Annals of the ICRP

ICRP PUBLICATION 117

Radiological Protection in Fluoroscopically Guided Procedures Performed Outside the Imaging Department

Editor
C.H. CLEMENT

Authors on behalf of ICRP
M.M. Rehani, O. Ciraj-Bjelac, E. Vañó, D.L. Miller, S. Walsh, B.D. Giordano, J. Persliden

PUBLISHED FOR

The International Commission on Radiological Protection

by

ELSEVIER

Please cite this issue as 'ICRP, 2010. Radiological Protection in Fluoroscopically Guided Procedures Performed Outside the Imaging Department. ICRP Publication 117. Ann. ICRP 40(6).'

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Editorial

ICRP RECOMMENDATIONS ON RADIOLOGICAL PROTECTION IN MEDICINE

The International X-ray and Radium Protection Committee (IXRPC) was established in Stockholm in 1928 at the Second International Congress of Radiology. The first recommendations of this committee, adopted on 27 July 1928, deal with the protection of workers in x-ray and radium departments of hospitals (ICR, 1929). The IXRPC was later renamed the 'International Commission on Radiological Protection' (ICRP); thus, ICRP was formed out of a recognised need for radiological protection in medicine.

Today, ICRP includes five standing committees, with Committee 3 being dedicated solely to radiological protection in medicine. The scope of Committee 3 includes not only medical exposures (primarily to patients), but also occupational exposures to healthcare staff, and public exposures resulting from the use of radiation in medicine.

The most recent evolution of the ICRP system of radiological protection is described in *Publication 103* (ICRP, 2007a). *Publication 105* (ICRP, 2007b) elaborates on how this system applies to exposure to ionising radiation in medicine. Since *Publication 105*, approximately one-third of ICRP publications have dealt directly with more specific aspects of radiological protection in medicine:

- *Publication 106:* Radiation dose to patients from radiopharmaceuticals (ICRP, 2008).
- *Publication 112:* Preventing accidental exposures from new external beam radiation therapy technologies (ICRP, 2009a).
- *Publication 113:* Education and training in radiological protection for diagnostic and interventional procedures (ICRP, 2009b).
- *Publication 117:* Radiological protection in fluoroscopically guided procedures performed outside the imaging department (the present publication).
- Radiological protection in cardiology (ICRP, 2013).
- Radiological protection in paediatric diagnostic and interventional radiology (ICRP, forthcoming).

In addition, several other ICRP publications in the same general field are under development. All of this points to the fact that radiological protection in medicine remains a major priority for ICRP.

Several of the publications referred to above, and many earlier ICRP publications not mentioned here, focus on specific clinical settings. Organising guidance in this way permits healthcare staff to refer to a single publication (or, at least, a small number of publications) relevant to their field of medicine.

The present publication was developed to address a number of emerging radiological protection issues related to certain fluoroscopically guided procedures. The use of fluoroscopy outside imaging departments is increasing rapidly; in some cases, radiological protection considerations are lagging behind, resulting in increased risks to healthcare staff and patients.

In addition, there have been recent reports of opacities detected in the lens of the eye among some groups of healthcare workers using fluoroscopy in interventional radiology and cardiology. If these effects are seen here, the potential for such effects exists for other uses of fluoroscopy outside imaging departments. To date, this appears to be the only circumstance where occupational exposures to ionising radiation may be routinely resulting in clinically observable tissue reactions.

The present publication provides guidance to healthcare workers and employers with respect to the provision of adequate training and assessment of competency, provision of safety equipment, and quality control of fluoroscopy equipment. It also provides guidance relevant to manufacturers of fluoroscopy equipment, suggesting features that could be included to improve the safety of both patients and healthcare workers.

Like all ICRP publications, the present publication aims to improve safety for workers, patients, and members of the public.

Christopher Clement
ICRP Scientific Secretary

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ELSEVIER

ICRP Publication 117

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Radiological Protection in Fluoroscopically Guided Procedures Performed Outside the Imaging Department

ICRP PUBLICATION 117

Approved by the Commission in October 2011

Abstract–An increasing number of medical specialists are using fluoroscopy outside imaging departments, but there has been general neglect of radiological protection coverage of fluoroscopy machines used outside imaging departments. Lack of radiological protection training of those working with fluoroscopy outside imaging departments can increase the radiation risk to workers[1] and patients. Procedures such as endovascular aneurysm repair, renal angioplasty, iliac angioplasty, ureteric stent placement, therapeutic endoscopic retrograde cholangio-pancreatography, and bile duct stenting and drainage have the potential to impart skin doses exceeding 1 Gy. Although tissue reactions among patients and workers from fluoroscopy procedures have, to date, only been reported in interventional radiology and cardiology, the level of fluoroscopy use outside imaging departments creates potential for such injuries.

A brief account of the health effects of ionising radiation and protection principles is presented in Section 2. Section 3 deals with general aspects of the protection of workers and patients that are common to all, whereas specific aspects are covered in Section 4 for vascular surgery, urology, orthopaedic surgery, obstetrics and gynaecology, gastroenterology and hepatobiliary system, and anaesthetics and pain management. Although sentinel lymph node biopsy involves the use of radio-isotopic methods rather than fluoroscopy, performance of this procedure in operating theatres is covered in this report as it is unlikely that this topic will be addressed in another ICRP publication in coming years. Information on radiation dose levels to patients and workers, and dose management is presented for each speciality.

[1] The term 'worker' is defined by the Commission in *Publication 103* (ICRP, 2007) as 'any person who is employed, whether full time, part time or temporarily, by an employer, and who has recognized rights and duties in relation to occupational radiological protection'. In this document, both terms are used: 'worker' in the context as above and 'staff' where use of 'worker' appears inappropriate.

Issues connected with pregnant patients and pregnant workers are covered in Section 5. Although ICRP has recently published a report on training, specific needs for the target groups in terms of orientation of training, competency of those who conduct and assess specialists, and guidelines on the curriculum are provided in Section 6.

This report emphasises that patient dose monitoring is essential whenever fluoroscopy is used.

It is recommended that manufacturers should develop systems to indicate patient dose indices with the possibility of producing patient dose reports that can be transferred to the hospital network, and shielding screens that can be effectively used for the protection of workers using fluoroscopy machines in operating theatres without hindering the clinical task.

Keywords: Radiological Protection; Fluoroscopy; Radiation; Dose

Authors on Behalf of ICRP

M.M. Rehani, O. Ciraj-Bjelac,
E. Vañó, D.L. Miller, S. Walsh,
B.D. Giordano, J. Persliden

Reference

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CONTENTS

PREFACE

Over the years, the International Commission on Radiological Protection (ICRP), referred to below as 'the Commission', has issued many reports providing advice on radiological protection and safety in medicine. *Publication 105* (ICRP, 2007b) is a general overview of this area. These reports summarise the general principles of radiological protection, and provide advice on the application of these principles to the various uses of ionising radiation in medicine and biomedical research.

At the Commission's meeting in Oxford, UK in September 1997, steps were initiated to produce reports on topical issues in medical radiological protection. It was realised that these reports should be written in a style which is understandable to those who are directly concerned in their daily work, and that every effort should be taken to ensure wide circulation of such reports.

Several such reports have already appeared in print (*Publications 84, 85, 86, 87, 93, 94, 97, 98, 102, 105, 112, 113* and *Supporting Guidance 2*) (ICRP, 2000a-d, 2001,2004a,b,2005a,b2007a,b,2009a,b).

After more than a century of use of x-rays to diagnose and treat disease, the expansion of their use to areas outside imaging departments is much more common today than at any time in the past.

In *Publication 85* (2000b), the Commission dealt with avoidance of radiation injuries from medical interventional procedures. Another ICRP publication targeted at cardiologists is forthcoming (ICRP, 2013). Procedures performed by orthopaedic surgeons, urologists, gastroenterologists, vascular surgeons, anaesthetists and others, either by themselves or in conjunction with radiologists, were not covered in earlier publications of the Commission, but there is a substantial need for guidance in this area given the increased use of radiation and the lack of training.

The present publication is aimed at filling this need.

The membership of the Task Group was as follows:

M.M. Rehani (Chairman)	E. Vañó
B.D. Giordano	J. Persliden

The corresponding members were:

O. Ciraj-Bjelac	D.L. Miller
S. Walsh	

In addition, C. Cousins and J. Lee, ICRP Main Commission members, made important contributions as critical reviewers.

The membership of Committee 3 during the period of preparation of this report was:

E. Vañó (Chairman)
M.R. Baeza
L.T. Dauer
J.W. Hopewell
P. Ortiz López
D.L. Miller
H. Ringertz
Y. Yonekura
M.M. Rehani (Secretary)
J.M. Cosset
I. Gusev
P.-L. Khong
S. Mattsson
K.Å. Riklund
M. Rosenstein
B. Yue

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MAIN POINTS

- **An increasing number of medical specialists are using fluoroscopy outside imaging departments, and expansion of its use is much greater today than at any time in the past.**
- **There has been general neglect of radiological protection coverage of fluoroscopy machines used outside imaging departments.**
- **Lack of radiological protection training of workers using fluoroscopy outside imaging departments can increase the radiation risk to workers and patients.**
- **Although tissue reactions among patients and workers from fluoroscopy procedures have, to date, only been reported in interventional radiology and cardiology, the level of fluoroscopy use outside imaging departments creates potential for such injuries.**
- **Procedures such as endovascular aneurysm repair, renal angioplasty, iliac angioplasty, ureteric stent placement, therapeutic endoscopic retrograde cholangio-pancreatography, and bile duct stenting and drainage have the potential to impart skin doses exceeding 1 Gy.**
- **Radiation dose management for patients and workers is a challenge that can only be met through an effective radiological protection programme.**
- **Patient dose monitoring is essential whenever fluoroscopy is used.**
- **Medical radiation applications on pregnant patients should be justified and tailored to reduce fetal dose.**
- **Termination of pregnancy at fetal doses of $<$100 mGy is not justified based upon radiation risk.**
- **The restriction of a dose of 1 mSv to the embryo/fetus of a pregnant worker after declaration of pregnancy does not mean that it is necessary for a pregnant woman to avoid work with radiation completely, or that she must be prevented from entering or working in designated radiation areas.**
- **Pregnant medical workers may work in a radiation environment provided that there is reasonable assurance that the fetal dose can be kept below 1 mSv during the course of pregnancy. It does, however, imply that the employer should review the exposure conditions of pregnant women carefully**
- **Every action to reduce patient dose will have a corresponding impact on occupational dose, but the reverse is not true.**
- **Recent reports of opacities in the eyes of workers who use fluoroscopy have drawn attention to the need to strengthen radiological protection measures for the eyes.**
- **The use of radiation shielding screens for protection of workers using x-ray machines in operating theatres is recommended, wherever feasible.**
- **A training programme in radiological protection for healthcare professionals has to be oriented towards the type of practice in which the target audience is involved.**
- **A worker's competency to carry out a particular function should be assessed by individuals who are suitably competent themselves.**
- **Periodic quality control testing of fluoroscopy equipment can provide confidence in equipment safety.**
- **Manufacturers should develop systems to indicate patient dose indices with the possibility of producing patient dose reports that can be transferred to the hospital network.**
- **Manufacturers should develop shielding screens that can be effectively used for the protection of workers using fluoroscopy machines in operating theatres without hindering the clinical task.**

1. WHAT IS THE MOTIVATION FOR THIS REPORT?

- **An increasing number of medical specialists are using fluoroscopy outside imaging departments, and expansion of its use is much greater today than at any time in the past.**
- **There has been general neglect of radiological protection coverage of fluoroscopy machines used outside imaging departments.**
- **Lack of radiological protection training of workers using fluoroscopy outside imaging departments can increase the radiation risk to workers and patients.**
- **Recent reports of opacities in the eyes of workers who use fluoroscopy have drawn attention to the need to strengthen radiological protection measures for the eyes.**

1.1. Which procedures are of concern and who is involved?

(1) After more than a century of the use of x rays to diagnose and treat disease, the expansion of their use to areas outside imaging departments is much more common today than at any time in the past. The most significant use of x rays outside radiology has been in interventional procedures, predominantly in cardiology, but there are also a number of other clinical specialities where fluoroscopy is used to guide medical or surgical procedures.

(2) In *Publication 85* (ICRP, 2001), the Commission dealt with the avoidance of radiation injuries from medical interventional procedures. Another ICRP publication targeted at cardiologists is forthcoming (ICRP, 2013). Procedures performed by orthopaedic surgeons, urologists, gastroenterologists, vascular surgeons, anaesthetists (or anaesthesiologists), and others, either by themselves or in conjunction with radiologists, were not covered in earlier publications of the Commission, but there is a substantial need for guidance in this area in view of the increased use of radiation and the lack of training. Practices vary widely across the world, as does the role of radiologists. In some countries, radiologists play a major role in such procedures. These procedures and the medical specialists involved are listed in Table 1.1, although the list is not exhaustive.

(3) These procedures allow medical specialists to treat patients and achieve the desired clinical objective. In many situations, these procedures are less invasive, result in decreased morbidity and mortality, are less costly, and result in shorter hospital stays than the alternative surgical procedures, or may be the best alternative if the patient cannot have an open surgical procedure. In some situations, these procedures may be the only alternative, particularly for very elderly patients.

(4) In addition to fluoroscopy procedures outside imaging departments, this report also addresses sentinel lymph node biopsy (SLNB), which uses radiopharmaceuticals as a radiation source rather than x rays. It was deemed appropriate to cover this in this report as it is unlikely that this topic will be addressed in another ICRP publication in coming years, and the topic requires attention from the radiological protection angle.

Table 1.1. Examples of common procedures (not exhaustive) that may be performed in or outside imaging departments (adapted from NCRP, 2011).

Organ system or region	Procedure
Bones, joints, or musculoskeletal Specialities: • Radiology • Orthopaedics • Neurosurgery • Anaesthesiology • Neurology	Fracture/dislocation reduction Implant guidance for anatomical localisation, orientation, and fixation Deformity correction Needle localisation for injection, aspiration, or biopsy Anatomical localisation to guide incision location Adequacy of bony resection Foreign body localisation Biopsy Vertebroplasty Kyphoplasty Embolisation Tumour ablation Nerve blocks Diagnostic (ipsilateral femoral neck/shaft fracture) Intramedullary nailing Kirshner wire/external fixator pin placement Percutaneous hardware placement Ligament reconstruction Trauma Level confirmation Cyst aspiration Radiofrequency ablation Assessment of limb alignment/joint line
Gastrointestinal tract Specialities: • Radiology • Gastroenterology	Percutaneous gastrostomy Percutaneous jejunostomy Biopsy Stent placement Diagnostic angiography Embolisation
Kidney and urinary tract Specialities: • Radiology • Urology	Biopsy Nephrostomy Ureteric stent placement Stone extraction Tumour ablation Intravenous pyelography/urography Cystometrography Cystography Excretion urography Urethrography Percutaneous nephrolithotomy Extracorporeal shock wave lithotripsy Kidney stent insertion

Table 1.1. (*continued*)

Organ system or region	Procedure
Liver and biliary system Specialities: • Radiology • Gastroenterology	Biopsy Percutaneous biliary drainage Endoscopic retrograde cholangio-pancreatography Percutaneous cholecystostomy Stone extraction Stent placement Transjugular intrahepatic portosystemic shunt Chemo-embolisation Tumour ablation Percutaneous transhepatic cholangiography Bile duct drainage
Reproductive tract Specialities: • Radiology • Obstetrics and gynaecology	Hysterosalpingography Embolisation Pelvimetry
Vascular system Specialities: • Radiology • Cardiology • Vascular surgery • Nephrology	Diagnostic venography Angioplasty Stent placement Embolisation Stent-graft placement Venous access Inferior vena cava filter placement Endovascular aneurysm repair
Central nervous system Specialities: • Radiology • Neurosurgery • Neurology	Diagnostic angiography Embolisation Thrombolysis
Chest Specialities: • Radiology • Vascular surgery • Internal medicine	Biopsy Thoracentesis Chest drain placement Pulmonary angiography Pulmonary embolisation Thrombolysis Tumour ablation

1.2. Who has the potential to receive high radiation doses?

(5) For many years, it was a common expectation that people who work full time in departments where radiation is used on a daily basis need to have radiological protection training and monitoring of their radiation doses. These departments include radiotherapy, nuclear medicine, and diagnostic radiology. As a result, many national regulatory authorities had the notion that if they looked after these facilities, they had fulfilled their responsibilities for radiological protection. In many countries, this is still the situation. However, the use of x rays for diagnostic or interventional procedures outside these departments has increased markedly in recent years. Fluoroscopy machines are of particular concern because of their potential for causing relatively high exposures of workers or patients. There are examples of

countries where national authorities have no idea about how many fluoroscopy machines exist in operating theatres outside the control of imaging departments. Workers in radiotherapy facilities either work away from the radiation source or only work near heavily shielded sources. As a result, in normal circumstances, occupational radiation exposure is typically minimal. Even if radiation is always present in nuclear medicine facilities, overall exposure of workers can still be less than the exposure for those who work near an x-ray tube, as the intensity of radiation from x-ray tubes is very high. The situation in imaging [radiography and computed tomography (CT)] is similar, in the sense that workers normally work away from the radiation sources, and are based at consoles that are shielded from the x-ray radiation source. On the other hand, working in a fluoroscopy room typically requires that workers stand near the x-ray source (both the x-ray tube itself and the patient, who is a source of scattered x rays). The radiation exposure of workers in fluoroscopy rooms can be more than the exposure of those working in radiotherapy or nuclear medicine, or those working in imaging who do not work with fluoroscopic equipment. The actual dose depends upon the time spent in the fluoroscopy room (when the fluoroscope is being used), the shielding garments used (lead apron, thyroid and eye protection), the mobile ceiling-suspended screen and other hanging lead flaps that are employed, as well as equipment parameters. In general, for the same amount of time spent in radiation work, the radiation exposure of workers in a fluoroscopy room will be higher than that of workers who do not work in a fluoroscopy room. If medical procedures require large amounts of radiation from lengthy fluoroscopy or multiple images, such as in vascular surgery, these workers may receive substantial radiation doses and therefore need a higher degree of radiological protection through the use of appropriate training and protective tools. The use of fluoroscopy for endovascular repair of straightforward abdominal and thoracic aortic aneurysms by vascular surgeons is increasing, and radiation levels are similar to those in interventional radiology and interventional cardiology. Over the next few years, the use of more complex endovascular devices, such as branched and fenestrated stents for the visceral abdominal aorta and the arch and great vessels, is likely to increase. These procedures are long and complex, requiring prolonged fluoroscopic screening. They also often involve extended periods during which the entrance surface of the radiation remains fixed relative to the x-ray tube, increasing the risk of skin injury. Image-guided injections by anaesthetists for pain management is also increasing.

1.3. Lack of training, knowledge, awareness, and skills in radiological protection

(6) In many countries, non-radiologist professionals work with fluoroscopy without direct support from their colleagues in radiology, using equipment that may range from fixed angiographic facilities, similar to an imaging department, to mobile image intensifier fluoroscopy systems. In most cases, physicians using fluoroscopy outside the imaging department (orthopaedic surgeons, urologists, gastroenterologists, vascular surgeons, gynaecologists, anaesthetists, etc.) have either minimal or no training in radiological protection, and may not have regular access to those

professionals who do have training and expertise in radiological protection, such as medical physicists. Radiographers/technologists working in these facilities outside radiology or cardiology departments may only be familiar with one or two specific fluoroscopy units used in the facility. Thus, their skills, knowledge, and awareness may be limited. Nurses in these facilities typically have limited skills, knowledge, and awareness of radiological protection. The lack of radiological protection culture in these settings adds to patient and occupational risk.

1.4. Patient vs occupational radiation doses

(7) It has commonly been believed that occupational radiological protection is much more important than patient protection. The underlying bases for this belief are that: (1) workers are likely to work with radiation for their entire career, (2) patients undergo radiation exposure for their own benefit, and (3) patients are only exposed to radiation for medical purposes a few times in their life. While the first two bases still hold, the situation with regard to the third point has changed drastically in recent years. Patients are undergoing examinations and procedures many times. Moreover, the types of examinations that patients undergo nowadays involve higher doses compared with several decades ago. Radiography was the mainstay of investigation in the past. In recent years, CT has become very common. A CT scan imparts a radiation dose to the patient that is equivalent to several hundreds of radiographs. In the past, fluoroscopic examinations were largely diagnostic, whereas nowadays, a larger number of fluoroscopic procedures are interventional and these impart a higher radiation dose to patients. An increase in the frequency of use of higher dose procedures per patient has been reported (NCRP, 2009). Many patients receive radiation doses that exceed the typical occupational dose that workers may receive during their entire career.

(8) According to the latest UNSCEAR report, the average annual dose (worldwide) for occupational exposure in medicine is 0.5 mSv/year (UNSCEAR, 2010). For a person working for 45 years, the total dose may be 22.5 mSv over their full working life. The emphasis on occupational radiological protection in the past century has yielded excellent results, as evidenced by the above figure, and occupational doses seem well under control. However, there are examples of very poor adoption of personal monitoring measures in many countries among those covered in this report.

(9) It is unfortunate that, particularly in clinical areas covered in this report, radiological protection of patients has not received much attention. Surveys conducted by the IAEA among non-radiologists and non-cardiologists from over 30 developing countries indicate that there is an almost complete (in over 90% of situations) lack of patient dose monitoring (IAEA, 2010). Surveys of the literature indicate a lack of reliable data on occupational doses in settings outside imaging departments. This needs to be changed.

1.5. Fear and overconfidence

(10) In the absence of knowledge and awareness, people tend to either overestimate or underestimate risk. Either they have unfounded fears or they have a disregard for appropriate protection. It is common practice for young medical residents to observe how their seniors deal with situations. They start with inquisitive minds about radiation risks, but if they find that their seniors are not greatly concerned about radiological protection, they tend to slowly lose interest and enthusiasm. This is not uncommon among the clinical specialists covered in this report. If residents do not have access to medical physicist experts, which is largely the case, they follow the example of their seniors, leading to fear in some cases and disregard in others. This is an issue of radiation safety culture, and propagation of an appropriate safety culture should be considered the responsibility of senior medical staff.

1.6. Training

(11) Historically, in many hospitals, x-ray machines were only located in imaging departments, so non-radiologists who performed procedures using this equipment had radiologists and radiographers/technologists available for advice and consultation. In this situation, there was typically some orientation of non-radiologists in radiological protection based on practical guidance. With time, as the use of radiation increased and x-ray machines were installed in other departments and areas of the hospital, outside the control of imaging departments, the absence of training has become evident and needs attention. In surveys conducted by the IAEA in training courses for non-radiologists and non-cardiologists (http://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Training/2_TrainingEvents/Doctorstraining.htm), it is clear that most non-radiologists and non-cardiologists in developing countries have not undergone training in radiological protection, and that medical meetings and conferences of these specialists typically include no lectures on, or component of, radiological protection. This lack of training in radiological protection poses risks to workers and patients, and needs to be corrected. The Commission recommends that the level of training in radiological protection should be commensurate with the use of radiation (ICRP, 2009).

