only a few countries were able to provide data that distinguished between conventional techniques in diagnostic radiology and interventional procedures. From these limited data, for conventional diagnostic radiology the reported mean annual effective dose was about 0.5 mSv for monitored personnel, while for interventional procedures it was about 1.6 mSv. A recent study with data from 23 countries gave an average median effective dose for interventional cardiologists of 0.7 mSv, averaged per country (Padovani et al., unpublished results). These figures would seem to be underestimates when compared with published facility-specific data, again raising the issues of monitoring compliance.

5. Conclusions

The continuing increase in the worldwide use of X-ray imaging is creating new challenges for occupational radiation protection of medical staff. Advances in technology and developments in techniques have seen an increase in the number of X-ray procedures in which medical personnel must maintain close physical contact with the patient during radiation exposures. The complexity of many procedures means the potential for significant occupational exposure is high, and appropriate steps must be taken to ensure actual occupational exposures are as low as reasonably achievable. Further attention to eye protection may be necessitated if a lowering of the dose limit for the lens of the eye is implemented in the near future. Education and training in radiation protection as it applies to specific situations, plus established working procedures, availability and use of appropriate protective tools, and an effective monitoring programme are all essential elements in ensuring that medical staff in X-ray imaging are adequately and acceptably protected.

References