



Roles and responsibilities of medical physicists in radiation protection

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1. Introduction

Many different modalities are now commonly used in medical imaging services. Many utilize radiation in some form (X-rays and radionuclides), while others, such as ultrasound and MRI do not. The delivery of imaging services is often divided into two, namely diagnostic radiology and nuclear medicine. A third area of radiation use, which includes medical imaging as an adjunct to the performance of a medical intervention, is that of image-guided interventional procedures. This paper will focus on defining the roles and responsibilities of medical physicists in radiation protection when using X-rays in diagnostic radiology and image-guided interventional procedures, which collectively will be referred to as X-ray imaging in this paper.

The role of the medical physicist in X-ray imaging is not as well established as it is in radiation oncology. In radiation oncology, clinical medical physicists are recognized as important members of the health care team, while for X-ray imaging, many radiology departments currently operate without such support. Possibly this occurs because the role of the medical physicist in X-ray imaging is poorly understood. This chapter will attempt to elucidate the main roles and responsibilities of medical physicists in X-ray imaging.

1.1. Why is a medical physicist needed in X-ray imaging?

Radiation protection is afforded in X-ray imaging, as in any other activity using ionizing radiation, by the application of the International Commission on Radiological Protection's (ICRP) principles of radiation protection, namely, justification of a given procedure, optimization of the radiation protection, and the limitation of dose for workers and members of the public. Responsibilities for radiation protection are shared among the different professionals in the imaging team, including the radiologists, other medical specialists, the medical radiation technologists and the medical physicists. However, it is the medical physicist who has the particular skills (see Section 1.2) to either perform, or be responsible for, specific aspects in the implementation of these ICRP principles. Indeed, the specific skills of the medical physicist have prompted international standards and requirements [1,2] to mandate their crucial role in radiation protection as elaborated in Section 1.3.

The roles and the responsibilities of the medical physicist in medical imaging fall into three main areas: (a) imaging equipment, (b) imaging procedures and (c) administrative and regulatory aspects. In addition, the medical physicist is usually involved in research and development in topics linked to the first two areas cited above. Research on equipment and procedures has allowed substantial advances in the management of radiation doses in medical imaging during recent years. Most commonly, it is the implementation of the optimization principle that dominates the medical physicist's role; in contributing to processes and procedures that help ensure the use of the minimum patient exposure necessary to achieve the clinical purpose.

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1.1.1. Role of the medical physicist—X-ray imaging equipment and X-ray facility

Appropriate selection of X-ray imaging equipment is a very important, yet complex process, which has ongoing implications for the imaging facility, including radiation protection. There are often many competing requirements for a given imaging device, such as imaging performance, ergonomics, dose features, cost, and servicing, and the medical physicist contributes to the selection process. For example, comparing the relative imaging performances of different devices for the same dose conditions is not a trivial task, and requires the specific knowledge and expertise of the medical physicist. Equipment is often offered with several additional options that can impact on radiation protection, such as radiation protection tools, software for patient dose reports and quality control (QC) tools in some specific imaging systems (e.g. rotational acquisitions). These options need to be evaluated and, if indicated, included in the purchase specification.

Once the purchase has been made, the medical physicist takes part in the acceptance tests and in conducting the commissioning procedures. Acceptance testing is primarily about ensuring you have received what you specified, including imaging and dose performance. The separate process of commissioning is to tailor the equipment to how it is going to be used within the facility, and to calibrate and establish the base line measurements for the quality control programme. Many modern imaging devices have a bewildering number of options for technical factors and other parameters, most of which affect the image quality–patient dose relationship. In performing base line measurements of image quality, doses and dose rates and other technical parameters, the medical physicist provides invaluable information to help establish optimized imaging protocols (see Section 1.1.1).