1.7. Why this report?

(12) The use of radiation is increasing outside imaging departments. The fluoroscopy equipment is becoming more sophisticated and can deliver higher radiation doses in a short time; therefore, fluoroscopy time alone is not a good indicator of radiation dose. There is a near absence of patient dose monitoring in the settings covered in this report. Overexposures from digital x-ray equipment may not be detected, machines that are not tested under a quality control system can give higher radiation doses and poor image quality, and repeated radiological procedures increase cumulative patient radiation doses. There are a number of image quality factors that, if not taken into account, can deliver poor-quality images and a higher

radiation dose to patients. On the other hand, there are simple techniques that use the principles of time, distance, and shielding (Sections 3 and 4) to help ensure the safety of both patients and workers. Lessons drawn from other situations, not directly involving fluoroscopy machines outside radiology, demonstrate that both accidental exposures and routine overexposures can occur, resulting in undesirable health effects of ionising radiation for patients and workers (ICRP, 2001; Ciraj-Bjelac et al., 2010; Vañó et al., 2010; http://www.nytimes.com/2010/08/01/health/01radiation.html?_r=3&emc=eta1). Radiation shielding screens and flaps are lacking in many fluoroscopy machines used in operating theatres, and radiological protection workers outside radiology and cardiology departments face specific problems. Personal dosimeters are not used by some professionals or their use is irregular. As a consequence, occupational doses in several practices are largely unknown.

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2. HEALTH EFFECTS OF IONISING RADIATION

- **Although tissue reactions among patients and workers from fluoroscopy procedures have, to date, only been reported in interventional radiology and cardiology, the level of fluoroscopy use outside imaging departments creates potential for such injuries.**
- **Patient dose monitoring is essential whenever fluoroscopy is used.**

2.1. Introduction

(13) Most people, health professionals included, do not realise that the intensity of radiation from an x-ray tube is typically hundreds of times higher than that from radioactive substances (radio-isotopes and radiopharmaceuticals) used in medicine. This lack of understanding has been partially responsible for the lack of radiological protection among many users of x rays in medicine. The level of radiological protection practice tends to be better in facilities using radioactive substances. For practical purposes, this report is concerned with the health effects of ionising radiation from x rays, which are electromagnetic radiation like visible light, ultra violet light, infra-red radiation, radiation from mobile phones, radio waves, and microwaves. The major difference is that these other types of electromagnetic radiation are non-ionising and dissipate their energy through thermal interaction (dissipation of energy through heat). This is how microwave diathermy and microwave ovens work. On the other hand, x rays are forms of ionising radiation – they may interact with atoms and can cause ionisation in cells. They may produce free radicals or direct effects that can damage DNA or cause cell death.

2.2. Radiation exposure in context

(14) As a global average, the natural background radiation in terms of effective dose is 2.4 mSv/year (UNSCEAR, 2010). In some countries, typical background radiation is approximately 1 mSv/year, and in other countries, it is approximately 3 mSv/year. There are some areas in the world, (e.g. India, Brazil, Iran) where the population is exposed to background radiation levels in terms of effective dose of 5–15 mSv/year. The Commission has recommended a whole-body effective dose limit for workers of 20 mSv/year (averaged over a defined 5-year period; 100 mSv in 5 years) and other limits as shown in Table 2.1 (ICRP, 2007, 2012).

(15) It must be emphasised that individuals who work with fluoroscopy machines and use the radiological protection tools and methods described in this report can keep their radiation dose from work with x rays to less than or around 1 mSv/year; thus, there is a role for radiological protection.

Table 2.1. Occupational dose limits (ICRP, 2007, 2012).

Type of limit	Occupational limit
Effective dose	20 mSv/year, averaged over a defined 5-year period
Annual equivalent dose in:	
Lens of the eye	20 mSv
Skin	500 mSv
Hands and feet	500 mSv

2.3. Health effects of ionising radiation

(16) Health effects of ionising radiation are classified into two types: those that are visible, documented, and confirmed within a relatively short time (weeks to a year or so) [called 'tissue reactions' or (formerly) 'deterministic effects': skin erythema, hair loss, cataract, infertility, circulatory disease]; and those that are only estimated and may take years or decades to manifest (called 'stochastic effects': cancer and genetic effects).

2.3.1. Tissue reactions

(17) Tissue reactions have thresholds that are typically quite high (Table 2.2). For workers, these thresholds are not normally reached when good radiological protection practices are used. For example, skin erythema used to occur in the hands of workers a century ago, but this has rarely happened in the last 50 years or so in workers using medical x rays. There are a large number of reports of skin injuries among patients from fluoroscopic procedures in interventional radiology and cardiology (ICRP, 2001; Balter et al., 2010), but none, to date, in other areas of fluoros-

Table 2.2. Thresholds for tissue reactions (ICRP, 2007).

Tissue and effect	Threshold	
	Total dose in a single exposure (Gy)	Annual dose in the case of fractionated exposure (Gy/year)
Testes		
Temporal sterility	0.1	0.4
Permanent sterility	6.0	2.0
Ovaries		
Sterility	3.0	>0.2
Lens		
Cataract (visual impairment)	0.5	0.5 divided by years of duration
Bone marrow		
Depression of haematopoiesis	0.5	>0.4
Heart or brain		
Circulatory disease	0.5	0.5 (total dose for fractionated exposure)

copy use. Hair loss has been reported on the legs of interventional radiologists and cardiologists in the area unprotected by the lead apron or lead table shield (Wiper et al., 2005; Rehani and Ortiz López, 2006), but has not been reported in orthopaedic surgery, urology, gastroenterology, or gynaecology because x rays are used to a lesser extent in these specialities. Although there is a lack of information regarding these injuries in vascular surgeons, these specialists use large amounts of radiation, and their exposure can match that of interventional cardiologists or radiologists. This creates the potential for tissue reactions in both patients and workers. Infertility is unlikely at the dose levels encountered in radiation work in fluoroscopy suites or even in interventional laboratories.

(18) The lens of the eye is one of the more radiosensitive tissues in the body (ICRP, 2012). Radiation-induced cataracts have been demonstrated among workers involved with interventional procedures using x rays (Vañó et al., 1998; ICRP, 2001). A number of studies have suggested that there may be a substantial risk of lens opacities in populations exposed to low doses of ionising radiation. These include patients undergoing CT scans (Klein et al., 1993), astronauts (Cucinotta et al., 2001; Rastegar et al., 2002), radiological technologists/radiographers (Chodick et al., 2008), atomic bomb survivors (Nakashima et al., 2006; Neriishi et al., 2007), and those exposed in the Chernobyl accident (Day et al., 1995).

(19) Until recently, cataract formation was considered to be a tissue reaction with a threshold for detectable opacities of 5 Sv for protracted exposures and 2 Sv for acute exposures (ICRP, 2001, 2012). The Commission continues to recommend that optimisation of protection should be applied in all exposure situations and for all categories of exposure. With the recent evidence, the Commission further emphasises that protection should be optimised not only for whole-body exposures, but also for exposures to specific tissues, particularly the lens of the eye, the heart, and the cerebrovascular system. The Commission has now reviewed recent epidemiological evidence suggesting that there are some tissue reaction effects, particularly those with very late manifestation, where threshold doses are or may be lower than previously considered. For the lens of the eye, the threshold in absorbed dose is now considered to be 0.5 Gy. Also, although uncertainty remains, medical practitioners should be made aware that the absorbed dose threshold for circulatory disease may be as low as 0.5 Gy to the heart or brain. For occupational exposure in planned exposure situations, the Commission now recommends an equivalent dose limit for the lens of the eye of 20 mSv/year, averaged over a defined 5-year period, with no single year exceeding 50 mSv (ICRP, 2012).

(20) If doctors and workers remain near the x-ray source and within a high scatter radiation field for several hours per day, and do not use radiological protection tools and methods, the risk may become substantial. Two recent studies conducted by the IAEA have shown a higher prevalence of lens changes in the eyes of interventional cardiologists and nurses working in cardiac catheterisation laboratories compared to the control group (Ciraj-Bjelac et al., 2010; Vañó et al., 2010).

2.3.2. Stochastic effects

(21) Stochastic effects include cancer and genetic effects, but the scientific evidence for cancer in humans is stronger than that for genetic effects. According to *Publication 103* (ICRP, 2007), the detriment-adjusted nominal risk coefficient for stochastic effects for the whole population after exposure to radiation at a low dose rate is 5.5%/Sv for cancer and 0.2%/Sv for genetic effects. Therefore, carcinogenic effects are 27 times more likely than genetic effects. To date, there have been no documented cases of radiation-induced genetic effects in humans, even in survivors of Hiroshima and Nagasaki. All of the literature on genetic effects comes from non-human species, where the effects have been documented in thousands of papers. As a result, and after careful review of many decades of literature, the Commission reduced the tissue weighting factor for the gonads by more than half from 0.2 to 0.08 (ICRP, 2007). Thus, emphasis is placed on cancer in this report.

(22) Cancer risks are estimated on the basis of probability, and are derived mainly from the survivors of Hiroshima and Nagasaki. Therefore, these risks are estimated risks. With the current state of knowledge, carcinogenic effects are more likely for organ doses of >100 mGy. For example, a chest CT scan that yields approximately 8 mSv effective dose can deliver approximately 20 mGy dose to the breast; five CT scans will therefore deliver approximately 100 mGy. There may be controversies about cancer risk at the radiation dose from one or a few CT scans, but the doses encountered from five to 15 CT scans approach the exposure levels where risks have been documented. As radiation doses to patients from fluoroscopic procedures vary greatly, one must determine the dose to get an approximate idea of the cancer risk. It must be mentioned that cancer risk estimates are based on models of a nominal standard human, and cannot be considered to be valid for a specific individual person. As stochastic risks have no threshold, and the Commission considers that the linear no-threshold relationship of dose effect is valid down to any level of radiation exposure, the risk, however small, is assumed to remain even at very low doses. The best way to achieve protection is to optimise exposures, keeping radiation exposure as low as reasonably achievable, commensurate with clinically useful images.

2.3.3. Individual differences in radiosensitivity

(23) It is well known that different tissues and organs have different radiosensitivities, and that females are generally more radiosensitive than males to cancer induction. The same is true for young patients (increased radiosensitivity) compared with older patients. For example, the lifetime attributable risk of lung cancer for a woman after an exposure of 0.1 Gy at 60 years of age is estimated to be 126% higher than that for a man exposed to the same dose at the same age (BEIR, 2006). If a man is exposed to radiation at 40 years of age, his risk of lung cancer is estimated to be 17% higher than if he was exposed to the same radiation dose at 60 years of age. These general aspects of radiosensitivity should be taken into account in the process of justification and optimisation of radiological protection in fluoroscopically guided procedures because, in some cases, the radiation dose level may be rel-

atively high for several organs. There are also individual genetic differences in susceptibility to radiation-induced cancer, and these should be considered in specific cases involving higher doses based on family and clinical history (ICRP, 1999).

(24) Pre-existing auto-immune and connective tissue disorders predispose patients to the development of severe skin injuries in an unpredictable fashion. The cause is not known. These disorders include scleroderma, systemic lupus erythematosus, and possibly rheumatoid arthritis, although there is controversy regarding whether systemic lupus erythematosus predisposes patients to these effects. Genetic disorders that affect DNA repair, such as the defect in the *ATM* gene responsible for ataxia telangiectasia, also predispose individuals to increased radiation sensitivity. Diabetes mellitus, a common medical condition, does not increase sensitivity to radiation, but does impair healing of radiation injuries (Balter et al., 2010).

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3. PATIENT AND OCCUPATIONAL PROTECTION

- **Manufacturers should develop systems to indicate patient dose indices with the possibility to produce patient dose reports that can be transferred to the hospital network.**
- **Manufacturers should develop shielding screens that can be used for the protection of workers using fluoroscopy machines in operating theatres without hindering the clinical task.**
- **Every action to reduce patient dose will have a corresponding impact on occupational dose, but the reverse is not true.**
- **Periodic quality control testing of fluoroscopy equipment can provide confidence in equipment safety.**
- **The use of radiation shielding screens for protection of workers using x-ray machines in operating theatres is recommended, wherever feasible.**

3.1. General methods and principles of radiological protection

(25) The basic principles of radiological protection are justification, optimisation, and dose limits. Time, distance, and shielding form the key aspects of methods to achieve optimisation as applicable to the situations within the scope of this report.

3.1.1. Time

(26) The duration of radiation use should be minimised. This is effective whether the object of minimisation is fluoroscopy time or the number of frames or images acquired.

3.1.2. Distance

(27) Distance from the x-ray source should be as much as is practical (this can reduce the radiation dose by a factor of 2–20 or more) (see Section 3.3.2 and Fig. 3.3).

3.1.3. Shielding

(28) Shielding should be used effectively. It is most effective as a tool for occupational protection (Section 3.4.1), and has a limited role for protecting patients' body parts, such as the breasts, female gonads, eyes, and thyroid, in fluoroscopy (with the exception of male gonads).

3.1.4. Justification

(29) The benefits of many procedures that use ionising radiation are well established and well accepted by the medical profession and society at large. When a procedure involving radiation is medically justifiable, the anticipated benefits are almost always identifiable and are sometimes quantifiable. On the other hand, the risk of adverse consequences is often difficult to estimate and quantify. In *Publication*

103, the Commission stated as a principle of justification that 'Any decision that alters the radiation exposure situation should do more good than harm' (ICRP, 2007a). The Commission has recommended a multi-step approach to justification of patient exposures in *Publication 105* (ICRP, 2007b). In the case of the individual patient, justification normally involves both the referring medical practitioner (who refers the patient and may be the patient's physician/surgeon) and the radiological medical practitioner (under whose responsibility the examination is conducted).

3.1.5. Optimisation

(30) Once examinations are justified, they must be optimised (i.e. can they be done at a lower dose while maintaining efficacy and accuracy?). Optimisation of the protection should be generic for the examination type and all the equipment and procedures involved. It should also be specific for the individual, and consideration should be given to whether or not it can be effectively done in a way that reduces dose for the particular patient (ICRP, 2007b).

3.2. Requirements for the facility

(31) Practice varies worldwide and there should be compliance with requirements laid down by national authorities. Typically, each x-ray machine should be registered with the appropriate state database under the overall oversight of national regulatory authority. Frequently, during the process of registration and authorisation, the authority will examine the specifications of the machine and the room where it is going to be used in terms of size and shielding. At international level, safety requirements for x-ray machines have been provided by international organisations such as the International Electrotechnical Commission and the International Standards Organization. In many countries, there are national standards for x-ray machines which are applicable. These considerations are aimed at protection of workers and members of the public who may be exposed. The process will also include availability of qualified staff. There are requirements for periodic quality control tests for constancy check and performance evaluation. Periodic quality control testing of fluoroscopy equipment can provide confidence in equipment safety and its ability to provide images of optimal image quality. If a machine is not working properly, it can provide unnecessary radiation dose to the patient and poor-quality images. Nevertheless, whatever national requirements are, it is essential that they are followed in order to ensure that facility design and operation is safe for patients, workers, and the public.

3.3. Common aspects of patient and occupational protection

(32) Many common factors affect both patient and occupational doses. Every action that reduces patient dose will also reduce occupational dose, but the reverse is not true. Workers using lead aprons, leaded glass eyewear, or other types of shields may reduce their own radiation dose, but these protective devices do not reduce

patient dose. In some situations, a sense of feeling safe on the part of the staff may lead to neglect of patient protection. Therefore, involvement of the medical physicist in patient and occupational dose optimisation and audit, particularly for higher dose procedures, is essential. Specific factors of occupational protection are covered in Section 3.4.

3.3.1. Patient-specific factors

Thickness of the body part in the beam

Most fluoroscopy machines adjust radiation exposure automatically through a system called 'automatic exposure control'. This electronic system has a sensor that detects how much signal is being produced at the image receptor, and adjusts the x-ray generator to increase or decrease exposure factors (typically kV, mA, and pulse time) so that the image is of consistent quality. When a thicker body part is in the beam, or a thicker patient is being imaged (compared with a thinner patient), the machine will automatically increase these exposure factors. The result is a similar image quality but an increase in the radiation dose to the patient. Increased patient dose will result in increased scatter and increased radiation dose to workers. Fig. 3.1 demonstrates the increase in entrance skin dose with body part thickness, while Fig. 3.2. shows how much radiation is absorbed in the patient's body.

Complexity of the procedure

(33) Complexity represents the mental and physical effort required to perform a procedure. The complexity index is an objective measure. An example would be placement of a guide wire or catheter in an extremely tortuous vessel or across a severe, irregular stenosis. Complexity is due to patient factors (anatomical variation, body habitus) and lesion factors (location, size, severity), but is independent of operator training and experience. More complex procedures tend to require higher radiation doses than less complex procedures (IAEA, 2008).

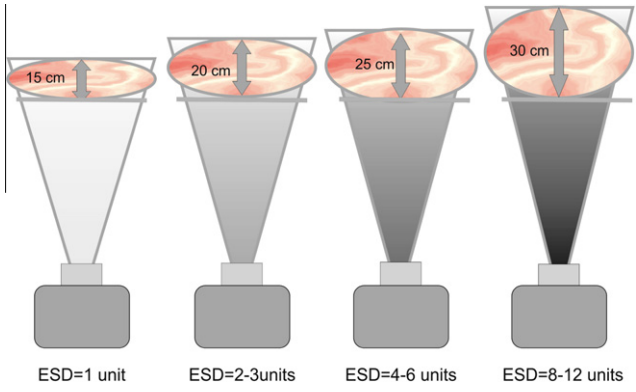

Fig. 3.1. Change in entrance surface dose (ESD) with thickness of body part in the x-ray beam for the same image quality.

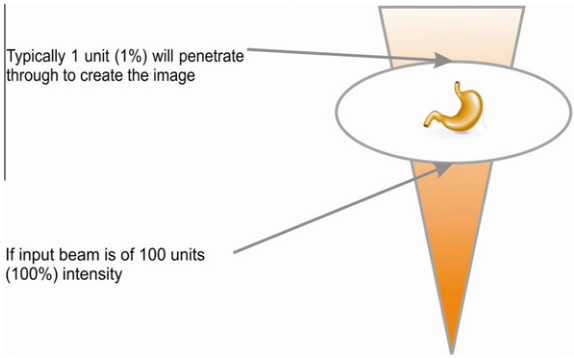

Fig. 3.2. Relative intensities of radiation on entrance and exit side of patient.

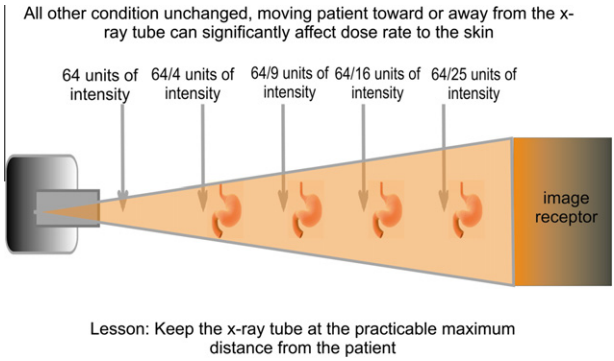

Fig. 3.3. Effect of distance between patient and x-ray tube on radiation dose to patient.

3.3.2. Technique factors

(34) The amount of radiation at the entrance surface of the body is different from the amount of radiation that exits on the exit surface of the body. The body attenuates x rays in an exponential fashion. As a result, radiation intensity decreases exponentially along its path through the body. Typically, only a small percentage of the entrance radiation exits the body. As a result, the major risk of radiation is on the entrance skin. Rotating the x-ray beam to avoid irradiation of the same area of skin is helpful. A large number of skin injuries have been reported in patients undergoing various types of interventional procedures, but to date, these injuries have not been reported as a result of procedures conducted by orthopaedic surgeons, urologists, gastroenterologists, and gynaecologists (ICRP, 2001; Koenig et al., 2001; Rehani and Ortiz López, 2006; Balter et al., 2010). When using overcouch geometry, fingers falling in the primary beam will typically receive doses that are approximately 100 times higher than those received when using undercouch geometry.

(35) In addition, it is important that users understand how their equipment functions, as each equipment has some unique features. The standards provided by the National Electrical Manufacturers Association (www.nema.org) reduce the variations, but there are always features that need to be understood. The complexity of modern equipment is such that the requirement to know your equipment should not be compromised.

Position of the x-ray tube and image receptor

(36) The distance between the x-ray source (the x-ray tube focus) and the patient's skin is called the 'source-to-skin distance' (SSD). As the SSD increases, the radiation dose to the patient's skin decreases (Fig. 3.3) due to the increased distance and the effect of the inverse square law. The patient should be as far away from the x-ray source as practical to maximise the SSD (this may not be possible if it is necessary to keep a specific organ or structure at the isocentre of the gantry). Once the patient is positioned to maximise the SSD, the image receptor (image intensifier or flat panel detector) should be placed as close to the patient as practical. All modern fluoroscopes automatically adjust radiation output during both fluoroscopy and fluorography to accommodate changes in the source to image receptor distance (SID). The radiation output adjustment by the equipment is aimed at maintaining image quality, which implies radiation dose to the image receptor and consequently to the patient (Fig. 3.4). In simplest terms, one should maximise SSD and place the detector as close to the patient as possible. This is an important tool for the prevention of tissue reactions. Mobile C-arm systems used in most cases outside imaging departments have a constant distance between the x-ray tube and the image receptor. In this case, as presented in Fig. 3.3, as SSD increases, the radiation dose to the patient's skin decreases due to the inverse square law effect as $(1/\mathrm{SSD})^2$. However, if this is not the case, it is important to note that geometry (SSD and SID) can influence the entrance skin dose in a complex way. If the detector is close to the patient, shifting the patient away from the source will decrease the skin dose, but will also shift the detector away

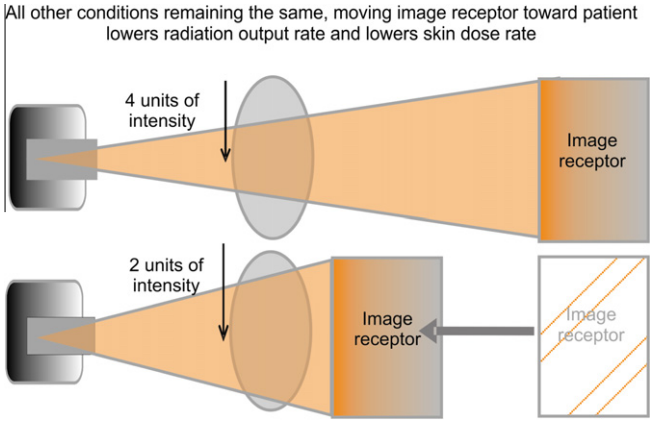

Fig. 3.4. Effect of distance between image intensifier and patient on radiation dose to patient.