A system of quality assurance with quality control tests is required to ensure the ongoing acceptable imaging performance of the imaging equipment. The medical physicist develops, adapts and implements the physics aspects of such a quality assurance programme, by performing tests at set intervals and after major reparations or updates. Comparisons are made with the baseline measurements, and values outside control limits result in corrective actions to ensure continued acceptability of performance.

Data transfer of the relevant dosimetry and the procedure's technical factors from the imaging equipment to the facility's Radiological Information System (RIS), or other dedicated system for storage, and its subsequent analysis require the intervention of a medical physicist. The transmission and storage of patient dose data will normally include the cooperation of computer engineering staff as part of the clinical team. The results of the analyses should be periodically discussed and shared with the clinical team to promote improvement in the implementation of radiation protection. Similarly, the connectivity of the imaging systems with the RIS and PACS may also have some influence on radiation protection (e.g. repetition of examinations if some of the previous images have been lost) and should be tested by the medical physicist in cooperation with the computer engineer.

In addition to the imaging equipment, the room and the facility into which it is to be installed must be appropriately designed to ensure that appropriate radiation protection is afforded to medical personnel and to members of the public who may be inside or close to the facility. The design should specify the appropriate room layout and size, together with the necessary shielding requirements, and the medical physicist has the necessary expertise to perform this task. The radiation protection adequacy of the room and facility also must be verified. The final assessment is performed after the imaging equipment has been installed and

commissioned, so that realistic scattered radiation measurements can be made.

1.1.2. Role of the medical physicist—X-ray imaging procedures

For a given imaging device, the number of technical factors that can influence the image quality, patient dose, or both is very large. The clinical needs such as the type of projections and the number of images must be appraised. High doses to patients are sometimes either the consequence of improper use of the X-ray system, the acquisition of images of higher quality than necessary, or gathering too many images during cine or DSA series. Implementation of the optimization principle of radiation protection requires that a systematic approach is taken to establish protocols for how a given imaging device will be used in performing a given procedure. The medical physicist is an important contributor to this process due to their expertise and understanding of the physics underpinning the way the particular imaging equipment operates.

Recent advances in high technology imaging systems have presented new challenges. For example, low dose modes in CT, rotational acquisitions in angiography, CT-like modes in angiography and cardiology, all require the medical physicist's expertise to analyze their performance, and to propose corrective actions when the image quality has become degraded or patient doses have increased significantly.

Particular attention needs to be made with respect to the imaging of children. This has attracted considerable attention in recent years, and equipment manufacturers are now developing sophisticated tools for the optimization of radiation protection in imaging paediatrics. It is incumbent upon the medical physicist to ensure that these features are appropriately validated and employed.

Part of the implementation of optimization requires knowledge of the patient doses being used in the imaging facility. Medical physicists need to conduct or supervise the periodic assessment of patient doses for common imaging procedures, and this would typically be part of the quality assurance programme. Direct measurements are made on some systems, while for others it may be verification of the values being reported by the imaging device. Analysis of the facility's doses with periodic comparisons to national diagnostic reference levels (DRLs) need to be made. If average values of patient doses are consistently higher than DRLs, or significantly below and with poor image quality, corrective optimization actions need to be discussed in cooperation with the other members of the imaging team.

In addition to the periodic surveys of patient dose, there is also an *ad hoc* need for specific dosimetry to be performed. For example, dose and risk estimates may need to be performed following the inadvertent irradiation of a pregnant woman. Assisting in the follow-up of high patient (or high staff) dose values is another important task the medical physicist must perform, as can and does occur in image-guided interventional procedures.

The principle of optimization of protection also applies to occupational exposure of medical personnel. The medical physicist has the expertise to provide specialist radiation protection training for staff, including equipment and room-specific practical radiation protection training. There is a strong inter-relationship between patient dose and personal dose in image-guided interventional procedures, and the medical physicist is best placed to provide training to ensure both parties are afforded optimized protection.

In some situations, a person, such as a mother, may willingly and knowingly act as a carer or comforter to a person undergoing an imaging procedure, which exposes them to a small amount of radiation. Estimating doses for such carers or comforters during medical exposures comes under the remit of the medical physicist, who also may propose dose constraints where appropriate to optimize the protection of the carers and comforters.

1.1.3. Role of the medical physicist—training and regulatory activities

As mentioned previously, training personnel in the X-ray imaging facility on imaging physics and radiation protection is an important role of the medical physicist. This includes training new staff and also the provision of refresher training as part of continuing professional development. The medical physicist also usually contributes to the training programme in imaging for radiology residents or registrars.

The medical physicist often plays a role in the implementation of the radiation protection principle of dose limitation as it applies to occupationally exposed personnel and to members of the public. This task includes managing the results of individual monitoring of occupationally exposed personnel, and the appropriate follow-up actions if an individual's results are unusual for their particular procedures and workload. Area monitoring is also performed, and the medical physicist can advise on which staff require special personal dosimetry, such as the use of two dosimeters (one over and one under the apron) or finger dosimeters, and on precautions for pregnant workers.

X-ray imaging is frequently used as a tool to quantify changes in a given parameter (e.g. bone mineral density) resulting from a trial in biomedical research. The medical physicist's role in this case is to estimate the doses and risks for the volunteers in a proposed research programme and to present this information to the appropriate ethics committee to help their decision whether or not to approve a given proposal.

Unintended and accidental medical exposures do occur in X-ray imaging, including irradiating the wrong person, the wrong body part, using a much higher dose than specified, inadvertent exposure of the embryo or foetus, or some equipment or operator failure. As part of the investigation, the medical physicist's job is to perform the necessary dose and risk estimates, and to provide input into any review of the optimization of protection that may be needed, such as when the dose was much higher than intended.

Finally, the medical physicist also liaises with the radiation protection regulatory body, providing records and documents attesting to, *inter alia*, equipment inventory, equipment acceptance tests, calibrations, results of the quality assurance programme and quality control tests, patient dosimetry results including comparisons with DRLs, personal monitoring results, and dose constraints for carers and comforters.

1.2. What knowledge and skills of medical physicist working in X-ray imaging?

As outlined above, medical physicists are core members of the multi-disciplinary X-ray imaging team. The performance of the medical physicist has a significant impact on the quality and safety of the X-ray imaging services and they must be fully qualified with the academic knowledge, professional skills and competency to be able to perform their duties effectively and safely.

1.2.1. Basic education and professional training

A qualified medical physicist will typically complete three main phases of training. The first phase of training is a Bachelor's degree in physics, or an equivalent degree in a relevant physical science subject at an academic institution. On completion of the undergraduate program, the potential medical physicist should have acquired a sound fundamental knowledge on physics and mathematics and other science and engineering science subjects that qualify him to the next phase of training. The second phase is for the student to complete a postgraduate program at the level of a master's degree level in medical physics. The program should be designed to provide the student with a good understanding of the principles and theoretical basis of radiation physics, radiation safety and

protection, the physical principles of the commonly used radiology and imaging modalities and equipment technologies, and a basic knowledge on anatomy and physiology. Students also should have a good knowledge of the principles and methods of image formation, detection, processing, and reconstruction of different imaging modalities, plus a good understanding of the physics of image quality, contrast, resolution, noise, and artifacts. On completion of the graduate program, a potential medical physicist will be qualified to apply for the third phase of the training. This phase is professional training in the form of residency training or an equivalent program analogous to the specialist training for radiologists. The training is usually in a major medical institution or a cluster of medical centres in which a comprehensive range of medical imaging and physics equipment is available. It should be conducted under the supervision of an experienced and competent clinical medical physicist for a period of at least two years. The structured training should be designed to provide the trainee with extensive hands on experience on a comprehensive range of clinical radiology physics work processes and services. The program should clearly specify the scope of the training and method of assessment. The IAEA programme is a good example of such a structured programme [3]. On completion of the program, the trainee will be competent to perform a wide range of clinical physics duties and services independently, including those described in Section 1.1.