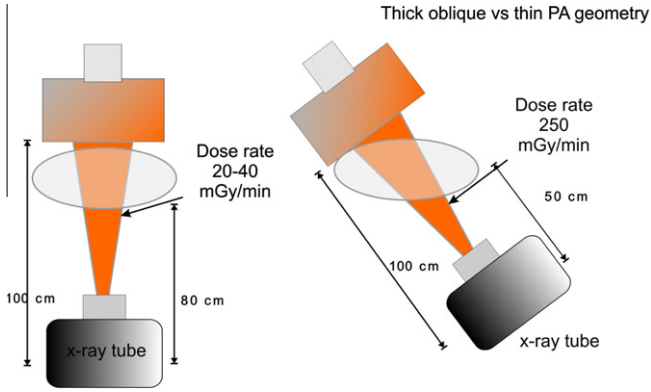

Fig. 3.5. Effect of angulations on patient dose. PA, postero-anterior.

from the source and thus increase the skin dose. In this case, the skin dose rate varies with the ratio $(SID/SSD)^2$ rather than with the simple inverse square law.

Avoid steep gantry angulations when possible

(37) Steep gantry angulations (steep oblique and lateral positions) increase the length of the radiation path through the body compared with a postero-anterior (frontal) projection (Fig. 3.5). A greater thickness of tissue must be penetrated, and this requires higher radiation dose rates. All modern fluoroscopes adjust radiation output automatically during both fluoroscopy and fluorography to accommodate the thickness of the body part being imaged (see Section 3.3.1). In addition to the greater thickness, the decrease in the SSD will result in a further increase in the skin dose. As a result, the radiation dose increases automatically when steep oblique or lateral angulations are used. Whenever possible, steep oblique and lateral gantry positions should be avoided. When these gantry positions are necessary, it should be recognised that the radiation dose is relatively high.

Keep unnecessary body parts out of the x-ray beam

(38) It is good practice to limit the radiation field to those parts of the body that must be imaged. When other body parts are included in the field, image artefacts from bones and other tissues can be introduced into the image. Also, if the arms are in the field while the gantry is in a lateral or oblique position, one arm may be very close to the x-ray tube. The dose to this arm may be sufficiently high to cause skin injury (Fig. 3.6). The patient's arms should be kept outside the radiation field unless an arm is intentionally imaged as part of the procedure.

Use pulsed fluoroscopy at a low pulse rate

(39) Pulsed fluoroscopy uses individual pulses of x rays to create the appearance of continuous motion. At low pulse rates, this can decrease the fluoroscopy dose substantially compared with conventional continuous fluoroscopy if the dose per pulse is constant. Pulsed fluoroscopy should always be used if it is available, with the low-

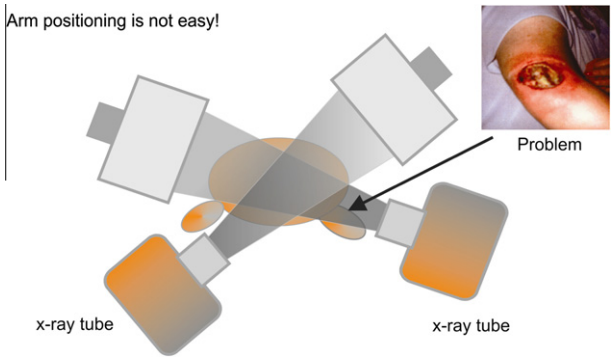

Fig. 3.6. Addition of extra tissue in the path of the radiation beam, such as an arm, increases the radiation intensity and can cause high dose to the arm. In a lengthy procedure, this can lead to skin injury.

est pulse rate compatible with the procedure. For most non-cardiac procedures, pulse rates of 10 pulses/s or less are adequate.

Use low fluoroscopy dose rate settings

(40) Both the fluoroscopy pulse rate and the fluoroscopy dose rate can be adjusted in many fluoroscopy units. Fluoroscopy dose rate is not the same as fluoroscopy pulse rate. These parameters are independent and can be adjusted separately. Lower dose rates reduce patient dose at the cost of increased noise in the image. If multiple fluoroscopy dose rate settings are available, the lowest dose rate setting that provides adequate image quality should be used.

Collimation

(41) The x-ray beam should be collimated to limit the size of the radiation field to the area of interest. This reduces the amount of tissue irradiated and also decreases scatter, yielding a better image quality. The scatter will increase linearly with the increase in the area of the radiation field. A poorly collimated primary beam, if it is outside the patient, will significantly increase the occupational dose. When beginning a case, the image receptor should be positioned over the area of interest, with the collimators almost closed. The collimators should be opened gradually until the desired field of view is obtained. Virtual collimation (positioning of the collimators without using radiation), available in newer digital fluoroscopy units, is a useful tool to reduce patient dose and should always be used if available.

Only use magnification when it is essential

(42) Electronic magnification produces relatively high dose rates at the patient's entrance skin. When electronic magnification is required, the least amount of magnification necessary should be used.

Fluoroscopy vs image acquisition and minimisation of the number of images

(43) Image acquisition requires dose rates that are typically at least 10 times greater than those for fluoroscopy for cine modes, and 100 times greater than those for

fluoroscopy for digital subtraction angiography modes. Image acquisition should not be used as a substitute for fluoroscopy.

(44) The number of images should be limited to those necessary for diagnosis or to document findings and device placement. If the last-image-hold fluoroscopy image demonstrates the finding adequately and can be stored, there is no need to obtain additional fluorography images.

Minimise fluoroscopy time

(45) Fluoroscopy should only be used to observe objects or structures in motion. The last-image-hold image should be reviewed for study, consultation, or education instead of continuing fluoroscopy. Short taps of fluoroscopy should be used instead of continuous operation. It is important not to step on the fluoroscopy pedal unless looking at the monitor screen.

Monitoring of patient dose

(46) Unfortunately, patient dose monitoring has been nearly absent in the fluoroscopy systems that are generally available outside imaging departments. There is a strong need to provide a means for patient dose estimation. Manufacturers should develop systems to indicate patient dose indices with the possibility of producing patient dose reports that can be transferred to the hospital network. Professionals should insist on this when buying new machines.

3.4. Specific aspects of occupational protection

(47) Workers can be protected by using shielding devices in addition to following the principles in Section 3.1 and the common factors discussed in Section 3.3. Furthermore, workers are typically required to have individual monitoring under national regulations in most countries.

(48) Fig. 3.7 shows relative radiation intensity near and around the patient table. The primary source of radiation is the x-ray tube, but the patient alone should be exposed to the primary x-ray beam. Radiation scattered from the patient, parts of the equipment, and the patient table, so-called 'secondary radiation' or 'scatter

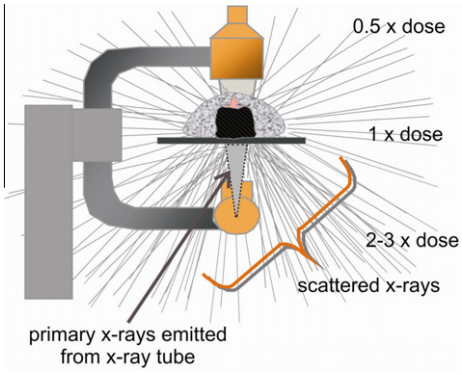

Fig. 3.7. Primary and secondary radiation, their distribution, and relative intensity.

radiation', is the main source of radiation exposure of workers. A useful rule of thumb is that radiation dose rates are higher on the side of the patient closest to the x-ray tube.

3.4.1. Shielding

Lead apron

(49) The lead apron is the most essential component of personal shielding in an x-ray room, and must be worn by all those present. It should be noted that the level of protection of the lead apron depends on the x-ray energy, which is represented by the voltage applied across the x-ray tube (kV).The thicker the part of the patient's body falling in the x-ray beam, the higher the kV set by the fluoroscopy machine. Higher kV means greater penetrative power of the x-ray beam, implying that greater lead thickness is needed for attenuation.

(50) Clinical staff taking part in diagnostic and interventional procedures using fluoroscopy wear lead protective aprons to shield tissues and organs from scattered

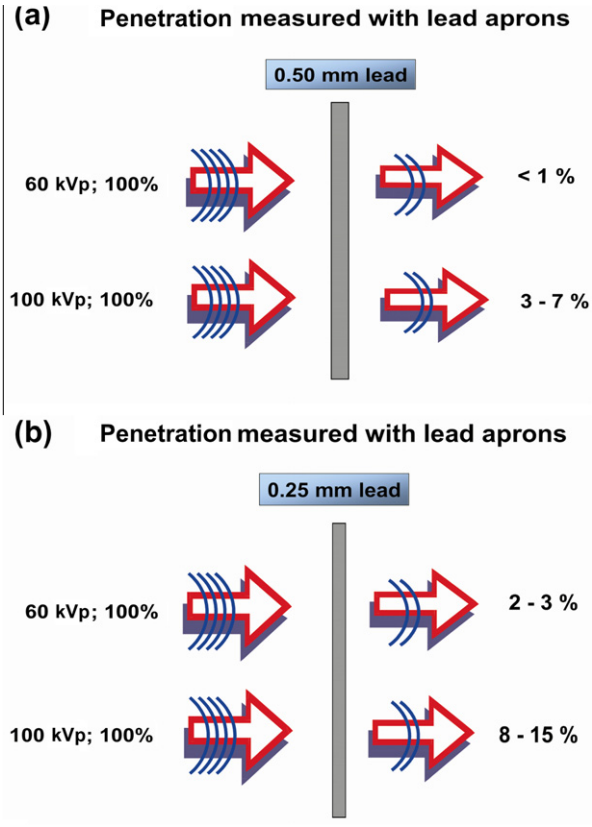

Fig. 3.8. Percent penetration of x rays of different kV through lead of (a) 0.5-mm thickness and (b) 0.25-mm thickness. The result will be different for different x-ray beam filtrations. Source: E. Vañó.

x rays (NCRP, 1995). Transmission will depend on the energies of the x rays and lead-equivalent thickness of the aprons. The attenuation of scattered radiation is assumed to be equal to that of the primary (incident) beam, and this provides a margin of safety (NCRP, 2005).

(51) Fig. 3.8 shows the relative penetration value as a percentage of the incident beam intensity with lead of 0.5-mm and 0.25-mm thickness. For procedures performed on thinner patients, particularly children, an apron of 0.25-mm lead equivalence will suffice. However, for thicker patients and with a heavy workload, a 0.35-mm lead apron may be more suitable. The wrap-around aprons of 0.25-mm lead equivalence are ideal; these have a thickness of 0.25 mm at the back and 0.5 mm at the front. Two-piece skirt-type aprons help to distribute the weight. Heavy aprons can pose a problem for workers who have to wear them for long periods of time. There are reports of back injuries due to the weight of lead aprons among workers who wear them for many years (NCRP, 2010). Some newer aprons are light weight while maintaining lead equivalence, and have been designed to distribute the weight through straps and shoulder flaps.

Ceiling-suspended shielding

(52) Ceiling-suspended screens that contain lead impregnated in plastic or glass are very common in interventional radiology and cardiology suites, but are hardly ever seen with fluoroscopy machines used in operating theatres. Shielding screens are very effective as they have lead equivalence of 0.5 mm or more and can reduce x-ray intensity by >90%. Practical problems make the use of radiation shielding screens for occupational protection more difficult but not impossible in fluoroscopy machines in operating theatres. Manufacturers should develop shielding screens that can be used for occupational protection without hindering the clinical task.

Mounted shielding

(53) These can be table-mounted lead rubber flaps or lead glass screens mounted on mobile pedestals. Lead rubber flaps are very common in most interventional radiology and cardiology suites, but are rarely seen with fluoroscopy systems used in operating theatres. Manufacturers are encouraged to develop detachable shielding flaps to suit situations of practice in operating theatres. Lead rubber flaps, normally impregnated with 0.5-mm lead equivalence, should be used as they provide effective attenuation.

(54) In addition, various types of leaded glass eyewear are commonly available. These include eyeglasses that can be ordered with corrective lenses for individuals who normally wear eyeglasses. There are also clip-on eye shields that can be clipped to the spectacles of the workers, and full face shields that also function as splash guards. Leaded eyewear should have side shields to reduce the radiation coming from the sides. The use of these protective devices is strongly recommended.

3.4.2. Individual monitoring

(55) The principles of radiological protection of workers from ionising radiation are discussed in *Publication 75* (ICRP, 1997) and reiterated in Paragraph 113 of

Publication 105 (ICRP, 2007b). In this section, practical points pertaining to who needs to be monitored and what protective actions should be taken are discussed.

(56) Individual monitoring of workers exposed to ionising radiation using film, thermoluminescent dosimeters, optically stimulated luminescence badges, or other appropriate devices is used to verify the effectiveness of radiation control practices in the workplace. The advice of a radiological protection expert/medical physicist should be sought to determine which method is most appropriate. An individual monitoring programme for external radiation exposure is intended to provide information about the optimisation of protection and to demonstrate that the worker's exposure has not exceeded any dose limit or the level anticipated for the given activities (IAEA, 1999). As an effective component of a programme to maintain exposures as low as reasonably achievable, it is also used to detect changes in the workplace and identify working practices that minimise dose (NCRP, 2000; IAEA, 2004). In 1990, the Commission recommended a dose limit for workers of 20 mSv/year (averaged over a defined 5-year period; 100 mSv in 5 years) and other limits as given in Table 2.1; these limits were retained in the 2007 Recommendations (ICRP, 1991, 2007a). However, all reasonable efforts to reduce doses to the lowest possible levels should be used. Knowledge of dose levels is essential for the use of radiological protection actions.

(57) The high occupational exposures in some situations, such as interventional procedures performed by vascular surgeons, require the use of robust and adequate monitoring arrangements for workers. A single dosimeter worn under the lead apron will yield a reasonable estimate of effective dose for most instances, and another dosimeter worn at collar level is optional. In the absence of a better way to measure dose to the lens of the eye, a dosimeter above the apron worn on the collar closest to the x-ray tube, usually the left collar, will provide a rough estimate of the dose to the head and lens of the eye. In view of increasing reports of radiation-induced cataracts in those involved in interventional procedures, monitoring the dose to the eye is important (Ciraj-Bjelac et al., 2010; Vañó et al., 2010). Recently, eye lens dosimetry has become an active research area. Many studies have been performed to determine which personal dose equivalent quantity is appropriate, and how it can be used for monitoring the dose to the lens of the eye, and to develop dosimeters to measure dose to the lens of the eye (Domienik et al., 2011). The Commission recommends that methods which provide reliable estimates of eye dose under practical situations should be established. Monitoring dose to the lens of the eye at the current level of fluoroscopy use outside imaging departments is optional for areas other than vascular surgeons and interventional cardiology or equivalent. Finger dose may be monitored using small ring dosimeters when hands are unavoidably placed in the primary x-ray beam. Finger dosimetry is optional in situations of SLNB, as the level of radio-isotope use is small. However, the practice of fingers in the primary beam should always be discouraged.

(58) Doses in departments should be analysed, and high doses and outliers should be investigated (Miller et al., 2010). A risk-based approach to occupational radiation monitoring should be adopted to avoid unnecessary monitoring of all workers. With the current level of practice of fluoroscopy outside imaging departments in areas

covered in this report, a single dosimeter worn under the lead apron may be adequate except in the case of vascular surgery. There is a need to raise awareness of the need to use a dosimeter at all times as there are many examples of infrequent use in practice.

(59) In spite of the requirement for individual monitoring, the lack of use or irregular use of personal dosimeters is still one of the main problems in many hospitals (Miller et al., 2010). Workers in controlled areas of workplaces are most often monitored for radiation exposures. A controlled area is a defined area in which specific protective measures and safety provisions are, or could be, required for controlling normal exposures during normal working conditions, and preventing or limiting the extent of potential exposures. The protection service should provide specialist advice and arrange any necessary monitoring provisions (ICRP, 2007a). For any worker who is working in a controlled area, or who occasionally works in a controlled area, and may receive significant occupational exposure, individual monitoring should be undertaken. In cases where individual monitoring is inappropriate, inadequate, or not feasible, the occupational exposure of the worker should be assessed on the basis of the results of monitoring the workplace and on information about the locations and durations of exposure of the worker (IAEA, 1996). In addition to individual monitoring, it is recommended that indirect methods using passive or electronic dosimeters (e.g. dosimeters attached to the C-arm device) should be used in these installations to enable the estimation of occupational doses to professionals who do not use their personal dosimeters regularly.

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4. SPECIFIC CONDITIONS IN CLINICAL PRACTICE

- **Procedures such as endovascular aneurysm repair (EVAR), renal angioplasty, iliac angioplasty, ureteric stent placement, therapeutic endoscopic retrograde cholangio-pancreatography (ERCP), and bile duct stenting and drainage have the potential to impart skin doses exceeding 1 Gy.**
- **Radiation dose management for patients and workers is a challenge that can only be met through an effective radiological protection programme.**
- **There are a number of technicalities that require involvement of or consultation with a medical physicist. These include radiation dose assessment, dose management in day-to-day practice, understanding of different radiation dose quantities, and estimating and communicating risks. Effective radiological protection programmes will involve teamwork of clinical professionals with radiological protection professionals.**

4.1. Vascular surgery

(60) Recent years have witnessed a paradigm shift in vascular intervention, away from open surgery towards endovascular therapy. Endovascular therapy requires image guidance, usually in the form of fluoroscopy. Consequently, radiation exposure has increased among vascular surgical staff and patients. Radiation exposure during EVAR is greater than that during peripheral arterial interventions such as peripheral angioplasty (Ho et al., 2007).

(61) EVAR has gained wide acceptance for the elective treatment of abdominal aortic aneurysms, leading to interest in similar treatment of ruptured abdominal aortic aneurysms. In a recent study covering US inpatient sample data from 2001 to 2006, an estimated 27,750 hospital discharges for ruptured abdominal aortic aneurysms occurred and 11.5% were treated with EVAR (McPhee et al., 2009). The use of EVAR has increased over time (from 5.9% in 2001 to 18.9% in 2006), while overall rates of ruptured abdominal aortic aneurysms have remained constant. EVAR accounts for approximately half of elective aneurysm repairs performed annually in the USA (Cowan et al., 2004). As the technology evolves, more patients may be offered complex repairs such as fenestrated and branched grafts.

(62) Practice varies between countries. In many institutions, long-term central venous access line placement requires fluoroscopic guidance. Renal angioplasty and iliac angioplasty are also performed by vascular surgeons at some institutions (Miller et al., 2003a,b).

4.1.1. Levels of radiation dose

Dose to patient

(63) Endovascular therapeutic procedures require greater screening time, and hence incur greater radiation exposure for patients and workers. The entrance skin dose during EVAR is typically 0.85 Gy, with a range of 0.51–3.74 Gy (Weerakkody et al., 2008). The mean dose–area product (DAP) in abdominal aortic aneurysm

Table 4.1 Typical patient dose levels (rounded) from vascular surgical procedures.

Procedure	Relative mean effective dose to patient 0 mSv 35	Relative mean radiation dose to patient[†]	Reported values				
			Fluoroscopy time (min)	Entrance skin dose (mGy)	Dose–area product ($Gycm^2$)	Effective dose (mSv)	Reference[‡]
Endovascular aneurysm repair		F,G	21	330–850	60–150	8.7–27	a,b
Venous access procedures		B	1.1–3.5	8–24	2.3–4.8	1.2	c
Renal/visceral angioplasty (stent/no stent)		G	20.4	1442	208	54	d,e
Iliac angioplasty (stent/no stent)		G	14.9	900	223	58	d,e

[†] A, <1 mSv; B, 1–<2 mSv; C, 2–<5 mSv; D, 5–<10 mSv; E, 10–<20; F, 20–35 mSv; G, >35 mSv, based on effective dose.

[‡] (a) Weerakkody et al., 2008; (b) Geijer et al., 2005; (c) Storm et al., 2006; (d) Miller et al., 2003a; (e) Miller et al., 2003b.

repair has been reported to be 1516 $Gycm^2$ (range 520–2453 $Gycm^2$) (Weiss et al., 2008). Routine EVAR for infrarenal aneurysm disease involves a mean effective dose to the patient of 8.7–27 mSv (Geijer et al., 2005; Weerakkody et al., 2008). After EVAR, patients require ongoing follow-up to ensure that the aneurysm remains excluded, and multi-slice CT remains the current standard investigation. Thus, these patients require regular and repeated radiation exposure for life, which may have cumulative effects. As an example, the effective dose in the first year of follow-up has been estimated to be 79 mSv (Weerakkody et al., 2008).

(64) In interventional procedures, as well as the associated risk of cancer, there is a possibility for skin injuries. Such injuries have been reported following a range of fluoroscopically guided procedures (ICRP, 2001). At present, it is difficult to find specific reports of skin injuries following EVAR. However, as surgeons undertake more complex procedures requiring longer operating and screening times, the risk of radiation injuries will increase (Weerakkody et al., 2008). A recent study indicated that up to one-third of patients may receive entrance skin doses greater than 2 Gy, the approximate threshold for transient erythema (Weerakkody et al., 2008).

(65) During abdominal aortic aneurysm repair, the mean total fluoroscopy time has been reported to be 21 min (range 12–24 min) (Table 4.1), 92% of which (on average) is spent in standard fluoroscopy and 8% in cinefluoroscopy (Weiss et al., 2008). According to the technique used by these authors, approximately 49% of total fluoroscopy time was spent in a normal field of view and 51% in a magnified view. Peak skin dose was shown to be well correlated with DAP and body mass index, but not with fluoroscopy time. For obese patients, peak skin dose was reported to be twice that of non-obese patients (1.1 Gy vs 0.5 Gy, respectively) (Weiss et al., 2008).

(66) Radiation doses from venous access procedures are low, with skin doses typically well below 1 Gy. However, these patients often require multiple repeated procedures, often within a relatively short time span (Storm et al., 2006).

(67) Typical patient doses from vascular surgical procedures are presented in Table 4.1.

(68) The scale of 0–35 mSv for effective dose was chosen to accommodate most procedures and keep it visually meaningful; 35 mSv has no other relevance.

Occupational dose levels

(69) There has been wide variation in reported occupational doses during EVAR. Annual hand doses to the surgeon in terms of equivalent dose during EVAR range from 0.2 to 19 mSv (Lipsitz et al., 2000; Ho et al., 2007). The wide variation may be due to the use of additional free-standing and table-mounted lead shielding in some centres. Annual body doses (in terms of effective dose) tend to be approximately 0.2 mSv and annual eye doses are approximately 1 mSv for a workload of 150 procedures/year where appropriate protective devices are used (Ho et al., 2007). The respective mean body, eye, and hand doses of the surgeon are 7.7, 9.7, and 34.3 μSv/procedure (Ho et al., 2007).

4.1.2. Radiation dose management

(70) With the level of radiation doses as above and the fact that many patients require follow-up examinations and procedures that involve radiation exposure, radiation dose management for patients and workers is a challenge that can only be met through an effective radiological protection programme.

Patient dose management

(71) During standard infrarenal EVAR, the radiation source (x-ray tube) is frequently moved in relation to the patient. The risk of tissue reactions or stochastic effects to the patient is minimal (see Section 2). Fenestrated or branched stent-graft placement may require cannulation and stenting of multiple visceral branches of the aorta. These manoeuvres may be prolonged with minimal repositioning of the x-ray beam. Thus, there is a greater risk of tissue reactions or stochastic effects during these procedures, particularly four-vessel fenestrated grafts. Patients should be counselled accordingly. The need for repeat procedures for the treatment of endoleaks and the CT scans needed for life-long surveillance for these devices will result in higher exposures.

(72) Fluoroscopically guided venous access procedures are a common part of interventional radiology practice. While the typical radiation dose for a single venous access case is relatively low and is reported to be below the threshold dose for skin effects (tissue reactions) in all cases studied, these procedures are often repeated in the same patient within a short period of time. There is evidence that venous access procedures performed by experienced operators can result in lower radiation doses. Thus, it is unlikely that any fluoroscopically guided venous access procedure performed by a reasonably well-trained operator will result in sufficient dose to cause concern for skin injury. Nevertheless, operators should remain cognisant of the cumulative health effects of ionising radiation, including the potential risk of stochastic effects (Storm et al., 2006).

(73) The dose management actions described in Section 3 are generally applicable in vascular surgical procedures.

Occupational dose management

(74) A number of specific technique- and operator-related factors may reduce the overall radiation dose during EVAR (Ho et al., 2007), such as:

- Operators should aim to perform a single cinematography run to confirm the stent-graft position immediately prior to deployment. Multiple initial runs to assess anatomy and plan stent-graft positioning are rarely necessary and should be avoided, as they increase both patient and occupational doses.
- Hands must be kept out of the radiation beam. Leaded surgical gloves are not useful for hand protection when hands are placed in the primary x-ray beam. Although other radiological protection tools are effective, they come with drawbacks, including physical discomfort for staff and reduced procedural efficiency. Sterile protective surgical gloves providing radiation attenuation levels in the range of 15–30% are available, but studies have shown that they provide minimal protec-

tion when hands are placed in the primary x-ray beam for several reasons. Forward and backscattered x rays within the glove add to hand exposure. In addition, the presence of attenuating material within the fluoroscopy automatic brightness control region results in an increase in x-ray technique factors, exposing the hands to a higher dose rate. These factors, coupled with the false sense of security that may result in increased time spent in the primary beam, more than cancel out any protection that the gloves may provide. As a result, further development of new protective devices is encouraged. It is recommended that hands should be kept out of the primary x-ray beam unless it is essential for the safety of the patient (Schueler, 2010). There is some evidence that depending on the procedure, the height of the practitioner, and the positioning of the radiation-attenuating surgical drape, use of this drape can substantially reduce the radiation dose to personnel with minimal or no additional radiation exposure to the patient (King et al., 2002).

- The use of a tableside lead shield and portable lead shielding reduces the overall effective dose to staff.

(75) In addition to the abovementioned specific items, all standard equipment factors (e.g. beam collimation, filter use, regular servicing of equipment, minimisation of SID, field of view size) described in Section 3 may reduce occupational exposure in vascular surgery.

4.2. Urology

(76) X rays have been used to diagnose diseases in the kidney and urinary tract for approximately 100 years. By visualising the urinary tract, x rays are able to detect a kidney stone or a tumour that may block urinary flow. Procedures without direct enhancement of the urinary tract or with intravenous administration of the iodinated contrast agent, such as intravenous pyelography (also called 'intravenous urography'), are normally performed by radiologists. Whenever there is direct administration of contrast agent into the urinary system, there is more active involvement of urologists. In the past, cystography, retrograde pyelography, and voiding cystourethrography were common procedures performed within radiology facilities. They involve catheter insertion into the urethra to fill the bladder with the iodinated contrast medium. The fluoroscopy machine then captures images of the contrast medium during the procedure to study the anatomical details or to study dynamics of the evacuation of urine. Nowadays, intravenous pyelography is rarely performed in many countries and has been superseded by CT. A number of procedures such as percutaneous nephrolithotomy, nephrostomy, ureteric stent placement, stone extraction, and tumour ablation created the need for the fluoroscopy unit to be more easily available to urologists (in some cases, even inside the operating theatre).

(77) Furthermore, in the past few decades, lithotripsy [extracorporeal shock wave lithotripsy (ESWL)] has become a common procedure for treating stones in the kidney and ureter. Most devices developed for lithotripsy use either x rays or ultrasound to help locate the stone(s). This works by directing ultrasonic or shock waves, created outside the body, through skin and tissue until they hit the stones. The stones break down into sand-like particles that can be easily passed through the urine.

(78) Urinary and renal studies account for 16% and 1.6% of all fluoroscopically guided diagnostic and interventional procedures, respectively, with mean effective doses of 2 mSv for urinary procedures and 5 mSv for renal procedures. The total contribution to collective dose is approximately 5% (NCRP, 2009).

(79) Most publications dealing with radiological protection in urology have focused on the radiation risks to the workers. Fewer studies have estimated radiation doses to patients in urological procedures. Despite the fact that the workers work with radiation for years whereas a patient only undergoes radiological procedures a few times during their lifetime, it must be remembered that the workers only face scattered radiation that is typically not more than 1% of the radiation intensity that is falling on the patient. As workers are further protected by lead aprons, their radiation exposure further decreases by almost 90% of the typical 1% figure. On a per-procedure basis, this works out to approximately 0.1% of the radiation dose received by the patient.

4.2.1. Levels of radiation dose

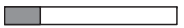
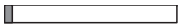
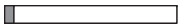
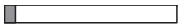
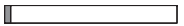
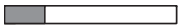
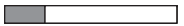
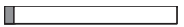
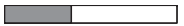
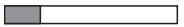
Dose to the patient

(80) Typical dose values from urological procedures are presented in Table 4.2.

(81) Radiological studies performed for an acute kidney stone episode may include a range of radiological procedures on patients including one or two plain kidney, urinary bladder (KUB) abdominal films, one or two abdomino-pelvic CT examinations, and intravenous pyelography during the first year of follow-up. The total effective dose from such studies may be in the range of 20 to >50 mSv (Ferrandino et al., 2009). With the increasing use of CT, there is evidence that many patients with urolithiasis may be subjected to relatively high doses of ionising radiation during acute stone episodes and throughout the management of their disease (Mancini and Ferrandino, 2010). However, the appropriate use of dose management techniques during diagnosis and follow-up may allow for a significant dose reduction.

(82) CT is replacing conventional radiography and intravenous urography for evaluation of the urinary tract in many centres of the world, despite the higher radiation exposure (ICRP, 2007a). When conventional and CT urography are compared, there is evidence of a significantly higher effective dose for CT urography, even when dose reduction strategies in CT are applied (Nawfel et al., 2004; Dahlman et al., 2009). These findings suggest that patient dose estimates should be taken into consideration when imaging protocols are established (Nawfel et al., 2004; Eikefjord et al., 2007; ICRP, 2007a). Several studies have shown that unenhanced CT is more accurate than excretory urography for the examination of patients with renal colic, and is the preferred technique due to better diagnostic accuracy (Tack et al., 2003; Eikefjord et al., 2007). In the past decade, evidence has been found of significant dose reduction through adoption of an appropriate CT kidney stone protocol. Studies focusing on evaluation of low-dose kidney CT protocols have come to the conclusion that the radiation dose is comparable with that associated with excretory urography (Tack et al., 2003; Larsen et al., 2005). Dahlman et al. (2009) reported a 60% decrease in the effective dose to patients undergoing CT urography, from 29.9 and 22.5 mSv in 1997 to 11.7 and 8.8 mSv in 2008 for female and male patients,

Table 4.2. Typical patient dose levels (rounded) from urological procedures.

Procedure	Relative mean effective dose to patient 0 mSv 35	Relative mean radiation dose to patient*	Reported values				Reference‡
			Fluoroscopy time (min)	Entrance skin dose (mGy)	Dose area product ($Gycm^2$)	Effective dose (mSv)	
Intravenous urography/ intravenous pyelography		C,D	n.a.	3.3–42	2–42	2.1–7.9	a,b,c,d,e
Cystometrography		B	n.a.	/	7	1.3	b
Cystography		B	n.a.	/	10	1.8	a,b
Excretion urography/ micturating cysto-urethrography		C	n.a.	/	0.43–9.9	1–3	a,b,f
Urethrography		B	n.a.	/	6	1.1	a,b
Percutaneous nephrolithotomy		C,D	6–12	1–250	14–29	1.9–9.2	g
Nephrostomy		D	1.3–20	/	30† (5–56)	7.7† (3.4–15)	a, h, i
Extracorporeal shock wave lithotripsy		B	2.6–3.4	40–80	5	1.3–1.6	j
Kidney stent insertion		E	/	/	49	13	a
Ureteric stent placement		C	/	/	18	4.7	a

n.a., not available.

† Mean value.

‡ (a) UNSCEAR, 2010; (b) NCRP, 2009; (c) European Commission, 2008; (d) Fazel et al., 2009; (e) Yakoumakis et al., 2001; (f) Livingstone et al., 2004; (g) Safak et al., 2009; (h) Miller et al., 2003b; (i) McParland, 1998; (j) Sandilos et al., 2006.

* A, <1 mSv; B, 1–<2 mSv; C, 2–<5 mSv; D, 5–<10 mSv; E, 10–<20; F, 20–35 mSv;G, >35 mSv, based on effective dose.

respectively. All studies concluded that considerable dose reduction is achievable with an acceptable level of image quality. Following the principle of optimisation of radiological protection, it is important to adapt the technical parameters on the basis of clinical indications (ICRP, 2007a). Therefore, with improvements in technology and optimisation of protection at the clinical level, it is expected that the tendency towards dose reduction will continue in the future.

(83) The effective radiation dose to the patient in ESWL through fluoroscopy and radiography is normally <1–2 mSv, with nearly 50–78% through fluoroscopy (Huda et al., 1989; MacNamara and Hoskins, 1999; Sandilos et al., 2006; UNSCEAR, 2010). However, it must be remembered that the dose from ESWL is always added to the dose from pre- and post-treatment KUB and intravenous urography procedures (Sandilos et al., 2006). For other urological procedures, typical effective doses range from <1 mSv for abdominal radiography to a mean of approximately 7 mSv for nephrostomy.

(84) A nephrostomy tube placement is performed by placing a needle into the collecting system of the kidney to provide percutaneous drainage. This procedure typically requires 10–15 min of fluoroscopy (reported range 1–56 min), and can result in relatively high doses, particularly when tube angulation is used (NCRP, 2000; Miller et al., 2003a). In some patients, repeated examinations may be necessary to provide information on proper nephrostomy tube placement. Typical effective dose from nephrostomy procedures is 7.7 mSv, with an associated range of 3.4–15 mSv (Sandilos et al., 2006; UNSCEAR, 2010).

Occupational dose levels

(85) The mean effective dose to the urologist for percutaneous nephrolithotomy is 12.7 μSv/procedure (Safak et al., 2009). With an average typical workload of five procedures/week, this can imply an effective dose of 3 mSv/year to urologists. With the above workload, the dose to the fingers can be 8–25 mGy/year (30–100 μGy/procedure) and that to the region of the head and neck can be 5–10 mGy/year (20–40 μGy/procedure), respectively (Hellawell et al., 2005). Bush et al. (1985) reported that for an average fluoroscopy time of 25 min (range 6–75 min), the average radiation dose received by the radiologist at collar level above the lead apron was 0.10 mSv/procedure (range 0.02–0.32 mSv/procedure). Doses to the nurse, radiological technologist/radiographer assisting with C-arm fluoroscopy, and anaesthetist were 0.04 mSv/procedure (range 0.01–0.11 mSv/procedure), 0.04 mSv/procedure (range 0.01–0.11 mSv/procedure), and 0.03 mSv/procedure (range 0.01–0.1 mSv/procedure), respectively (Bush et al., 1985). The dose to the fingers of urologists is typically 0.27 mSv/procedure (range 0.10–2 mSv/procedure) (Bush et al., 1985; Kumari et al., 2006).

(86) Depending on the position of the x-ray tube and image detector, the radiation dose to lower extremities can be higher than 126–167 μSv/procedure (Hellawell et al., 2005; Safak et al., 2009). However, for a predicted annual workload of 250 cases, the dose received is approximately 40 mSv. This may be compared with dose limits of 500 mSv to extremities (ICRP, 2007b).

(87) Based on reported dose levels in the region of the urologist's head and neck (0.10 mSv/procedure) (Bush et al., 1985), the radiation dose to the lens of the eye

without protection for a typical workload of 250 procedures/year can be 25 mSv, and this requires protection of the eyes in view of recent reports of lens opacities observed in interventional cardiology staff (Ciraj-Bjelac et al., 2010; Vañó et al., 2010). With the appropriate use of protection, occupational doses can be sufficiently low to avoid tissue reactions. The mean equivalent dose per procedure is 33 μSv for the fingers and 26 μSv for the eyes, and the whole-body effective dose to the urologist is 12 μSv (Safak et al., 2009). For a typical workload of 250 procedures/year, whole-body occupational dose to personnel would reach 3 mSv, which is well below the occupational dose limit.

(88) The above radiological protection actions are valid for all urological and renal procedures involving x rays.

4.2.2. Radiation dose management

Patient dose management

(89) It is necessary for the urologist to weigh the anticipated clinical benefits to the patient from the urological procedure requiring x-ray fluoroscopy against the radiation risks involved. This will be in line with the Commission's principle of justification. Once justified, it is the responsibility of the operator to perform the procedure using the Commission's principle of optimisation of radiological protection using techniques as described in this publication and other available techniques. One of the most efficient radiological protection requirements is the avoidance of unnecessary examinations and procedures.

(90) Certain imaging modalities, most notably those using digital image receptors, have shown promising decreases in patient dose while maintaining image quality. Significant dose reduction in urethrocystography has been reported by Zoeller et al. (1992) with the use of photostimulable phosphor plates compared with screen-film radiography. A tube potential of 77 kVp with a phototimer was used for screen-film radiography. Exposure parameter settings of 81 kVp and 6.4 mAs were used to achieve sufficient image quality while using photostimulable phosphor plates.

(91) During ESWL, radiation exposure increases with stone burden. A larger stone requires longer treatment, with possibly more associated x rays. If unilateral radiography of the kidney, ureter, and bladder (hemi-KUB) is performed whenever possible and appropriate during diagnosis and follow-up, the radiation exposure associated with ESWL can be reduced significantly (Talati et al., 2000). Also, the use of ultrasound for stone localisation could reduce patient dose significantly compared with cases where x rays are used for stone localisation. Dose reduction could be four- to five-fold, as typical effective dose levels are 0.25 mSv and 1.2 mSv for ultrasound and x-ray localisation, respectively (MacNamara and Hoskins, 1999). A typical ESWL procedure involves approximately 2.6–3.4 min of fluoroscopy time and four to 26 spot films, and results in an average dose of 1.6 mSv/patient (Carter et al., 1987; Sandilos et al., 2006). Dose reduction strategies described in Section 3 apply for all urological and renal procedures. By introducing radiological protection actions such as reduction of the number of spot films, use of last image hold, and

training of the operators, significant dose reduction may be obtained. The entrance surface dose from an ESWL procedure performed by an experienced operator is approximately 30% lower than that for a procedure performed by an inexperienced operator (26.4 mGy vs 33.8 mGy, respectively) (Chen et al., 1991), while the reduction in the number of images results in a dose reduction of 20–62% depending on the patient's body mass (Griffith et al., 1989).

(92) The dose management actions described in Section 3 are generally applicable in urological procedures.

Occupational dose management

(93) The majority of the most common procedures in urology can be performed with little radiation exposure of workers, much below the limits prescribed by the Commission, provided that radiological protection principles, approaches, and techniques as briefly mentioned in this publication are used. On the other hand, radiation injuries and long-term risks are possible when radiological protection is not employed.

(94) In radiography and diagnostic CT imaging, workers are typically outside the room and the room is well shielded. Thus, workers are exposed to a very low radiation dose. However, within the operating theatre, a few staff members including the operators are in the same room as the fluoroscopy unit, and thus they are exposed to much higher levels of radiation. Radiation exposure of workers in the fluoroscopy room can be significant when suitable radiological protection tools are not used. The actual exposure depends upon the time, workload, and shielding (e.g. lead apron and additional lead glass protective screens).

(95) For endourological procedures, dose rates to the urologist of up to 11 mSv/h have been reported, with a dose reduction of 70–96% due to the use of fluoroscopic drapes (Giblin et al., 1996; Yang et al., 2002). Therefore, urologists should be cognisant of the radiation risk, and the concepts of time, distance, and shielding (as described in Section 3) are critically important.

(96) At present, in many cases (except in operating theatres), overcouch x-ray tube systems are still used for urological procedures involving x rays. The scatter radiation distribution in those systems is such that radiation dose to the lens of the eye may be relevant if eye protection is not used. Therefore, the use of undercouch systems is recommended in addition to personal protective devices for workers.

4.3. Orthopaedic surgery

(97) Orthopaedic specialities commonly use x rays as a diagnostic tool and as a technical aid during various procedures. Despite its widespread use among orthopaedic surgeons, x-ray radiation and the risks associated with its use are infrequently discussed in the orthopaedic literature.

(98) Although x rays have been used since the early 20th Century to image bones and joints, the use of fluoroscopy for orthopaedic imaging did not gain popularity until much later. In the 1980s, fluoroscopy gained a prominent foothold in the orthopaedic trauma community where it was championed as a valuable tool during femoral nailing and hip pinning (Giachino and Cheng, 1980; Levin et al., 1987;

Giannoudis et al., 1998). Nowadays, nearly all orthopaedic disciplines have adopted the use of fluoroscopy to meet their various needs. In the orthopaedic literature, C-arm fluoroscopy has been reported for a wide variety of procedures including anatomical localisation, bony reduction, implant placement, correction of malalignment, arthrodesis, intra- and extramedullary bony fixation, joint injections, aspirations, and a myriad of other common procedures. As indications for the use of mobile C-arm fluoroscopy have expanded, its relative popularity has grown commensurately. Through its relevance to numerous applications and overall convenience, the use of fluoroscopy has become commonplace, and in some cases indispensable, in the daily clinical practice of orthopaedics (Table 4.3).

Table 4.3. Indications for the use of mobile C-arm fluoroscopy in various orthopaedic procedures.

Orthopaedic applications	Use of C-arm fluoroscopy
General	Removal of some metallic items Foreign/loose body removal
Trauma	Anatomical localisation Diagnostic (ipsilateral femoral neck/shaft fracture) Fracture reduction (for casting/splinting or surgical fixation) Intramedullary nailing Kirshner wire/external fixator pin placement Percutaneous hardware placement (i.e. cannulated/headless screws, minimally invasive plate osteosynthesis plating, etc.)
Sports	Guidance of joint entry for arthroscopy Orientation and confirmation of acceptable implant placement (i.e. distal biceps repair) (i.e. anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medical collateral ligament (MCL), posterolateral corner / lateral collateral ligament (LCL) reconstruction) Assessment of depth and extent of bony resection
Spine	Trauma Level confirmation Deformity correction
Hand/upper extremity	Trauma Assessment of adequate bony resection Deformity correction Anatomical localisation
Tumour	Percutaneous biopsy Cyst aspiration Diagnostic (adjacent lesions) Fracture reduction and implant placement Radiofrequency ablation
Foot/ankle	Trauma Deformity correction Assess adequacy of bony resection
Joint reconstruction	Assessment of implant orientation/fixation Assessment of limb alignment/joint line

(99) Currently, the trend among many orthopaedic surgeons is to strive for minimal invasiveness when performing surgery. Through the collective initiative of medicine and industry, new technological advances have emerged, enabling orthopaedic surgeons to execute procedures with much less soft tissue damage and resultant morbidity for the patient. Unfortunately, operating in this manner creates a heightened dependence on indirect visualisation to view pertinent anatomy. Thus, radiation exposure of the patient and surgical team has increased commensurately with this pursuit. Although some ascribe to the philosophy of 'as low as reasonably achievable', this is not true for all, which is not desirable. Practitioners, more so in teaching institutions, should be aware that their attitudes towards radiation safety get passed on to trainees. A sense of responsibility towards patient and occupational radiological protection is necessary.

(100) At present, arthrography, orthopaedics, and joint imaging procedures represent 8.4% of all fluoroscopy guided procedures in the USA, with an average effective dose to the patient of 0.2 mSv/procedure, contributing 0.2% to the total collective dose (NCRP, 2009). Similarly, in the UK, various imaging procedures in orthopaedics result in an effective dose of a few μSv to 1 mSv per procedure, contributing <1% to the total collective dose to the population (Hart and Wall, 2002).

4.3.1. Levels of radiation dose

Dose to patient

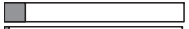
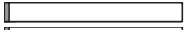
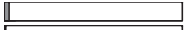
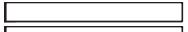
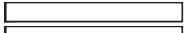
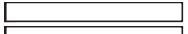
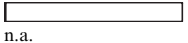
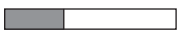
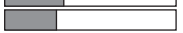
(101) Patients receive radiation by direct exposure to the x-ray beam. This exposure is much more intense than the scattered radiation that reaches workers. Nonetheless, orthopaedic patients are at low risk for exhibiting tissue reactions, unlike patients undergoing interventional vascular or cardiac procedures. Table 4.4 gives typical fluoroscopy times and radiation doses to the patient during various orthopaedic procedures.

(102) For commonly performed procedures (intramedullary nailing of petrochanteric fractures, open reduction and internal fixation of malleolar fractures, and intramedullary nailing of diaphyseal fractures of the femur), mean fluoroscopy times of 3.2, 1.5, and 6.3 min, respectively, have been reported, while the estimated mean entrance skin doses were 183, 21, and 331 mGy, respectively (Tsalafoutas et al., 2008).

(103) The typical effective dose to patients with a femoral fracture treated surgically is 11.6–21.7 μSv (Perisinakis et al., 2004). The effective dose to patients for nailing osteosynthesis of proximal pertrochanteric fractures has been shown to average 14 mSv, while the effective dose to patients for lower extremity fractures averaged 0.1 mSv (Suhm et al., 2001).

(104) Orthopaedic trauma surgeons are often responsible for stabilising pelvic fractures. C-arm fluoroscopy is indispensible to the trauma surgeon for guiding bony reduction and implant placement adjacent to major neurovascular structures. Given the large cross-sectional diameter of the pelvis, fluoroscopic pelvic imaging has the potential to lead to increased exposure of the patient and surgeon. Exposure data have been collected during pelvic phantom imaging, and have demonstrated considerable dose rate in the primary beam at the entrance surface (40 mGy/min)

Table 4.4 Typical patient dose levels (rounded) from various orthopaedic procedures.