1.2.2. Professional accreditation

As a quality assurance measure to ensure that the level of competency and standard of practice of the clinical medical physicist is compatible with national and international norms, some form of accreditation process, such as professional certification, should be implemented to formally qualify the medical physicist to practice in a clinical setting. Similarly, to ensure the quality and standard of the training, the training institution itself should also be subject to some form of external audit or accreditation process.

1.2.3. Continuing professional development

The advancement in equipment technology has resulted in changes in the practice in radiology. The large increase in the use of CT is a typical example of such changes and this has raised some concerns on the significant increase in population dose in USA [4,5]. The recently reported incident of patient overdose in CT perfusion studies has caused further alarm [6]. Clearly, the latest practices in radiology require more intensive and extensive quality and dose management than ever before. New approaches in quality management and patient dose optimization must be developed and implemented on an ongoing basis to minimize the risk of radiation incidence. These are typical challenges being faced regularly and clinical medical physicists should be prepared to face such challenges throughout their careers. To maintain the professional competency to face future challenges, a clinical medical physicist should be subject to an appropriate continuing professional development (CPD) program to update their professional knowledge and expertise.

1.3. Regulatory responsibilities of medical physicists for radiation protection in X-ray imaging

As outlined above, the medical physicist has a crucial role in the implementation of radiation protection in the X-ray imaging facility. The presence of a medical physicist to perform these roles cannot be left to chance or to the goodwill of administrators or managers, or be provisional on the availability of funds. Consequently, international standards and requirements, the international BSS [1] and the European Directive [2] have mandated the role of the medical physicist in radiation protection. There are many approaches throughout the world to regulating the use of radiation, but typ-

ically a medical X-ray imaging facility will have an authorization (licence) to use radiation, and as part of that authorization there will be regulations or licence conditions requiring the presence of a medical physicist to perform particular functions.

It is worth noting that these requirements have evolved over the years. At the time the international BSS and the EU Directive were published, in 1996 and 1997 respectively, the requirements for involving a medical physicist in X-ray imaging were not as compelling as they were for radiotherapy. Both these standards are currently undergoing revision, and in both the requirements have been strengthened in light of developments in the use of X-rays in imaging and interventions over the last 10–15 years. For example, the January 2010 draft of the revised international BSS³ states that for diagnostic and image-guided interventional uses of radiation, the imaging, calibration, dosimetry and quality assurance (including medical radiological equipment acceptance and commissioning) requirements are fulfilled by, under the oversight, or with the documented advice of a medical physicist, where the degree of involvement of the medical physicist is determined by the complexity of the particular use of radiation and the ensuing radiation risks.

Not only has the mandate for the role of the medical physicist been strengthened, but also stricter specifications have been imposed on who may assume that role. This underscores the importance of ensuring that only appropriately qualified, trained and recognized persons are allowed to assume the role of the medical physicist. The process to assess this competence is outlined in Section 1.2. The IAEA recognizes that not all countries have such a system in place and, in the draft revised international BSS, states that such countries must apply processes to ensure standards as if such a system existed.

2. Conclusion

The need for clinical medical physicists in X-ray diagnostic radiology is not well recognized by many radiologists, but also is not

explicitly required under many national regulations. Furthermore, there is some confusion and lack of clarity on education and training requirements for medical physicists in general, and also on their roles and responsibilities, particularly in medical imaging. This chapter summarizes the education and training requirements of medical physicists in imaging and emphasizes the need to include structured clinical residency training into training programmes. A well educated and clinically trained medical physicist is fully qualified and competent to fulfill their main responsibilities in an imaging department, which are to contribute to ensuring that the minimum patient exposure necessary to achieve the clinical purpose of the imaging procedure is used, to implement a quality assurance programme, educate and train staff on radiation protection, and to provide support for compliance with regulations.

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