Procedure	Relative mean effective dose to patient 0 mSv 35	Relative mean radiation dose to patient*	Reported values				Reference‡
			Fluoroscopy time (min)	Entrance skin dose (mGy)	Dose–area product ($Gycm^2$)	Effective dose (mSv)	
Skull		A	n.a.	n.a.	n.a.	0.1	a
Cervical spine		A	0.2–0.8	n.a.	0.42–1.3	0.1–0.2	a,b
Thoracic spine		A,B	0.85	n.a.	3.26	0.3–1.0	a,b
Lumbar spine		A,B	0.10–1.4	n.a.	0.54–10	0.07–1.5	a,b
Pelvis		A	n.a.	n.a.	n.a.	0.6	a
Hip		A	0.020–1.15	n.a.	0.64–2.6	0.10–0.74	a,b
Shoulder		A	n.a.	n.a.	n.a.	0.01	a
Knee		A	n.a.	n.a.	n.a.	0.005	a
Other extremities		A	n.a.	n.a.	n.a.	0.001	a
Hand/wrist		B,C	0.20–0.55	0.08–1.1	0.04–0.22	<0.004	b,c
Distal radius plate osteosynthesis	n.a.	n.a.	1.8†	17†	n.a.	n.a.	d
Osteosynthesis of malleolar fracture	n.a.	n.a.	1.5†	21†	n.a.	n.a.	d
Plate osteosynthesis of tibial plateau fracture	n.a.	n.a.	1.2†	35†	n.a.	n.a.	d
Arthroscopy for anterior cruciate ligament (ACL) reconstruction	n.a.	n.a.	0.9†	19†	n.a.	n.a.	d
Tibial intramedullary nailing	n.a.	n.a.	5.7†	137†	n.a.	n.a.	d
Intramedullary nailing of diaphyseal femoral fracture	n.a.	n.a.	6.3†	331†	n.a.	n.a.	d
Intramedullary nailing of peritrochanteric fracture	n.a.	n.a.	3.2†	183†	n.a.	n.a.	d
Bilateral pedicle screw placement in the lumbar spine	n.a.	n.a.	0.8†	46†	n.a.	n.a.	d
Bilateral pedicle screw placement in the cervical spine	n.a.	n.a.	4.2†	173†	n.a.	n.a.	d
Vertebroplasty		D,E	5–16	70–323	n.a.	8.5–13	d,e,f
Kyphoplasty		C,D	10.1	320† (50–860)	n.a.	4.3† (0.47–10)	f,g

n.a., not available.

† Mean value.

‡ (a) Mettler et al., 2008; (b) Crawley and Rogers, 2000; (c) Giordano et al., 2007; (d) Tsalafoutas et al., 2008; (e) Miller et al., 2003a; (f) Seibert, 2004; (g) Boszczyk et al., 2006.

* A, <1 mSv; B, 1–<2 mSv; C, 2–<5 mSv; D, 5–<10 mSv; E, 10–<20 mSv; F, 20–35 mSv; G, >35 mSv, based on effective dose.

(Mehlman and DiPasquale, 1997). Other studies have found that during femoral or tibial fracture nailing, the entrance skin dose to the patient is 183 mGy with a mean fluoroscopy time of 3.2 min (Tsalafoutas et al., 2008). The same study examined patient exposure during pedicle screw placement in both the lumbar and cervical spine. The surgical time for these cases averaged <1–7.7 min, which produced average entrance surface doses of 46 and 173 mGy for the lumbar spine and the cervical spine, respectively. Associated ranges were 18–118 and 5–407 mGy, respectively (Tsalafoutas et al., 2008).

(105) Another study found that an average pedicle screw insertion procedure requires 1.2 and 2.1 min of fluoroscopic exposure along antero-posterior and lateral projections, respectively, resulting in DAPs of 2.32 and 5.68 $Gycm^2$, respectively. Gender-specific normalised data for the determination of effective, gonadal, and entrance skin dose to patients undergoing fluoroscopically guided pedicle screw internal fixation procedures were derived. The effective dose from an average procedure was 1.52 and 1.40 mSv, and the gonadal dose was 0.67 and 0.12 mGy for female and male patients, respectively (Perisinakis et al., 2004). Minimally invasive spine procedures require indirect visualisation to facilitate implant placement. Intuitively, this would require longer procedural times with greater associated direct and scatter radiation exposure. The mean dose to the patient's skin is 60 mGy (range 8.3–252 mGy) in the postero-anterior plane and 79 mGy (range 6.3–270 mGy) in the lateral plane (Bindal et al., 2008). Overall, almost 90% of the collective dose from all orthopaedic screening can be attributed to examination in five categories, namely dynamic hip screw, cannulated hip screw, hip injection, lumbar spine fusion, and lumbar spine discectomy. In fact, hips and spines account for 99% of total collective dose from these common orthopaedic procedures, and therefore present as the obvious target for dose reduction strategies (Crawley and Rogers, 2000).

Occupational dose levels

(106) A host of studies have established that orthopaedic surgeons who use C-arm fluoroscopy are subject to occupational radiation exposure at levels that are typically much lower than the dose limits recommended by the Commission. Reported doses during various orthopaedic procedures usually fall well below international standards for annual occupational exposure limits (Jones et al., 2000; Singer, 2005; Giordano et al., 2007, 2009a). However, there is a lack of real and reliable data on radiation doses to workers, as many professionals do not use their personal dosimeters regularly. Orthopaedic surgeons sustain the bulk of their exposure in the form of scattered radiation, but also sometimes in the primary beam. Typical scatter radiation dose levels arising from one of the most common orthopaedic procedures (intramedullary nailing of peritrochanteric fracture) for hands, chest, thyroid, eyes, gonads, and legs of the operating surgeon are, on average, 0.103, 0.023, 0.013, 0.012, 0.066, and 0.045 mGy/min, respectively (Tsalafoutas et al., 2008). For 204 procedures, the corresponding cumulative doses would be 72, 16, 9.4, 8.3, 46, and 31 mGy. When protective aprons and collars are used, the actual effective dose is only a small fraction (approximately 10%) of the personal dosimeter reading (Tsalafoutas et al., 2008).

(107) The reported radiation doses to the eyes and thyroid of the surgeon and supporting staff from a mini C-arm unit during fluoroscopically guided orthopaedic ankle surgery range from 0.36 to 3.7 μGy/min, depending on the distance from the patient (Mesbahi and Rouhani, 2008). The 10-fold decrease in scattered dose rate corresponds with increased distance from 20 to 60 cm from the central beam axis. For a typical 5-min procedure and a workload of 250 procedures/year, the unshielded equivalent dose to the lens of the eye would be <5 mSv when radiological protection is employed.

(108) The use of intra-operative C-arm fluoroscopy in hand surgery is common (Table 4.3). Both standard and mini C-arm units are used. Some data indicate that exposure of the surgeon is higher than predicted during elective procedures involving operative treatment of the fingers, hand, and wrist (Singer, 2005). The dose to the hands of surgeons has been found to range from <10 to 320 μSv/case during mini C-arm fluoroscopy (Singer, 2005; Giordano et al., 2007). Exposure of the surgeon is believed to occur mainly as the result of direct exposure from beam contact during extremity positioning, implant placement, and confirmation of acceptable bony alignment. Radiation sustained from scattered exposure, on the other hand, has been shown to be low. During hand surgery, depending on the position of the surgeon, typical dose rates at chest level range from 4 to 20 μGy/h for a mini C-arm device; when a standard C-arm device is used, the dose rate is typically 230 μGy/h. Corresponding in-beam radiation doses are 37 and 65 mGy/h for mini- and standard C-arm fluoroscopes, respectively (Athwal et al., 2005).

(109) Cadaveric specimens have been used to procure exposure data for patients and surgeons during simulated foot/ankle procedures using both large and mini C-arm fluoroscopes (Giordano et al., 2009b). Variable levels of dose to the patient and surgeon have been found to depend on the location of the specimen within the arc of the C-arm and the distance of the surgeon from the x-ray source. Surgeon exposure has been shown to be universally low throughout all imaging configurations during foot/ankle procedures (Gangopadhyay and Scammell, 2009; Giordano et al., 2009b). An average rate of 2.4 μGy/min has been documented for mini C-arm imaging of a foot/ankle specimen at a distance of 20 cm from the x-ray beam (Badman et al., 2005). When the distance is increased, dose rates decrease according to the inverse square law, as described in Section 3. For typical positions with respect to a beam axis of 30 cm for the surgeon, 70 cm for the first assistant, and 90 cm for the scrub nurse, the corresponding scatter dose rates at eye level are 0.1 mSv/min for the surgeon, 0.06 mSv/min for the first assistant, and negligible for the nurse. This indicates that individuals working $\geqslant$90 cm from the beam receive an extremely low amount of radiation (Mehlman and DiPasquale, 1997).

(110) Procedures such as intramedullary nailing of tibial and femoral fractures require an average procedural time of 1–10 min, resulting in an average unprotected dose rate to the surgeon of 0.128, 0.015, and 0.028 mSv/min for hands, eyes, and chest, respectively. These values correspond to doses of 0.44, 0.05, and 0.10 mSv/case (Sanders et al., 1993; Müller et al., 1998; Tsalafoutas et al., 2008). The average unprotected thyroid dose rate during such procedures is 0.016 mSv/min or 0.06 mSv/case for a fluoroscopy time of 3.2 min/case (Tsalafoutas et al., 2008).

(111) During intramedullary nailing of femoral and tibial fractures, the equivalent doses to the hands of the primary surgeon and the first assistant are 1.27 and 1.19 mSv, respectively, and the average fluoroscopy time is 4.6 min/procedure (Müller et al., 1998). For an average workload of 250 procedures/year, this would lead to a dose to extremities of 300 mSv, which is significantly less than the dose limit of 500 mSv for extremities (Section 2).

(112) In a trauma setting, it is sometimes necessary for the surgeon to practice 'damage control orthopaedics'. In this scenario, the severity of a patient's injuries and overall haemodynamic stability prevent execution of the definitive stabilisation procedure. In this case, the patient would not tolerate a lengthy surgical time; therefore, external fixation of unstable musculoskeletal injuries is an appropriate temporising measure to achieve acceptable bony alignment and reduce haemorrhage. Fluoroscopy is used to confirm adequate bony alignment and external fixator pin placement. Exposure during external fixator placement has been measured, and it has been found that the cumulative equivalent dose to the fingers of a surgeon for a total of 44 procedures ranges from 48 to 2329 μSv. In 80% of procedures, the radiation dose to the surgeon's hand was <100 μSv (Goldstone et al., 1993). Nordeen et al. (1993) reported monthly levels of radiation dose to orthopaedic surgeons involved in the care of injured patients of 1.25 mSv total-body dose, 3.75 mSv eye dose, and 12.5 mSv extremity dose. The dose to the hands was slightly higher at 3.95 mSv/month.

(113) Sports medicine specialists and surgeons practising arthroscopy do not usually need to use C-arm fluoroscopy as an adjunctive measure during surgery. Most procedures are performed under direct visualisation using the arthroscope or through open means. Nonetheless, some surgeons prefer to use C-arm fluoroscopy during drilling of bony tunnels for ligament reconstruction and to confirm proper implant positioning (Larson et al., 1995). In general, primary ligament reconstructions require less intra-operative fluoroscopy time, and primary allograft reconstruction seems to require the least amount of radiation if C-arm fluoroscopy is used. The dose to the surgeon has been measured during such procedures and has been found to be uniformly low at a dose rate of 0.7 μSv/min (Larson et al., 1995). For a typical fluoroscopy time of 2.38 min, the average effective dose to the surgeon is 16 μSv/ procedure or 4 mSv/year for a workload of 250 procedures/year. Further studies using other techniques and implants confirm low scatter radiation to the surgeon (Larson and DeLange, 2008; Tsalafoutas et al., 2008).

(114) Orthopaedic surgeons who practice spinal surgery frequently use C-arm fluoroscopy to localise anatomical levels, assess bony alignment during deformity correction, and guide implant placement. As large body segments are imaged and these areas fill the entire field of view of the image intensifier, the potential for amplified radiation exposure of the patient and surgeon is high. Fluoroscopically assisted thoracolumbar pedicle screw placement exposes the spinal surgeon to significantly greater radiation levels (10–12 times) than other, non-spinal musculoskeletal procedures that involve the use of a fluoroscope (Rampersaud et al., 2000). Radiation dose rates to the surgeon's neck and dominant hand are 0.08 and 0.58 mGy/min, respectively. The dose rate to the torso was greater when the surgeon was positioned lateral to the

beam source (0.53 mGy/min, compared with 0.022 mGy/min on the contralateral side) (Rampersaud et al., 2000). Use of standard C-arm fluoroscopy during pedicle screw fixation has been shown to expose the surgeon to an average dose rate of 0.58 mSv/min. This relatively high exposure requires strict adherence to radiological protection measures.

(115) During minimally invasive transforaminal interbody lumbar fusion, for an average fluoroscopy time of 1.7 min, the mean equivalent dose per case to the surgeon is 0.76 mSv on the dominant hand, 0.27 mSv at the waist under a lead apron, and 0.32 mSv at unprotected thyroid level. Kyphoplasty and vertebroplasty, which are minimally invasive spinal procedures, require both antero-posterior and lateral real-time visualisation, often using biplane fluoroscopy equipment. In fact, 90% of the orthopaedic surgeon's effective dose and risk is attributed to kyphoplasty, while another 8% is attributed to spinal procedures (Theocharopoulos et al., 2003). The effective dose to the orthopaedic surgeon working tableside during a typical hip, spine, and kyphoplasty procedure was 5.1, 21, and 250 μSv, respectively, when a 0.5-mm lead-equivalent apron alone was used. The additional use of a thyroid shield reduced the effective dose to 2.4, 8.4, and 96 μSv per typical hip, spine, and kyphoplasty procedure, respectively.

(116) Procedures involving standard C-arm fluoroscopy of the cervical spine have been shown to lead to a dose rate of 0.25–0.30 mSv/min to the surgeon's hands, which is somewhat lower than that for procedures involving the lumbar spine (0.53–0.58 mSv/min) (Jones et al., 2000; Rampersaud et al., 2000; Giordano et al., 2009a).

4.3.2. Radiation dose management

Patient dose management

(117) Diagnostic testing in orthopaedics relies heavily on imaging studies. Many of these imaging modalities can be used interchangeably, with variable sensitivity for soft tissue or bony anatomy. Meanwhile, procedures that rely on imaging for localisation, indirect visualisation, or instrument guidance often depend specifically on ionising radiation as an imaging tool. For some minimally invasive orthopaedic procedures, C-arm fluoroscopy has supplanted direct visualisation and is requisite to successful completion of the procedure. To help reduce intra-operative radiation exposure, some authors have started to use alternative imaging modalities such as ultrasound to perform procedures that previously relied more heavily on fluoroscopy (Weiss et al., 2005; Hua et al., 2009; Mei-Dan et al., 2009). Although the use of such modalities is relatively untested, they offer promising new alternatives to imaging tools that use ionising radiation.

(118) Patient exposure has been shown to be reduced considerably (10 times) by adhering to proper radiation safety practices and imaging the specimen closest to the image intensifier. A significant learning curve is expected when using C-arm fluoroscopy during surgical procedures. Beam orientation, surgeon positioning, image optimisation, and other logistical challenges require time for the surgeon to make

the most efficient use of the C-arm device. Screening times can be a useful tool to measure optimum use of the C-arm fluoroscope during such surgical cases.

(119) Recent data suggest that although the mini C-arm device is capable of limiting exposure dose to the patient and surgeon, care must still be taken during its use (Giordano et al., 2007, 2008, 2009a,b). If the mini C-arm device is used in an injudicious manner, the surgeon, patient, and surrounding staff may be subjected to considerable scattered radiation exposure. Careless use of the mini C-arm device can even exceed doses encountered when using the large C-arm device under equivalent imaging conditions. Therefore, strict radiological protection measures, including the routine use of protective lead garments, should be observed when using both mini- and large C-arm fluoroscopes. The mini C-arm device should be used whenever feasible in order to eliminate many of the concerns associated with use of the large C-arm device, specifically those related to cumulative radiation hazards, positioning considerations, relative distance from the beam, and the need for protective shielding (Badman et al., 2005).

(120) Depending on the imaging configuration used, patient entrance skin dose rate with the mini C-arm device can be approximately half that of the standard C-arm device. The typical reported values are: 0.60 mGy/min (mini C-arm) and 1.1 mGy/min (large C-arm) for wrist surgery with cadaveric upper extremity (Athwal et al., 2005) and immobilisation of wrist fractures. A frequent mistake in using the C-arm device is to increase exposure parameters to improve image quality. However, most imaging problems can be solved by adjusting brightness and contrast (Athwal et al., 2005). Distance from the C-arm radiation source to the imaged object also determines the amount of direct radiation exposure. Surgeons should make a conscious effort to image patients as far from the x-ray source as possible. With the mini C-arm device, this would mean placing the imaged extremity directly on to the image intensifier. With the standard C-arm device used in the recommended vertical position, the source should be lowered to the floor to maximise the SSD (Athwal et al., 2005).

(121) As the cross-sectional dimensions of the imaged body area or tissue density of a patient increases, there is a precipitous amplification in exposure of both the patient and the surgical team. Thicker body portions remove more x rays than thinner portions, and must be compensated for to provide consistent image information. When the C-arm fluoroscope is set to the 'normal' mode, technique factors are adjusted automatically to produce an image of good clarity. Radiation production may therefore increase significantly when imaging a larger body area. For orthopaedic surgeons, this concept is pertinent because the amount of direct and scattered exposure may vary considerably depending on the body area to be imaged. As the size of the imaged extremity or tissue density increases, there is a notable augmentation of direct exposure of the patient as well as indirect scatter exposure of the surgical team (Giordano et al., 2007, 2008, 2009a,b; Yanch et al., 2009). This idea is particularly relevant to orthopaedic surgeons who perform spinal surgery, as mentioned previously.

(122) Even for orthopaedic surgeons who do not practice spinal surgery, the same principles still apply and are critical to maintaining appropriate safety precautions.

During fluoroscopic examination using a large C-arm device, radiation dose to the patient has been shown to increase nearly 10-fold when imaging a foot/ankle specimen compared with a cervical spine. The dose to the surgical team, meanwhile, was found to increase two- to three-fold (Giordano et al., 2007, 2008, 2009a,b). If a mini C-arm fluoroscope was used for the same scenario, the dose to the patient increased three- to four-fold, and the dose to the surgical team increased two-fold.

(123) Finally, all patient dose reduction actions described in Section 3 also apply to orthopaedic surgery.

Occupational dose management

(124) X rays travel in straight lines and diverge in different directions as shown in Fig. 3.7. The intensity decreases with distance according to the inverse square law. A study in orthopaedic operating theatres showed that standing 90 cm from the x-ray source vs 10 cm from the x-ray source decreased surgeon exposure from 0.20 mSv/case to 0.03 mSv/case (Mehlman and DiPasquale, 1997). Traditionally, surgeons have been taught that provided they stand at least 1.8 m from the x-ray source, they are at essentially zero risk of being exposed to radiation (Tsalafoutas et al., 2008). This is not correct and has been called into question in studies which have demonstrated higher exposure levels at a distance of 6 m from the x-ray source (Badman et al., 2005).

(125) Over the past several decades, mini C-arm fluoroscopy has emerged as a convenient imaging tool that has the potential to reduce radiation dose. Exposure levels have been studied during various orthopaedic procedures and scenarios (Athwal et al., 2005; Giordano et al., 2007, 2009b; Larson et al., 2008; Love et al., 2008). Some operators may believe that provided they are outside the primary beam and they do not see their body part in the image, their exposure is negligible. This is based on the fact that most studies which give such advice have been conducted under ideal circumstances, in contrast to more realistic applications that are encountered in practice. Exposure of the surgeon and operating team has been shown to vary in relation to the orientation of the x-ray beam. In some cases, it is unavoidable that the surgeon must stand in close proximity to the beam in order to maintain a reduction or to secure implant placement. In those instances, the surgeon may be at risk of exposure either by direct beam contact or through scatter radiation. Some authors have demonstrated a dramatically reduced exposure dose when the surgeon stood on the image intensifier side of the patient (Rampersaud et al., 2000). In effect, placing the x-ray source under the operating table provides an effective beam stop in some cases (Jones et al., 2000). When using the C-arm unit in a lateral or oblique orientation, the surgeon should work on the image intensifier side of the table to reduce exposure from scattered radiation. While this may be true when imaging body areas that intercept the beam fully, the same principle may not necessarily apply when imaging a smaller body area where the beam may not be collimated to the smaller size. In such a situation, some of the x-ray beam passes by the specimen unattenuated, resulting in a higher dose on the opposite side. This must be taken into consideration when positioning operating staff safely.

(126) Lead shielding is commonly used to attenuate exposure from scattered radiation. Manufacturers cite variable protection depending on the thickness of

the garment. In general, one can expect greater than 90% reduction in scatter exposure from a lead gown of 0.5-mm lead thickness. Realistically, the ability of a lead garment to attenuate scattered radiation is dependent upon the quality control actions taken to ensure that lead garments are well maintained. The protective benefit afforded by lead can be compromised by poor maintenance. In a study of 41 lead aprons, 73% were found to be outside the tolerance level of 5% for nominal lead-equivalent values (Finnerty and Brennan, 2005). Furthermore, a recent report by the American Academy of Orthopaedic Surgeons showed under-lead exposures to be only 30–60% less than over-lead exposures (American Academy of Orthopaedic Surgeons, 2008). This underscores the fallibility of this protective measure, as well as the importance of proper maintenance and storage. Lead aprons should not be folded but should be hung to improve their longevity. Imaging factors such as higher tube voltages and imaging larger body areas can further decrease effectiveness. These often-ignored variables should be clearly understood and corrected to improve protective measures.

(127) Use of a lead thyroid shield can reduce radiation exposure by a factor of 90% or more depending upon the kV used and lead equivalence (see Section 3). The highest levels of exposure to the hands of the surgeon arise from inadvertent exposure to the direct beam. Surgeons should ensure that they are positioned on the exit side of the x-ray beam, rather than on the entrance side. The radiation intensity on the exit side of the x-ray beam is typically around 1% (Section 3). Thus, every care should be taken for staff to be on the exit side. Lack of awareness of this leads to unnecessary exposure of staff. It is recognised that this may be unavoidable when maintaining a difficult reduction, confirming adequate bony alignment, or securing implant placement. In most cases, however, direct hand exposure is avoidable. When the orthopaedic surgeon's or assistant's hand is visible on a stored fluoroscopic image, it is generally evidence of poor radiological protection practices (Fig. 4.1). In cases where direct hand exposure is unavoidable, consideration may be given to using lead gloves.

(128) Some of the first radiation exposure data recorded in the orthopaedic literature were collected during hip pinning and femoral nailing in the traumatised patient (Giachino and Cheng, 1980; Giannoudis et al., 1998). As described in Section 3, increased distance from the patient is an efficient tool for dose reduction. For a lateral projection and laterally directed x-ray beam (surgeon stands beside image receptor), the dose rate decreased from 1.9 to 0.2 mGy/h when distance was increased from 2.5 to 45 cm. Similarly, for a lateral projection and x-ray beam directed towards the midline (surgeon stands beside x-ray tube), the dose rate decreased from 77 to 1.5 mGy/h when distance was increased from 2.5 to 45 cm (Giachino and Cheng, 1980).

4.4. Obstetrics and gynaecology

(129) Most radiological examinations in obstetrics and gynaecology are performed within radiology, but there are situations where they are performed in gynaecology practice and thus are included in this report.

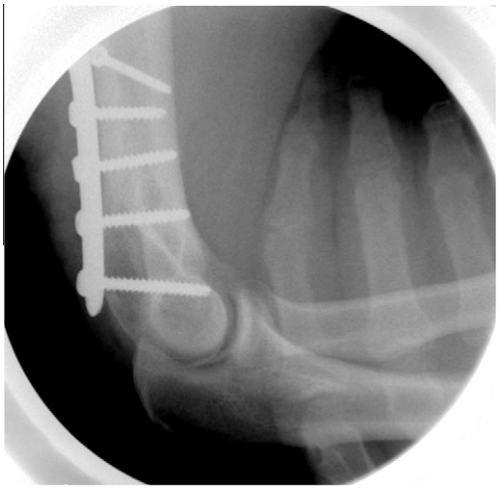


Fig. 4.1. Fluoroscopic image obtained to demonstrate satisfactory internal fixation of a fracture of the distal humerus. The assistant is holding the forearm, and three of the assistant's fingers are included in the image. This is poor practice. Source: D. Miller.

(130) Obstetrics and gynaecological studies in the USA account for 4.5% of all fluoroscopically guided diagnostic and interventional procedures, with a mean effective dose of 1 mSv. This contributes <1% to the total collective dose (NCRP, 2009).

(131) Hysterosalpingography is a relatively common radiological procedure that is used to assess the uterine cavity and the patency of the Fallopian tubes. The common indication for hysterosalpingography is primary and secondary infertility. It should not be forgotten that pregnancy can occur in these patients, and pregnancy tests should be performed unless there is information that precludes a pregnancy.

(132) Pelvimetry is an old procedure that was performed for assessment of maternal pelvic dimensions. This procedure may still be in use in some countries. Pelvimetry is usually considered necessary where vaginal delivery is contemplated in a breech presentation, or if reduced pelvic dimensions are suspected in a current or previous pregnancy.

(133) Historically, in a number of countries, pelvimetry represented the major single source of ionising radiation to the fetus. While radiographic pelvimetry is sometimes of value, it should only be undertaken on the rare occasions when this is likely to be the case, and should not be carried out on a routine basis. X-ray pelvimetry only provides limited additional information to physicians involved in the management of labour and delivery. In the few instances in which the clinician thinks that pelvimetry may contribute to a medical treatment decision, the reasons should be clearly delineated (ICRP, 2000).

(134) Conventional pelvimetry includes radiography, but digital fluorography, CT, magnetic resonance imaging (MRI), and ultrasound are currently used for pelvimetry (Thomas et al., 1998; ICRP, 2000).

(135) Uterine artery embolisation is a minimally invasive procedure for therapy for uterine fibroids (leiomyomata). It can be accepted as an alternative to surgery in general practice; however, radiation effects from this procedure should be assessed carefully, as it is associated with relatively long fluoroscopy times and a large number of images (Nikolic et al., 2000).

4.4.1. Levels of radiation dose

Dose to patient

(136) The radiation dose to mother and fetus in pelvimetry can vary by a factor of 20–40 depending upon the techniques used, namely CT, conventional radiography, or digital fluorography (Table 4.5).

(137) CT pelvimetry with a lateral scanogram generally gives the lowest radiation dose, and conventional radiography using an air gap technique with a single lateral view is a relatively low-dose alternative where CT is not available (Thomas et al., 1998). In comparison, the reported effective dose from conventional pelvimetry is in the range of 0.5–5.1 mSv, which is significantly higher than the effective dose of 0.2 mSv from CT pelvimetry (Hart and Wall, 2002).

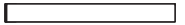
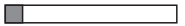
(138) A typical effective dose to a patient undergoing hysterosalpingography as part of their infertility work-up is 1.2–3.1 mSv (Table 4.5), with ovarian doses in the range of 2.7–9.0 mGy. However, higher effective doses of 8 mSv and ovarian doses of 9–11 mGy have been reported (Fernández et al., 1996; Nakamura et al., 1996; Gregan et al., 1998). The effective dose from uterine artery embolisation can be even higher, ranging from 15 to 26 mSv, with relatively high skin and ovarian doses (Nikolic et al., 2000; Glomset et al., 2006). Reported estimated mean uterine and ovarian doses are 81–101 mGy and 85–105 mGy, respectively (Glomset et al., 2006).

Occupational dose levels

(139) During hysterosalpingography, if the examination protocol involves fluoroscopic guidance, workers will need to be located inside the x-ray room. When the procedure involves radiography alone, workers will be located outside the room at the console. A protective lead apron should be worn by workers when inside the x-ray room, and other protective measures mentioned in Section 3 should also be adopted.

(140) There are few publications on this subject. One recent paper reported an entrance surface dose value of 0.18 mGy/procedure, with a slight increase when hysterosalpingography is performed on conventional x-ray film compared with digital (0.21 mGy vs 0.14 mGy). Doses to the lens of the eye, thyroid, and hands of workers are reported to be 0.22, 0.15, and 0.19 mGy/procedure, respectively. The risk for workers is negligible when a lead apron of 0.35–0.5 mm lead equivalence is worn (Sulieman et al., 2008).

Table 4.5. Typical patient dose levels from gynaecological procedures (rounded) and comparison with computed tomography.

Procedure	Relative mean radiation effective dose to patient 0 mSv 35	Relative mean radiation dose to patient*	Reported values				Reference†
			Fluoroscopy time (min)	Entrance skin dose (mGy)	Dose–area product ($Gycm^2$)	Effective dose (mSv)	
Pelvimetry, conventional		A	n.a.	4.2–5.1	1.4	0.4–0.8	a,b,c
Pelvimetry, digital fluorography		A	0.3	3.6	0.10–0.46	0.43	d
Computed tomography pelvimetry		A	n.a.	n.a.	n.a.	0.2	c
Hysterosalpingography		B,C	0.3–14	9.7–30	4–7	1.2–3.1	b,c,e,f,g,h,i,j
Uterine artery embolisation		E,F	21–36	453–1623	53–89	22–32	l,m

n.a., not available.

† (a) Russel et al., 1980; (b) NCRP, 2009; (c) Hart and Wall, 2002; (d) Wright et al., 1995; (e) Sulieman et al., 2008; (f) Gregan et al., 1998; (g) Perisinakis et al., 2003; (h) Fife et al., 1994; (i) Fernández et al., 1996; (j) Calcchia et al., 1998; (l) Nikolic et al., 2000; (m) Glomset et al., 2006.

* A, <1 mSv; B, 1–<2 mSv; C, 2–<5 mSv; D, 5–<10 mSv; E, 10–<20; F, 20–35 mSv; G, >35 mSv, based on effective dose.

4.4.2. Radiation dose management

Patient dose management

(141) Section 3 deals with patient dose management in great detail.

(142) In hysterosalpingography, a standard procedure may involve around 0.3 min of fluoroscopy and three to four images (Perisinakis et al., 2003). Prolonged fluoroscopy time and a higher number of acquired images will increase the patient dose. Hysterosalpingography is typically performed in antero-posterior and oblique projections. For a total effective dose in hysterosalpingography of 2 mSv, the contributions from antero-posterior and oblique projections are typically 1.3 and 0.7 mSv, respectively (Calcchia et al., 1998).

(143) Increasing the tube voltage is an efficient method for dose reduction in hysterosalpingography, as ovarian dose is decreased by approximately 50% when tube voltage is increased from 70 to 120 kV (Kramer et al., 2006). Choice of posterior–anterior projection and increased filtration are other possible steps to reduce the dose to patients. As an example, the use of additional filtration could lead to dose reduction of >80% without loss of image quality in hysterosalpingography in computed radiography systems (Nagashima et al., 2001).

(144) There is evidence of almost six-fold dose reduction as a result of transition from screen-film to digital imaging equipment. In a comparative dosimetric study of hysterosalpingography performed on conventional screen-film undercouch x-ray units and digital C-arm radiological fluoroscopy units, entrance surface doses of 15 and 2.5 mGy were found for screen-film and digital units, respectively (Gregan et al., 1998). The corresponding ovarian doses were 3.5 and 0.5 mGy (Gregan et al., 1998). As almost 75% of the total dose in hysterosalpingography is due to radiography and only 25% is due to fluoroscopy (Fernández et al., 1996), a significant dose reduction could be achieved by using stored digital images without further patient exposure. The use of C-arm fluoroscopic imaging systems with pulsed fluoroscopy and last-image-hold capability is desirable (Phillips et al., 2010).

(145) The fundamental approach in dose reduction in hysterosalpingography is to reduce fluoroscopy time and the number of images taken.

Occupational dose management

(146) It has been demonstrated that mean screening time is highly operator dependant. The observed screening time for procedures performed by gynaecologists or trainee doctors is higher compared with that for radiologists (Sulieman et al., 2008). Therefore, hysterosalpingography should be performed by experienced physicians with training and skill in radiological protection and radiation management. In general, all patient dose reduction methods can also reduce the dose to physicians and support personnel involved in the examination. Furthermore, the use of an overcouch x-ray unit increases scatter dose to the face, neck, and upper parts of the operator's body.

(147) The occupational dose management actions described in Section 3 are also generally applicable in gynaecological procedures.

4.5. Gastroenterology and hepatobiliary system

(148) The use of ionising radiation in gastroenterology and hepatobiliary procedures is somewhat in transition. In the past, gastroenterologists performed a variety of interventions involving radiation exposure, including gastrointestinal and hepatobiliary x-ray studies, placement of small bowel biopsy tubes, oesophageal dilation, and assistance with colonoscopy, as well as diagnostic and therapeutic procedures on the pancreaticobiliary system during ERCP. ERCP and other biliary procedures require fluoroscopic guidance, and most of the current x-ray exposure is from ERCP, luminal stents, and dilation. The other procedures are becoming supplanted by improvements in diagnostic equipment and techniques. Gastroenterologists who are involved in ERCP procedures may work at specialised centres and may perform multiple procedures daily. In many circumstances where fluoroscopic and/or X-ray equipment are used, gastroenterologists have the opportunity to minimise risk to patients, staff, and themselves.

(149) ERCP studies account for 8.5% of all fluoroscopically guided diagnostic and interventional procedures in the USA, with a mean effective dose of 4 mSv. They contribute 4–5% to the total collective dose from fluoroscopically guided interventions (NCRP, 2009).

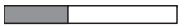
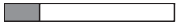
(150) During ERCP, fluoroscopy is used to verify the position of the endoscope and its relationship within the duodenum. The placement of catheters and guide wires is also verified fluoroscopically. Once contrast injections are performed, fluoroscopy is used to evaluate the anatomy of the ductal systems of both the biliary tree and the pancreas, and to help define potential diseases present. Images are usually taken to record the findings, either by capturing the last fluoroscopic image or spot radiographs. Finally, the use of fluoroscopy to assist therapy, such as sphincterotomy, stone extraction, biopsy or cytology, and stent placement is required. Additional devices that allow direct visualisation of ductal anatomy may ultimately reduce the need for fluoroscopy (World Gastroenterology Organisation, 2009).

4.5.1. Levels of radiation dose

Dose to patient

(151) Typical patient dose levels for common gastroenterology and hepatobiliary procedures involving x rays are presented in Table 4.6. Single and double contrast barium enemas are x-ray examinations of the large intestine (colon and rectum). Barium swallow is an x-ray examination of the upper gastrointestinal tract. These traditional x-ray examinations in gastroenterology are associated with effective doses ranging from 1–3 mSv (barium swallow and barium meal) to 7–8 mSv (small bowel enema and barium enema) (UNSCEAR, 2010). Although these studies are mainly performed within imaging departments, it is important that gastroenterologists are aware of typical dose levels and risks. At present, many barium studies have been replaced by endoscopic procedures that exclude the use of ionising radiation.

Table 4.6. Typical patient dose levels (rounded) from gastroenterology and hepatobiliary procedures.

Procedure	Relative mean effective dose to patient 0 mSv 35	Relative mean radiation dose to patient*	Reported values				Reference†
			Fluoroscopy time (min)	Entrance skin dose (mGy)	Dose–area product ($Gycm^2$)	Effective dose (mSv)	
ERCP (diagnostic)		C,D	2–3	55–85	15	3–6	a,b
ERCP (therapeutic)		E,F	5–10	179–347	66	20	a,b
Biopsy		C	n.a.	n.a.	6	1.6	a,c
Bile duct stenting		E	n.a.	499	43–54	11–14	a,c,d
Percutaneous transhepatic cholangiography		D	6–14	210–257	31	8.1	a
Bile duct drainage		F,G	12–26	660	38–150	10–38	a,d,e
Transjugular intrahepatic portosystemic shunt creation		F,G	15–93	104–7160	14–1364	19–87	a,e,f
Transjugular hepatic biopsy		D	6.8	n.a.	34	5.5	f

ERCP, endoscopic retrograde cholangio-pancreatography; n.n., not available.

† (a) UNSCEAR, 2010; (b) Olgar et al., 2009; (c) Hart et al., 2002; (d) Dauer et al., 2009; (e) Miller et al., 2003a; (f) McParland, 1998.

* A, <1 mSv; B, 1–<2 mSv; C, 2–<5 mSv; D, 5–<10 mSv; E, 10–<20; F, 20–35 mSv; G, >35 mSv, based on effective dose.

(152) For the patient, the source of exposure is the direct x-ray beam from the x-ray tube. It is estimated that patients receive approximately 2–16 min of fluoroscopy during ERCP, with therapeutic procedures taking significantly longer. Studies have found that DAP values of approximately 13–66 $Gycm^2$ are typical for ERCP. Effective doses ranging from 2 to 6 mSv/procedure have been reported (World Gastroenterology Organisation, 2009).

(153) Care of the patient undergoing an endoscopic procedure continues to become more complex as technology advances. Due to higher complexity, doses from therapeutic ERCP are typically higher than doses from diagnostic ERCP. For diagnostic ERCP, the average DAP is 14–26 $Gycm^2$, while it reaches 67–89 $Gycm^2$ for therapeutic ERCP. Corresponding entrance skin doses are 90 and 250 mGy for diagnostic and therapeutic ERCP, respectively. The mean effective doses are 3–6 mSv for diagnostic ERCP and 12–20 mSv for therapeutic ERCP (Larkin et al., 2001; Olgar et al., 2009). Fluoroscopic exposure accounts for almost 70% of the dose for diagnostic ERCP, and >90% of the dose for therapeutic ERCP, indicating that reduction of fluoroscopy time is an efficient method for dose management (Larkin et al., 2001).

(154) The estimated radiation dose and associated risks for fluoroscopically guided percutaneous transhepatic biliary drainage and stent implantation procedures indicate that radiation-induced risk may be considerable for young patients undergoing these procedures. The average effective dose varies from 2 to 6 mSv depending on procedure approach (left vs right access) and procedure scheme. However, effective dose may be higher than 30 mSv for prolonged fluoroscopy times (Stratakis et al., 2006; UNSCEAR, 2010). In the available literature, the reported DAP values for biliary drainage are in the range of 38–150 $Gycm^2$, which, based on an appropriate conversion factor from DAP to effective dose, corresponds to an effective dose of 10–38 mSv/procedure (Miller et al., 2003a; Dauer et al., 2009; UNSCEAR, 2010).

Occupational dose

(155) For gastroenterologists and other staff, the major source of x-ray exposure is scattered radiation from the patient, rather than the primary x-ray beam. Average effective doses of approximately 2–70 μSv/procedure have been observed for endoscopists wearing lead aprons (Olgar et al., 2009; World Gastroenterology Organisation, 2009). Although the endoscopist's body is well protected by a lead apron, there can also be substantial doses to unshielded parts. For a single ERCP procedure, typical doses of 94–340 μGy to the head and neck region (eyes and thyroid) and 280–830 μGy to the fingers have been reported (Buls et al., 2002; Olgar et al., 2009). For PTC (percutaneous transhepatic cholangiography), reported doses are in the range of 300–360 μGy/procedure for the head and neck and 530–1000 μGy/procedure for the fingers (Olgar et al., 2009). For a workload of three to four procedures/week, Naidu et al. (2005) reported extrapolated annual doses to the thyroid gland and extremities for operators performing ERCP studies of 40 and 7.92 mSv, respectively. Doses to assisting personnel are usually lower,

depending on position and the time spent near the x-ray source, as they usually stand further away from the patient (World Gastroenterology Organisation, 2009).

(156) Jorgensen et al. (2010) reported the typical annual workload for the ERCP providers, stating that 34% of them perform <100 ERCP procedures/year, 38% perform 100–200 procedures/year, and 28% perform >200 procedures/year.

(157) It is not possible to document the health effects of ionising radiation at the dose levels to which gastroenterologists performing ERCP or fluoroscopy are exposed; annual effective doses are typically 0–3 mSv when appropriate radiological protection tools and principles are applied (World Gastroenterology Organisation, 2009). Nevertheless, many gastroenterologists involved in diagnostic and therapeutic procedures using ionising radiation do not routinely wear full protective clothing (protective aprons, thyroid shield, lead glasses). Audits of radiation exposure of personnel performing ERCP found that workers can be exposed to significant radiation exposure, as only half of the respondents reported regular use of a thyroid shield (Frenz and Mee, 2005).

(158) Typical equivalent doses for hands, neck, forehead, and gonads during percutaneous procedures under fluoroscopic guidance, such as percutaneous cholangiography and transhepatic biliary drainage, are: 13–220 μSv for hands, 0.007–0.027 μSv for thyroid and lens of the eye, and negligible for gonads under a lead apron. The assessed annual dose levels fall below regulatory dose limits for occupational exposure (Benea et al., 1988).

(159) While it is well known that an overcouch tube x-ray unit is not adequate for performing interventional procedures, ERCP commonly involves the use of this type of equipment. Olgar et al. (2009) reported typical doses of 94 and 75 μGy for the eye and neck, respectively, of a gastroenterologist. With an overcouch unit, typical eye and neck doses are 550 and 450 μGy, with maximal doses up to 2.8 and 2.4 mGy/procedure, respectively (Buls et al., 2002). Dose to the lens of the eye is critical, as for a moderate workload, the annual equivalent dose limit for the lens of the eye of 20 mSv could be reached. This is clearly dependent on the type of x-ray equipment used.

4.5.2. Radiation dose management

Patient dose management

(160) Where possible, ERCP should be reserved for situations where intervention is likely, using alternative modalities for purely diagnostic purposes (e.g. magnetic resonance cholangio-pancreatography) (Williams et al., 2008). Reported occupational dose levels using overcoach tube units may indicate that ERCP procedures are often performed without attention to equipment and radiological protection. There is evidence that a correctly operated C-arm unit with the availability of pulsed fluoroscopy will dramatically reduce the dose to both patients and workers (Buls et al., 2002). In addition, use of a grid-controlled pulsed fluoroscopy unit could achieve significantly lower patient doses without loss in diagnostic accuracy compared with a conventional continuous fluoroscopy unit

for a variety of abdominal and pelvic fluoroscopic examinations (Boland et al., 2000).

(161) In any procedure when fluoroscopy is used for guidance, the shortest possible period of fluoroscopy is recommended. Therefore, both patient and occupational doses could be reduced by time-limited fluoroscopy that significantly decreases fluoroscopy time and dose (Uradomo et al., 2007).

(162) Best practice during ERCP includes positioning of the x-ray tube below the table as far away as possible, positioning oneself as far away as possible from the X-ray tube and patient, and, wearing a protective apron, thyroid shield, and leaded eyewear. Maintaining x-ray equipment in optimum operating condition, using pulsed fluoroscopy, minimising fluoroscopy time, limiting the number of radiographic images, using shielding barriers, collimation, and reduced use of magnification will help to reduce x-ray exposure of the workers as well as that of the patient. Anything that increases the amount of radiation exposure (e.g. longer fluoroscopy time, generation of more radiographic images, proximity to the radiation source, positioning the X-ray source above the patient, and proximity of the worker to the patient) will increase the radiation dose and potential risk from ionising radiation.

(163) The patient dose management actions described in Section 3 are generally applicable in gastroenterology and hepatobiliary procedures.

Occupational dose management

(164) Patient and occupational exposure are related. Any action to reduce patient dose will also reduce the dose to workers.

(165) It is obvious that ERCP and TIPS (transjugular intrahepatic portosystematic shunt) have the potential to cause high occupational doses, and consequently require attention regarding radiological protection. The reported dose levels indicate that ERCP and TIPS require the same radiological protection practices as all interventional procedures. The Commission covered radiological protection issues in interventional procedures in *Publication 85* (ICRP, 2001).

(166) Specific written policies and procedures for the safe use of radiographic equipment must be available to all gastroenterology personnel. Endoscopy personnel can limit occupational exposure to radiation by using the principles based on distance, time, and shielding, as described in Section 3 of this report. For example, a well-positioned, 0.5-mm lead-equivalent acrylic shield will reduce occupational exposure by a factor of 11 (Chen et al., 1996). Besides basic dose management actions, if a single-sided apron is being used, it is important to face the radiation-emitting unit at all times. If this is not possible and duties require staff members to turn away from the radiation source, exposing their backs, a wrap-around apron that provides protection around the body must be used (SGNA, 2008).

(167) As outlined in Section 3, training and experience are powerful dose reduction tools. The fluoroscopy time is shorter when ERCP is performed by endoscopists with more years of experience of performing ERCP and who performed a greater number of ERCPs in the preceding year. Endoscopists who performed <100 and 100–200 ERCP procedures in the preceding year had 59% and 11% increases in fluoroscopy

time, respectively, compared with endoscopists who performed >200 ERCP procedures in the preceding year. Every 10 years of experience was associated with a 20% decrease in fluoroscopy time (Jorgensen et al., 2010).

4.6. Anaesthetics and pain management

(168) Local spinal pain and radiculopathy are very common conditions. As imaging abnormalities do not correlate with symptoms in most cases, many patients do not receive a specific diagnosis and have continued pain. Percutaneous injection techniques have been used to treat back pain for many years, and have been controversial. Many of these procedures have historically been performed without imaging guidance. Imaging-guided techniques with fluoroscopy or CT increase the precision of these procedures and help to confirm needle placement. As imaging-guided techniques should lead to better results and reduced complication rates, they are becoming more popular (Silbergleit et al., 2001). Epidural injections are commonly used for the treatment of lower back pain in patients for whom conservative disease management has failed and who may wish to avoid, or cannot have, surgery (Wagner, 2004).

(169) Reported patient doses during fluoroscopy guided epidural injections are higher when continuous fluoroscopy is used. When pulsed fluoroscopy is used, the patient effective dose per minute of fluoroscopy is significantly lower: 0.08, 0.11, and 0.18 mSv for 3, 7.5, and 15 pulses/s, respectively (Schmid et al., 2005). During CT fluoroscopic guidance, typical effective patient doses are in the range of 1.5–3.5 mSv for a standard protocol and 0.22–0.43 mSv for a low-dose protocol, depending on the number of consecutive scans performed. Therefore, an 80–90% reduction in effective dose has been reported by applying pulsed fluoroscopy, while the use of a low-dose CT protocol in terms of reduced mA and tube rotation time reduces the effective dose by >85% (Schmid et al., 2005).

(170) The reported radiation dose to the operator during CT fluoroscopy guided lumbar nerve root blocks outside the lead protection is typically 1–8 μSv/procedure (Wagner, 2004).

(171) The factors that greatly influence the dose to the operator are: equipment technology, use of shielding, operator's experience, use of lower mA, and smaller scan volume. The patient dose has also been greatly reduced by these techniques, and by using pulsed fluoroscopy and reduced mA values during CT fluoroscopic guidance (Wagner, 2004; Schmid et al., 2005).

4.7. Sentinel lymph node biopsy

(172) The sentinel lymph node (SLN) is the first lymph node to which cancer is likely to spread from the primary tumour. Cancer cells may appear in the SLN before spreading to other lymph nodes. A SLNB is based on the premise that cancer cells spread (metastasise) in an orderly way from the primary tumour to the SLN, and then to other nearby lymph nodes. A negative SLNB result suggests that cancer has not spread to the lymph nodes. A positive result indicates that cancer is present

in the SLN and may be present in other lymph nodes in the same area (regional lymph nodes).

(173) Several reports have demonstrated accurate prediction of nodal metastasis with radiolocalisation and selective resection of the radiolocalised SLN in patients with cancer of the breast, vulva, penis, head and neck, and melanoma. The list is expanding with ongoing research. Accurate identification of the SLN is paramount for the success of this procedure. SLNB is the evolving standard of care for the management of early breast cancer. In SLNB, only the first node draining a tumour is removed for analysis. Clearance to achieve local control is reserved for those with a positive SLNB.

(174) Various techniques are described for SLN identification, but injection of a radiotracer into the tumour is most common. Pre-operative lymphoscintigraphy provides a road map for the surgeon and requires a reporting template. ^{99m}Technetium (Tc) sulphur colloid has been used for over a decade and offers the potential for improved staging of breast cancer with decreased morbidity. Intra-operative gamma-ray detection is used to identify and remove the 'hot' node(s).

(175) The use of radioactive materials in the operating theatre generates significant concern about radiation exposure. As reliance on this technique grows, its use by those without experience in radiation safety will increase.

4.7.1. Levels of radiation dose

Dose to patient

(176) ^{99m}Tc sulphur colloid or nano colloid is a commonly used radiotracer, and there has been an inclination to find positron-emitting radiopharmaceuticals in recent years. ^{99m}Tc is a pure gamma emitter. When injected as a colloid, it remains localised, and the radiation dose to the patient is extremely small with the activity used for this procedure. As a result, there is a lack of published reports on radiation doses to patients in SLNB procedures, and most papers address the issue of occupational exposure. One needs to address the concern of radiation dose to the pregnant patient and fetus. Estimated fetal dose is normally <0.1 mGy (typically ≤ 0.01 mGy), and effective dose to the patient is generally <0.5 mSv using 18.5 MBq of ^{99m}Tc colloid. These doses are too small to preclude the use of this technique in pregnancy when there is clinical benefit and alternative techniques cannot provide the same information. The fact that due considerations have taken place should be recorded (Pandit-Taskar et al., 2006; Spanheimer et al., 2009).

Occupational dose levels

(177) Physicians administering the radiotracer injection in SLNB receive equivalent doses to the hands of 2.3–48 μSv/case, with a maximal dose up to 164 μSv. Surgeons receive equivalent doses to the hands of 2–8 μSv/case (Nejc et al., 2006). However, there are studies indicating that the equivalent dose to the hands of operating surgeons can be as high as 22–153 μSv, depending on the technique

applied (De Kanter et al., 2003). Notably, other members of the medical team receive similar doses (4.3–7.9 μSv/case) (Nejc et al., 2006). Several other studies have reported similar minimal occupational radiation doses with SLNB (Miner et al., 1999; Waddington et al., 2000; Klausen et al., 2005). Considering a typical workload in a moderate hospital of approximately 20 patients/year, the annual equivalent dose to the hands using these figures can be up to 3 mSv, whereas the Commission's dose limit is 500 mSv.

4.7.2. Radiation dose management

Patient dose management

(178) Use of the principle of optimisation of radiological protection promotes administration of the lowest amount of radioactivity required to obtain the desired clinical information. Furthermore, the use of alternative techniques using non-ionising radiation is preferred when similar information can be obtained, particularly in pregnancy.

Occupational dose and radioactive waste management

(179) There are indications that the radiation dose to the hands of medical staff is smaller when SLNB is performed as a 2-day procedure, where surgery is performed 24 h after the injection of radiotracer. Four physical half-lives of the radiotracer pass over 24 h (^{99m}Tc, $t_{1/2}$=6.02 h). Moreover, the activity is further diminished due to clearance of the radiotracer from the blood (Waddington et al., 2000; Nejc et al., 2006).

(180) Radioactive waste is created in the operating theatre, and may be generated in the pathology laboratory if specimens are not routinely stored until fully decayed.

(181) A general framework for radiological protection and disposal of radioactive waste was published by the Commission in *Publication 77* (ICRP, 1997). It should be remembered that the primary aim of radiological protection is to provide an appropriate standard of protection for humans without unduly limiting the beneficial practices giving rise to radiation exposure. For the control of public exposure from waste disposal, the Commission retained the *Publication 77* value for the dose constraint for members of the public (no more than approximately 0.3 mSv/year) in its 2007 Recommendations (ICRP, 2007b). Special considerations for radioactive waste materials are not required, but it is suggested that such waste materials should be sealed and stored for decay before disposal at the designated place in accordance with local rules.

(182) Radioactivity contamination in operating room materials is also minimal and requires normal precautions in handling. Letting radioactivity decay with time by storing the specimens for a few hours is a sufficient precaution for pathologists handling the SLNB specimens. Following the safety guidelines, the specimens arising from SLNB procedures should be stored for decontamination until the dose rate falls to background levels (Stratmann et al., 1999). Depending upon the administered activity, this takes approximately 60–70 h for primary specimens and 30–40 h for nodes following ^{99m}Tc sulphur colloid injection (Miner et al.,

1999; Filippakis and Zografos, 2007). A local risk assessment should be carried out prior to undertaking these procedures. Transport and disposal of decayed radioactive waste should be performed in accordance with national regulatory requirements.

4.8. References

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5. PREGNANCY AND CHILDREN

- **Medical radiation applications on pregnant patients should be justified and tailored to reduce fetal dose.**
- **Termination of pregnancy at fetal doses of <100 mGy is not justified based upon radiation risk.**
- **The restriction of a dose of 1 mSv to the embryo/fetus of pregnant worker after declaration of pregnancy does not mean that it is necessary for a pregnant woman to avoid work with radiation completely, or that she must be prevented from entering or working in designated radiation areas.**
- **Pregnant medical workers may work in a radiation environment provided that there is reasonable assurance that the fetal dose can be kept below 1 mSv during the course of pregnancy. It does, however, imply that the employer should review the exposure conditions of pregnant women carefully.**

5.1. Patient exposure and pregnancy

(183) Medical exposure of a pregnant female presents a unique challenge to professionals because of the concern about the radiation risk to the fetus compared with the risk of not carrying out the procedure. Thousands of pregnant patients and workers are exposed to ionising radiation each year. Lack of knowledge is responsible for great anxiety and probably unnecessary termination of pregnancies (ICRP, 2000). This section is focused on situations of known pregnancy, as well as exposure in situations of unknown or undeclared pregnancy. The Commission covered this topic extensively in *Publication 84* (ICRP, 2000).

(184) The potential biological effects of in-utero radiation exposure of a developing fetus include prenatal death, intra-uterine growth restriction, small head size, mental retardation, organ malformation, and childhood cancer. The risk of each effect depends on gestational age at the time of exposure, fetal cellular repair mechanisms, and absorbed radiation dose level (ICRP, 2000; McCollough et al., 2007).

(185) It is unlikely that radiation from diagnostic radiological examinations will result in any known deleterious effects on the unborn child, but the possibility of a radiation-induced effect cannot be ruled out entirely. However, for invasive procedures, the radiation dose to the fetus will vary, and can range from a very small dose of little significance when the fetus is not in the primary beam, to a significant dose when the fetus lies in the primary beam or adjacent to the primary beam boundary. This requires prospective planning. Radiation risks are most significant during organogenesis and the early fetal period, somewhat less significant in the second trimester, and least significant in the third trimester (ICRP, 2000).

(186) As the Commission stated in *Publication 84* (ICRP, 2000), analysis of many of the epidemiological studies conducted on prenatal x-ray and childhood cancers

are consistent with a relative risk of 1.4 (a 40% increase over the background risk) following a fetal dose of approximately 10 mGy. The absolute risk estimate studies indicate a risk of one cancer death per 1700 children exposed to 10 mGy in utero (ICRP, 2000).

(187) Prenatal doses from most properly performed diagnostic procedures typically present no measurably increased risk of prenatal death, malformation, or impairment of mental development over the background incidence of these entities. Typical fetal doses from selected x-ray procedures are presented in Table 5.1.

(188) When the number of cells in the conceptus is small and their nature is not yet specialised, the effect of damage to these cells is most likely to take the form of failure to implant or undetectable death of the conceptus; malformations are unlikely or

Table 5.1. Typical fetal absorbed dose from x-ray examinations.

Examination	Typical fetal dose (mGy)	Reference*
Abdomen: antero-posterior	2.9	a
Abdomen: postero-anterior	1.3	a
Pelvis: antero-posterior	3.3	a
Chest	<0.01	b
Lumbar spine (average for various projections)	4.2	b
Hip joint	0.9	b
Intravenous pyelography (four images)	6	c
Intravenous urography	1.7–4.8	d
Small bowel study	7	c
Double contrast barium enema	7	c
Barium meal	1.5	b
Cholecystography	3.9	b
Abdominal CT, routine	4	c
Abdomen/pelvis CT, routine	25	c
Abdomen/pelvis CT, stone protocol	10	c
Endoscopic retrograde cholangio-pancreatography	3.5–56	e
Pelvimetry	0.1–1.0	f
Fluoroscopically assisted surgical treatment of hip	0.425	g
Sentinel lymph node biopsy	<0.1	h
Fluoroscopically assisted surgical treatments of spinal disorders (conceptus outside the primary beam)	4	i
Fluoroscopically assisted surgical treatments of spinal disorders (conceptus in primary beam)	105	i
Transjugular intrahepatic portosystemic shunt	5.5	j

CT, computer tomography.

* (a) UNSCEAR, 2010; (b) Osei and Faulkner, 1999; (c) McCollough et al., 2007; (d) ICRP, 2000; (e) Samara et al., 2009; (f) Radiological Protection Institute of Ireland, 2010; (g) Damilakis et al., 2003; (h) Pandit-Taskar et al., 2006; (i) Theocharopoulos et al., 2006; (j) Savage et al., 2007.

very rare. Since organogenesis starts 3–5 weeks after conception, it is felt that radiation exposure very early in pregnancy cannot result in malformation. The main risk is fetal death, and a fetal dose of >100 mGy is needed for this to occur. Fetal doses in excess of approximately 100 mGy may result in a decrease in the intelligence quotient (IQ). Regardless of gestational age, IQ reduction cannot be clinically identified at fetal doses of <100 mGy. It is also important to relate the magnitude of health effects of ionising radiation to those abnormalities that occur spontaneously in the population in the absence of radiation exposure other than natural background radiation (ICRP, 2000).

(189) Occasionally, a patient will not be aware of a pregnancy at the time of an x-ray examination, and will naturally be very concerned when the pregnancy becomes known. In such cases, the radiation dose to the fetus/conceptus should be estimated by a medical physicist or other professional experienced in dosimetry. The patient can then be better advised regarding the potential risks involved.

(190) When a pregnant patient requires an x-ray procedure, the indications should be evaluated to ensure justification. The procedure should then be optimised by strict adherence to good technique, as described in Section 3.

5.2. Guidelines for patients undergoing radiological examinations/procedures at childbearing age

(191) Prior to radiation exposure, female patients of childbearing age should be evaluated, and an attempt should be made to determine individuals who are or could be pregnant.

(192) Particular problems may be experienced in obtaining this information from females under 16 years of age. There should be agreed procedures in place in all clinical imaging facilities to cover this, and also to deal with unconscious patients and those with special needs (Health Protection Agency, 2009). In addition, it should not be forgotten that pregnancy can occur in adolescent girls; thus, precautions for this group should be followed for exposures which may involve a fetus. With this group, care and sensitivity must be exercised with regard to the circumstances in which they are asked the relevant questions, both to respect their privacy and to optimise the possibility of being told the truth. With respect to pregnancy tests, many are of little value in excluding early pregnancy and generate a false sense of security.

(193) It is prudent to consider as pregnant any female of reproductive age presenting herself for an x-ray examination at a time when a menstrual period is overdue, or missed, unless there is information that precludes a pregnancy (e.g. hysterectomy or tubal ligation). In addition, every woman of reproductive age should be asked if she is, or could be, pregnant. In order to minimise the frequency of unintentional radiation exposures of the embryo and fetus, advisory notices should be posted in several places in areas where x-ray equipment is used.

(194) As fetal doses are usually well below 50 mGy in x-ray procedures, pregnancy tests are not usually performed. In cases where a high-dose fluoroscopy procedure of

the abdomen or pelvis (e.g. embolisation) is contemplated, the physician may want to order a pregnancy test depending on the reliability and history of the patient (ICRP, 2000).

(195) If there is no possibility of pregnancy, the examination can be performed. If the patient is definitely or probably pregnant, the justification for the proposed examination must be reviewed, and the decision on whether to defer the investigation until after delivery must be made, bearing in mind that a procedure of clinical benefit to the mother may also be of indirect benefit to her unborn child, and that delaying an essential procedure until later in pregnancy may present a greater risk to the fetus (Health Protection Agency, 2009).

(196) When a patient has been determined to be pregnant or possibly pregnant, a number of steps are usually taken prior to performing the procedure, as described in Section 5.3.

5.3. Guidelines for patients known to be pregnant

(197) Medical exposure of pregnant women poses a different benefit/risk situation than most other medical exposures. In most medical exposures, the benefit and risk are to the same individual. In the situation of in-utero medical exposure, two different entities (the mother and the fetus) must be considered (ICRP, 2000).

(198) Medical radiation applications should be optimised to achieve the clinical purposes with no more radiation than is necessary, given the available resources and technology. If possible, for pregnant patients, medical procedures should be tailored to reduce fetal dose. Prior to and after medical procedures involving high doses of radiation on pregnant patients, fetal dose and potential fetal risk should be estimated (ICRP, 2000).

(199) Termination of pregnancy at fetal doses of <100 mGy is not justified based upon radiation risk. At higher fetal doses, informed decisions should be made based upon individual circumstances (ICRP, 2000).

5.4. Occupational exposure and pregnancy

(200) It is the Commission's policy that methods of protection at work for women who are pregnant should provide a level of protection for the embryo/fetus that is broadly similar to that provided for members of the public. The Commission recommends that the working conditions of a pregnant worker, after declaration of pregnancy, should be such as to ensure that the additional dose to the embryo/fetus would not exceed approximately 1 mSv during the remainder of the pregnancy. The restriction of a dose of 1 mSv to the embryo/fetus of a pregnant worker after declaration of pregnancy does not mean that it is necessary for a pregnant woman to avoid work with radiation completely, or that she must be prevented from entering or working in designated radiation areas. It does, however, imply that the employer should review the exposure conditions of pregnant women carefully (ICRP, 2007a).

(201) There are many situations in which the worker may wish to continue doing the same job, or the employer may depend on her to continue in the same job in order to maintain the level of patient care that the work unit is customarily able to provide. From a radiological protection point of view, this is perfectly acceptable provided that the fetal dose can be estimated reasonably accurately and falls within the recommended limit of 1 mGy fetal dose after the pregnancy is declared. It would be reasonable to evaluate the work environment in order to provide assurance that high-dose accidents are unlikely (ICRP, 2000).

(202) The recommended dose limit applies to the fetal dose and is not directly comparable to the dose measured on a personal dosimeter. A personal dosimeter worn by diagnostic radiology workers may overestimate fetal dose by an approximate factor of 10 or more. If the dosimeter has been worn outside a lead apron, the measured dose is likely to be approximately 100 times higher than the fetal dose (ICRP, 2000).

(203) Finally, factors other than radiation exposure should be considered in evaluating the activities of pregnant workers. In a medical setting, there are often requirements for lifting patients and for stooping or bending below knee level. A number of national groups have established non-radiation-related guidelines for such activities at various stages of pregnancy (ICRP, 2000).

(204) The position of the Commission is that discrimination should be avoided based on radiation risks during pregnancy; if a pregnant woman wishes to continue her work in a fluoroscopy guided procedures laboratory, this should be allowed with the following conditions: (a) she should do it on a voluntary basis and confirm that she has understood the information provided on radiation risks; (b) a specific dosimeter should be used at the level of the abdomen to monitor the dose to the fetus monthly, and the worker should be informed of the dose values: (c) a radiological protection programme should exist in the hospital or clinic, supervised by a medical physicist or equivalent competent expert; (d) the worker should know the practical methods to reduce her occupational dose, including use of the existing radiological protection tools; (e) the worker should try to control the workload in fluoroscopy guided procedures during her pregnancy; and (f) the worker should know the risk of potential exposures and how to reduce their probability. It should be noted that Points (d), (e), and (f) should be part of a radiological protection programme, and Point (d) is applicable irrespective of pregnancy.

5.5. Procedures in children

(205) X-ray procedures in children involve a different spectrum of disease conditions specific to the very young child, and some conditions common in the adult population. The data derived from UNSCEAR estimates suggest that approximately 250 million paediatric radiological examinations (including dental) were performed worldwide each year between 1997 and 2007 (UNSCEAR, 2010). Children undergoing these examinations require special attention because of the diseases specific to childhood and the additional risks to them. In addition, they also need special care,

both in the form of care provided by parents and carers, and additional care provided by specially trained personnel.

(206) In the last 15 years, particular issues that arise in protecting children undergoing radiological examinations have come to the consciousness of a gradually widening group of concerned professionals and members of the public (Sidhu et al., 2009; Strauss et al., 2010). There are many reasons for this, not least the natural instinct to protect children from unnecessary harm. There is also their known additional sensitivity to radiation damage, and potentially longer lifetime in which disease due to radiation damage may become manifest. Their sensitivity to cancer induction is considered to be three to five times higher than that in adults (ICRP, 2007a).

(207) Children, particularly those with life-threatening disease in very early life, are at the greatest risk as a consequence of the substantial radiation doses they incur during investigations. These children may subsequently develop leukaemia within a few years as a result of the irradiation of bone marrow, and breast cancer or thyroid cancer as a result of chest or neck irradiation (ICRP, 2000).

(208) Therefore, the justification and optimisation principles are even more important when children are exposed to ionising radiation (ICRP, 2007a). The Commission recommended a multi-step approach to justification of patient exposures in *Publication 105* (ICRP, 2007b). Optimisation of radiological protection in child examinations should be generic for the examination type and all the equipment and procedures involved. It should also be specific for the individual in order to reduce dose for the particular paediatric patient.

(209) It is important that the equipment used for paediatric imaging is well designed and suited for the purpose for which it is applied. This is best ensured by having an appropriate procurement policy that includes rigorous specification of what is required, and verification that this is what the supplier delivers. In addition, it requires a good quality control programme to ensure that the equipment continues to be both functional and safe throughout its life, and involvement of the medical physicist in dose optimisation and audit, particularly for higher dose procedures performed in children.

5.5.1. Levels of radiation dose

(210) At present, approximately 15% of all fluoroscopy procedures and <1% of interventional procedures performed in the USA are performed on paediatric patients (NCRP, 2009). There is a lack of published information on patient dose levels for children undergoing x-ray procedures outside the imaging department. Therefore, in addition to examinations performed outside the imaging department, typical dose levels for patients of different ages undergoing radiological examinations are presented in Table 5.2 for the purpose of comparison. However, the introduction of new imaging technologies has, in some instances, resulted in increased use of paediatric imaging, influencing the age profile for the examinations performed (UNSCEAR, 2010).

Table 5.2. Patient dose levels for various radiological examinations in children (Martinez et al., 2007; Righi et al., 2008; Molina López et al., 2008; Calama Santiago et al., 2008; UNSCEAR, 2010).

Examination	Age (years)	Entrance surface dose (mGy)	Dose–area product (mGy cm^2)	Effective dose (mSv)
Abdomen PA	0	0.11	n.a.	0.10–1.3
	1	0.34	n.a.	
	5	0.59	n.a.	
	10	0.86	n.a.	
	15	2.0	n.a.	
Chest AP/PA	0	0.06	n.a.	0.005
	1	0.080	n.a.	
	5	0.11	n.a.	
	10	0.070	n.a.	
	15	0.11	n.a.	
Pelvis AP	0	0.17	n.a.	n.a.
	1	0.35	n.a.	
	5	0.51	n.a.	
	10	0.65	n.a.	
	15	1.30	n.a.	
Skull AP	1	0.60	n.a.	n.a.
	5	1.2	n.a.	
Skull LAT	1	0.34	n.a.	n.a.
	5	0.58	n.a.	
MCU (micturating cysto-urethrogram)	0	n.a.	430	0.8–4.6
	1	n.a.	810	
	5	n.a.	940	
	10	n.a.	1640	
	15	n.a.	3410	
Barium meal	0	n.a.	760	n.a.
	1	n.a.	1610	
	5	n.a.	1620	
	10	n.a.	3190	
	15	n.a.	5670	
Cardiac interventions (various)	<1	46	19	2.1–12
Percutaneous treatment of varicocele	n.a.	n.a.	n.a.	18
Biliary drainage with bilioplasty	1–3	35–50	1500–2300	0.9–1.5
Pieloureteral surgery	5	20	n.a.	0.36 (per min fluoroscopy)
Varicocele embolisation	14	250	60,000	8.8

AP, antero-posterior; PA, postero-anterior; LAT, lateral; n.a., not available.

(211) Data on paediatric doses are very difficult to analyse because the height and weight of children is very dependent on age. In addition, it is inappropriate to use effective dose to quantify patient dose levels for paediatric and neonatal imaging. As further explained in Annex A, when planning the exposure of patients and risk/benefit assessments, the equivalent dose – or preferably, the absorbed dose to irradiated tissues – is the more relevant quantity. This is particularly true when risk estimates are intended. In order to compare centres, an agreement was reached within the European Union to collect data for five standard age groups: newborn, 1-year-old, 5-year-old, 10-year-old, and 15-year-old children (UNSCEAR, 2010).

(212) The main issue following childhood exposure at typical diagnostic levels (a few to a few tens of mGy) is cancer induction. It should be emphasised that interventional procedures lead to higher doses to patients than conventional diagnostic investigations. The Commission covered this topic extensively in *Publication 85* (ICRP, 2001).

(213) As a general principle, parents or family members should support the child during any radiological examination. The reported effective dose level for parents present in the room during x-ray examination of a child are typically 4–7 μSv (Mantovani and Giroletti, 2004).

5.5.2. Radiation dose management

(214) All dose management actions described in Section 3 also apply for x-ray examinations of children. Examination parameters must be tailored to the child's body size. For children, dose reduction is achieved by using technical factors specific for children, and not using routine adult factors (Sidhu et al., 2009). Techniques to reduce patient dose are very much the same as for adult examinations and include: (a) no grids; (b) collimation solely to the irradiation volume of interest; (c) extra beam filtration (extra Al or Cu filters); (d) low pulsed fluoroscopy; (e) reducing magnification; (f) large distance between the x-ray tube and the patient, and short distance between the patient and the detector; and (g) digital subtraction angiography and road-mapping techniques in fluoroscopy which can save contrast medium and patient dose. In x-ray procedures in children, care should be taken to minimise the radiation beam to affect the area of interest alone. Thus, collimation is even more important for children (Section 3.3.2). One should always reduce the irradiation beam to the organ/organs of interest and nothing else in order to reduce the dose. With the automatic brightness control used in the equipment, this could result in a slightly higher dose within the field, but a lower effective dose and better image quality.

(215) In the exposure of comforters and carers (parents holding a child during examination), dose constraints are applicable to limit inequity and because there is no further protection in the form of a dose limit (ICRP, 2007b). Parents must be provided with suitable radiological protection tools, and be informed about the need for their protection prior to supporting their child during the examination.

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6. TRAINING

- **A training programme in radiological protection for healthcare professionals has to be oriented towards the type of practice in which the target audience is involved.**
- **A worker's competency to carry out a particular function should be assessed by individuals who are suitably competent themselves.**
- **The main purpose of training is to make a qualitative change in practice that helps operators use radiological protection principles, tools, and techniques to reduce their own exposure without cutting down on work, and to reduce patient exposure without compromising on image quality or intended clinical purpose. The focus has to remain on achievement of skills. Unfortunately, in many situations, it takes the form of complying with requirements of number of hours. While number of hours is an important way to provide a yardstick, actual demonstration of skills to reduce occupational and patient exposure is an essential part. In large parts of the world, clinical professionals engaged in fluoroscopy outside the imaging department have either no training or inadequate training. The Commission has recommended that the levels of education and training should be commensurate with the level of radiation use (ICRP, 2009).**
- **Legislation in most countries requires that individuals who take responsibility for medical exposures must be properly trained in radiological protection.**
- **Training activities in radiological protection should be followed by an evaluation of the knowledge acquired from the training programme (a formal examination system).**
- **Physicians who have completed training should be able to demonstrate that they possess the knowledge specified by the curriculum by passing an appropriate certifying examination.**
- **Nurses and other healthcare professionals who assist during fluoroscopic procedures should be familiar with radiation risks and radiological protection principles in order to minimise their own exposure and that of others.**
- **Medical physicists should become familiar with the clinical aspects of the specific procedures performed at the local facility.**
- **Training programmes should include both initial training for all incoming staff, and regular updating and retraining.**
- **Scientific congresses should include refresher courses on radiological protection, attendance at which could be a requirement for continuing professional development.**
- **The issue of delivery of training has been dealt with in a recent publication (ICRP, 2009) and the text has been drawn from this publication.**

6.1. Introduction

(216) In *Publication 75*, the Commission requires the provision of relevant and adequate information on, and training in, radiological protection. This should be regarded as an essential component of the programme of implementation of the principle of optimisation of protection in the control of both normal and potential exposures (ICRP, 1997).

(217) Despite the extensive and routine use of ionising radiation in their clinical practice, physicians worldwide typically have little or no training in radiological protection. Traditionally, medical students do not receive training in radiological protection during medical school. Medical professionals who subsequently specialise in radiological specialties, such as diagnostic radiology, nuclear medicine, and radiotherapy, are taught radiological physics and radiological protection as part of their specialty training. In many countries, there is no radiological protection education during training in other specialties that form the target audience of this publication.

(218) In the past, training in radiological physics and radiological protection was not necessary for non-radiologists, as x-rays and other radiation sources were only used in imaging departments by staff with a reasonable amount of training in radiological protection. Although x-ray fluoroscopy has been in use for more than a century, its early application involved visualisation of body anatomy, movement of structures, or passage of contrast media through the body. Radiologists normally performed these procedures. When fluoroscopically guided procedures were introduced, other specialists began to perform these procedures. Initially, they did so jointly with radiologists in imaging departments. Over the years, equipment has been installed in other clinical departments and outpatient facilities, and this is used by non-radiologists without the participation of a radiologist. These non-radiologists have not been subject to the training requirements of radiological physics and radiological protection that are mandatory for radiologists. It is now clear that this training is essential; hence the need for specific guidance for these specialists.

(219) The Commission has addressed the specifics of training for interventionalists, nuclear medicine specialists, medical physicists, nurses, and radiographers/technologists, among others, in *Publication 113* (ICRP, 2009).

6.2. Curriculum

(220) Conventional training programmes use a structure that is curriculum based. There is a fundamental difference between training methodologies employed in non-medical subjects and in medical, or rather clinical, subjects. While much of the training in sciences such as physics or biology is based on knowledge transmission, there is much greater emphasis in clinical training on imparting skills to solve day-to-day problems. A training programme in radiological protection for healthcare professionals has to be oriented towards the type of practice with which the target audience is involved. Lectures should deal with essential background knowledge and advice on practical situations, and the presentations should be tailored to clinical situations to impart skills in the appropriate context. Practical training should be in a similar environment to that in which the participants will be practising, and should provide the knowledge and skills required for performing clinical procedures. It should deal with the full range of issues that the trainees are likely to encounter (ICRP, 2009). For further details, the reader is referred to *Publication 113* (ICRP, 2009).

6.3. Who should be the trainer?

(221) The primary trainer in radiological protection should normally be an expert in radiological protection in the practice with which he or she is dealing (normally a medical physicist). In other words, a person with knowledge about clinical practice in the use of radiation, the nature of radiation, the way in which it is measured, how it interacts with the tissues, what type of effects it can lead to, principles and philosophies of radiological protection, and international and national guidelines. As radiological protection is covered by legislation in almost all countries of the world, awareness of national legislations and the responsibilities of individuals and organisations is essential (ICRP, 2009).

(222) In many situations, the radiological protection trainer may lack the knowledge of practicalities, and may talk from an unrealistic standpoint relating to idealised or irrelevant situations. The foremost point in any successful training is that the trainer should have a clear perception about the practicalities in the work that the training has to cover. It should deal with what people can practice in their day-to-day work. Many trainers in radiological protection cannot resist the temptation of dealing with basic topics such as radiation units, interaction of radiation with matter, and even structure of the atom and atomic radiations in more depth and detail than is appropriate for this audience and for the practical purposes of this training. Such basic topics, while being essential in educational programmes, should only be dealt with to a level such that they make sense. A successful trainer will not be too focused on definitions which are purely for academic purposes, but will be guided by the utility of the information to the audience. The same applies to regulatory requirements. The trainer should speak the language of users to convey the necessary information without compromising on the science and regulatory requirements. Health professionals who use radiation in day-to-day work in hospitals and impart the radiation dose to patients have knowledge about the practical problems in dealing with patients who may be very sick. They understand problems with the radiation equipment they deal with, the time constraints for dealing with large numbers of patients, and the lack of radiation measuring and radiological protection tools. Inclusion of lectures from practising clinicians to dwell on good and bad radiological protection practices is strongly recommended. It may be useful for the radiological protection trainer to be on hand during such lectures to comment and discuss any issues raised (ICRP, 2009).

6.4. How much training?

(223) Most people and organisations follow the relatively easy route of prescribing the number of hours. The Commission gives some recommendations on the number of hours of education and training; this should act as a simple guideline, rather than be applied rigidly (ICRP, 2009). This has advantages in terms of implementation of training and monitoring the training activity, but is only a guide.

(224) The issue of how much training is given should be linked with the evaluation methodology. One has to be mindful about the educational objectives of the training

(i.e. acquiring knowledge and skills). Many programmes are confined to providing training without assessing the achievement of the objectives. Although some programmes have pre- and post-training evaluations to assess the knowledge gained, fewer training programmes assess the acquisition of practical skills. Using modern methodologies of online examination, results can be determined instantaneously. It may be appropriate to encourage development of questionnaire and examination systems that assess knowledge and skills, rather than prescribing the number of hours of training. Due to the magnitude of the requirement for radiological protection training, it may be worthwhile for organisations to develop online evaluation systems. The Commission is aware that such online methods are currently available, mainly from organisations that deal with large-scale examinations. The development of self-assessment examination systems is encouraged to allow trainees to use them in the comfort of the home, on a home PC, or anywhere where the internet is available. The Commission recommends that evaluation should have an important place (ICRP, 2009).

(225) The amount of training depends upon the level of radiation employed in the work, and the probability of occurrence of overexposure to the patient or workers. For example, radiotherapy employs the delivery of several Gy of radiation per patient, and a few tens of Gy each day to groups of patients. Interventional procedures could also deliver skin doses in the range of a few Gy to specific patients. The level of radiation employed in radiography practice is much lower than the above two examples, and the probability of significant overexposure is lower, unless the wrong patient or wrong body part is irradiated. The radiation doses to patients from CT examinations are also relatively high, and thus the need for radiological protection is correspondingly greater. Another factor that should be taken into account is the number of times that a procedure such as CT may be repeated on the same patient.

(226) The training given to other medical specialists such as vascular surgeons, urologists, endoscopists, and orthopaedic surgeons before they direct fluoroscopically guided invasive techniques is significantly less or even absent in many countries. Radiological protection training is recommended for physicians involved in the delivery of a narrow range of nuclear medicine tests relating to their speciality.

6.5. Recommendations on training

(227) Training for healthcare professionals in radiological protection should be related to their specific jobs and roles.

(228) The physicians and other health professionals involved in procedures that irradiate patients should always be trained in the principles of radiological protection, including the basic principles of physics and biology (ICRP, 2007a).

(229) The final responsibility for radiation exposure lies with the physician providing the justification for the exposure being carried out, who should therefore be aware of the risks and benefits of the procedures involved (ICRP, 2007b).

(230) Education and training, appropriate to the role of each category of physician, should be given at medical schools, during residency, and in focused specific courses. There should be an evaluation of the training, and appropriate recognition

that the individual has completed the training successfully. In addition, there should be corresponding radiological protection training requirements for other clinical personnel who participate in the conduct of procedures utilising ionising radiation, or in the care of patients undergoing diagnosis or treatment with ionising radiation (ICRP, 2007b).

(231) Scientific and professional societies should contribute to the development of the syllabuses, and to the promotion and support of the education and training. Scientific congresses should include refresher courses on radiological protection, attendance at which could be a requirement for continuing professional development for professionals using ionising radiation.

(232) Professionals involved more directly in the use of ionising radiation should receive education and training in radiological protection at the start of their career, and the education process should continue throughout their professional life as the collective knowledge of the subject develops. It should include specific training on related radiological protection aspects as new equipment or techniques are introduced into a centre.

(233) Nurses and other healthcare professionals who assist during fluoroscopic procedures should be familiar with radiation risks and radiological protection principles in order to minimise their own exposure and that of others.

(234) Medical physicists should become familiar with the clinical aspects of the specific procedures performed at the local facility.

(235) Training programmes should include both initial training for all incoming staff, and regular updating and retraining.

6.6. References

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7. RECOMMENDATIONS

- There is a need to rectify the neglect of radiological protection coverage to facilities outside the control of imaging departments.
- There is high radiation risk to workers and patients in fluoroscopy facilities outside imaging departments, primarily due to the lack of radiological protection training of workers in many countries.
- A number of procedures, such as EVAR, renal angioplasty, iliac angioplasty, ureteric stent placement, therapeutic ERCP, and bile duct stenting and drainage, involve radiation levels exceeding the threshold for skin injuries. If due attention is not given, radiation injuries to patients are likely to occur in the future.
- Many patients require regular and repeated radiation exposure for many years, and quite a few patients will require this for life. In some cases, the effective dose for each year of follow-up has been estimated to be a few tens of mSv. Unfortunately, this has not received the attention it needs. The Commission recommends that urgent attention should be given to application of justification and optimisation of protection to achieve the lowest exposure consistent with the desired clinical outcomes.
- Workers should be familiar with the radiation dose quantities used in fluoroscopy equipment to represent patient dose.
- Modern sophisticated equipment requires understanding of features that have implications for patient dose and how patient dose can be managed.
- For fluoroscopy machines in operating theatres, there are specific problems that make the use of radiation shielding screens for workers' protection more difficult, but not impossible. Such occupational protective measures should be used.
- Manufacturers should develop shielding screens that can be used for protection of workers using fluoroscopy machines in operating theatres without hindering the clinical task.
- Manufacturers should develop systems to indicate patient dose indices with the possibility of producing patient dose reports that can be transferred to the hospital network.
- Manufacturers are encouraged to develop devices that provide representative occupational doses without the need for extensive cooperation of staff.
- Health professionals involved in procedures that irradiate patients should always be trained in radiological protection. The Commission recommends a level of radiological protection training commensurate with radiation use.
- Medical professionals should be aware about their responsibilities as set out in regulations.
- Scientific and professional societies should contribute to the development of training syllabuses, and to the promotion and support of education and training. Scientific congresses should include refresher courses on radiological protection, attendance at which could be a requirement for continuing professional development for professionals using ionising radiation.

ANNEX A. DOSE QUANTITIES AND UNITS

(A1) Dosimetric quantities are needed to assess radiation exposures to humans in a quantitative way. This is necessary in order to describe dose–response relationships for the health effects of ionising radiation, which provide the basis for setting protection standards as well as for the quantification of exposure levels.

(A2) Absorbed dose in tissue is the energy absorbed per unit mass in a body tissue. The unit of absorbed dose is joule per kilogram (J/kg), whose special name is gray (Gy). It is assumed that the mean value of absorbed dose in an organ or tissue is correlated with radiation detriment from stochastic effects in the low-dose range. The averaging of absorbed doses in tissues and organs of the human body and their weighted derivatives are the basis for the definition of protection quantities.

(A3) The protection quantities are used for risk assessment and risk management to ensure that the occurrence of stochastic effects is kept below unacceptable levels and tissue reactions are avoided. The average absorbed dose to an organ or tissue is called 'organ absorbed dose' or simply 'organ dose'.

(A4) The equivalent dose to an organ or tissue is the organ dose multiplied by a radiation weighting factor that takes account of the relative biological effectiveness of the radiation relevant to the exposure. This radiation weighting factor is numerically 1 for x rays. The equivalent dose has the same SI unit as that of absorbed dose, but it is called 'sievert' (Sv) to distinguish between them.

(A5) For medical exposures, the assessment of stochastic risk is complex as more than one organ is irradiated. The Commission has introduced the quantity 'effective dose' as a weighted sum of equivalent doses to all relevant tissues and organs, intended to indicate the combination of different doses to several different tissues in a way that is likely to correlate well with the sum of the stochastic effects. This is therefore applicable even if the absorbed dose distribution over the human body is not homogeneous. The effective dose has the same unit and special name as equivalent dose (i.e. J/kg and Sv).

(A6) While absorbed dose in a specified tissue is a physical quantity, the equivalent dose and effective dose include weighting factors which are based on radiobiological and epidemiological findings. The main and primary use of effective dose is to provide a means of demonstrating compliance with dose limits in occupational and public exposures. In this sense, effective dose is used for regulatory purposes worldwide. Effective dose is used to limit the occurrence of stochastic effects (cancer and genetic effects), and is not applicable to the assessment of the possibility of tissue reactions.

(A7) The use of effective dose for assessing the exposure of patients has severe limitations that must be taken into account by medical professionals. Effective dose can be of value for comparing doses from different diagnostic procedures, in a few special cases from therapeutic procedures, and for comparing the use of similar technologies and procedures in different hospitals and countries, as well as using different technologies for the same medical examination. For planning the exposure of patients and risk/benefit assessments, however, the equivalent dose – or preferably, the absorbed

dose to irradiated tissues – is the more relevant quantity. This is especially the case when risk estimates are intended (ICRP, 2007).

(A8) Collective dose is a measure of the total amount of effective dose multiplied by the size of the exposed population. Collective dose is usually expressed in terms of person-Sv.

A.1. Quantities for assessment of patient doses

(A9) Air kerma (kinetic energy released in a mass) is the sum of the initial kinetic energies of all electrons released by the x-ray photons per unit mass of air. For the photon energies used in x-ray procedures, the air kerma is numerically equal to the absorbed dose free in air, except where there is no equilibrium of secondary electrons such as in air in the vicinity of an interface. The unit of air kerma is J/kg or Gy (ICRU, 2005; IAEA, 2007).

(A10) A number of earlier publications have expressed measurements in terms of the absorbed dose to air. Recent publications point out the experimental difficulty in determining the absorbed dose to air, especially in the vicinity of an interface; in reality, what the dosimetry equipment registers is not the energy absorbed from the radiation by the air, but the energy transferred by the radiation to the charged particles resulting from the ionisation. For these reasons, ICRU (2005) recommends the use of air kerma rather than absorbed dose to air, which applies to quantities determined in air, such as the entrance surface air kerma (rather than entrance surface air dose) and the kerma–area product (rather than DAP). Notwithstanding this remark, the quantities 'DAP' and 'entrance surface dose', both in air, have been retained in some places in this report, as they appear in the given references and readers are more familiar with them.

(A11) In diagnostic radiology, the incident air kerma (K_i) is often used. This is the air kerma from the incident beam on the central x-ray beam axis at focal spot-to-skin distance (i.e. at skin entrance plane). Incident air kerma can be calculated from the x-ray tube output, where output is measured using a calibrated ionising chamber (ICRU, 2005).

(A12) Entrance surface air kerma (K_e) is the air kerma on the central x-ray beam axis at the point where the x-ray beam enters the patient. The contribution of backscatter radiation is included through backscatter factor (B), thus: $K_e = B \cdot K_i$. The backscatter factor depends on the x-ray spectrum, the x-ray field size, and the thickness and composition of the patient or phantom. Typical values of backscatter factor in diagnostic and interventional radiology are in the range of 1.2–1.6 (ICRU, 2005). The unit for entrance surface air kerma is the Gy. Entrance surface air kerma can be calculated from incident air kerma using suitable backscatter factor, or determined directly using small dosimeters (thermoluminescent or semiconductor) positioned at the representative point on the skin of the patients.

(A13) Incident air kerma and entrance surface air kerma are recommended quantities for establishment of diagnostic reference levels in projection radiography, or to assess maximal skin dose in interventional procedures (ICRU, 2005).

(A14) The incident and entrance surface air kerma do not provide information on the extent of the x-ray beam. However, the air kerma–area product (P_{KA}), as the product of air kerma and area A of the x-ray beam in a plane perpendicular to the beam axis, provides such information.

(A15) The common unit for air kerma–area product is $Gycm^2$. The P_{KA} has the useful property of being approximately invariant with distance from the x-ray tube focal spot. It can be measured in any plane between the x-ray source and the patient using specially designed transparent ionising chambers mounted at the collimator system or, in digital systems, calculated using data of the generator and the digitally recorded jaw position (ICRP, 2001). The air kerma–area product is the recommended quantity to establish diagnostic reference levels in conventional radiography and complex procedures including fluoroscopy. It is helpful in dose control for stochastic effects to patients and operators (ICRP, 2001).

(A16) In radiology, it is common practice to measure a radiation dose quantity that is then converted into organ doses and effective dose by means of conversion coefficients. These coefficients are defined as the ratio of the dose to a specified tissue or effective dose divided by the normalisation quantity. Incident air kerma, entrance surface air kerma, and kerma–area product can be used as normalisation quantities. Conversion coefficients to convert air kerma–area product or entrance surface kerma to effective dose for selected procedures are given in Table A.1.

A.2. Quantities for occupational dose assessment

(A17) Dose limits for occupational exposures are expressed in equivalent doses for tissue reactions in specific tissues, and expressed as effective dose for stochastic effects throughout the body. When used for tissue reactions, equivalent dose is an indicator of whether or not the threshold for the tissue reaction is being approached.

(A18) Occupational dose limits are recommended by the Commission (ICRP, 1991, 2007) for stochastic effects (dose limits for effective dose) and tissue reactions (dose limits for equivalent dose to the relevant tissue). As presented in Table 2.1, dose limits are given in mSv. For x-ray energies in diagnostic and interventional procedures, the numerical value of the absorbed dose in mGy is essentially equal to the numerical value of the equivalent dose in mSv.

(A19) The main radiation source for workers is the patient's body, which scatters radiation in all directions during fluoroscopy and radiography. A personal dosimeter should be worn, and the dose determined can be used as a substitute for the effective dose. To monitor doses to the skin, hands and feet, and lens of the eye, special dosimeters (e.g. ring dosimeter) should be used (ICRP, 2001). The instruments used for dose measurement are commonly calibrated in terms of operational quantities, defined for practical measurement and assessment of effective and equivalent dose (ICRU, 1993).

Table A.1. Conversion coefficients to convert air kerma–area product and entrance surface kerma to effective dose for adults in selected x-ray procedures (European Commission, 2008; NCRP, 2009; Health Protection Agency, 2010).

Group	Examination	Conversion coefficient (mSv/Gy cm^2) (NCRP, 2009)	Conversion coefficient (mSv/Gy cm^2) (European Commission, 2008)	Conversion coefficient (mSv/Gy cm^2) (Health Protection Agency, 2010)	Conversion coefficient (mSv/mGy) (Health Protection Agency, 2010)
Urinary and renal studies	Cystography	0.18			
	Excretion urography, micturating cysto-urethrography	0.18			
	Antegrade pyelography	0.18			
	Nephrostography	0.18			
	Retrograde pyelography	0.18			
	Intravenous urography		0.18		
Endoscopic retrograde cholangio-pancreatography		0.26			
Orthopaedics and joints		0.01			
	Femur AP			0.036	0.023
	Femur LAT			0.0034	0.002
	Knee AP			0.0034	0.001
	Knee LAT			0.003	0.001
	Foot (dorsiplantar)			0.0032	0.001
	Foot (oblique)			0.0032	0.001
Obstetrics and gynaecology	Pelvimetry	0.29			
	Hysterosalpingography	0.29			
Renal	Retrograde pyelography	0.18			
	Nephrostography	0.18			
Barium meal			0.2		
Barium enema			0.28		

Table A.1. (*continued*)

Group	Examination	Conversion coefficient (mSv/Gy cm^2) (NCRP, 2009)	Conversion coefficient (mSv/Gy cm^2) (European Commission, 2008)	Conversion coefficient (mSv/Gy cm^2) (Health Protection Agency, 2010)	Conversion coefficient (mSv/mGy) (Health Protection Agency, 2010)
Barium follow			0.22		
Cardiac angiography			0.2		
Percutaneous transluminal angioplasty		0.26			
Stents	Renal/visceral percutaneous transluminal angioplasty (all) with stent; Iliac percutaneous transluminal angioplasty (all) with stent; Bile duct, dilation and stenting	0.26			
Radiography	Chest (PA + LAT) low kVp		0.10		
	Chest (PA + LAT) high kVp		0.18	0.158/0.125	0.131/0.090
	Thoracic spine		0.19	0.244/0.093	0.094/0.031
	Lumbar spine		0.21	0.224/0.092	0.116/0.027
	Abdomen		0.26	0.180	0.132
	Pelvis		0.29	0.139	0.099
	Hip		0.29	0.13	0.064
Skeletal survey	Average of arms, legs, skull LAT, lumbar spine LAT, chest AP, abdomen/pelvis AP			0.09	
Whole spine/scoliosis	Average of thoracic and lumbar spine AP			0.22	
	Average of cervical, thoracic and lumbar spine (AP + lateral)			0.16	

AP, antero-posterior; PA, postero-anterior; LAT, lateral.

A.3. References

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