Radiation Protection in Interventional Radiology (*)

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Abstract. Interventional procedures are used by a significant number of medical specialities. Radiation protection (RP) for patients and staff is one of the main issues in Interventional Radiology (IR). UNSCEAR, ICRP and IAEA have devoted significant time over the last years to improve radiation safety in IR. Several combined factors: prolonged localized fluoroscopy, multiple radiographic exposures, and repeated procedures can cause acute radiation injury to the skin. The values of dose-area product and effective dose for IR are typically larger than those used in common diagnostic x-ray examinations. The studies carried out among the Chernobyl survivors show that cataracts may appear after doses of less than 1 Gy and these are the doses interventionists are likely to receive after several years' work. ICRP recommends taking into account occupational risks to justify IR procedures. The diagnostic reference levels can also be a useful tool to optimize IR procedures. In this paper, we present some of the ICRP practical recommendations concerning training in RP, patient dose records, clinical follow-up when skin doses are estimated too high, the use of personal dosimeters, etc. We also include the actions of other international and national organizations as well as scientific societies on radiation safety in IR. We also discuss the influence on IR of the new radiation risk and tissue weighting factors proposed by the ICRP in 2007. We finally give some results on patient dose surveys and staff dose estimations in IR and conclude with a list of challenging topics for the years to come.

KEYWORDS: Interventional radiology, interventional cardiology, reference levels, radiation injuries, deterministic effects, radiation protection, training.

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1. Introduction

Interventional procedures are used today by a significant number of medical specialities. When referring to "interventional radiology" (IR) in this paper, we will refer to fluoroscopically-guided therapeutic and diagnostic procedures. The relevance of radiation protection (RP) aspects and patient doses are sometimes similar for both therapeutic and diagnostic procedures.

The Cardiovascular and Interventional Radiology Society of Europe (CIRSE, www.cirse.org) identify IR as the use of imaging guidance for treating patients. CIRSE highlights that IR techniques can replace some open surgical procedures, allowing patients to be treated with less risk and minimizing hospital stay. Interventional radiologists are doctors trained in radiology and experts in reading radiological images, ultrasounds, computed tomography scans and other medical images. This expertise with imaging techniques enables them to guide small catheters and guide-wires through blood vessels or other pathways in the body to treat diseases without surgery. These small catheters (tubes) are usually only a few millimetres in diameter. IR could be termed as "Pinhole Surgery" because of the small punctures the size of a pinhole that is made in the skin to perform these procedures. The advantages to patients are obvious: general anaesthesia is usually not required and risk, pain and recovery time are often significantly reduced.

Patient safety was incorporated into the IR practice and training programmes include radiation safety, radiation physics, the biological effects of radiation and injury prevention.

The tools used in IR include balloons, catheters, microcatheters, stents, and therapeutic embolization (deliberately closing off a blood vessel). The speciality of IR overlaps other fields including interventional cardiology, vascular surgery, endoscopy, laparoscopy, and other minimally invasive techniques, such as biopsies. Specialists performing IR procedures today include not only radiologists but also other types of physicians such as general surgeons, vascular surgeons, cardiologists, gastroenterologists, gynaecologists, and urologists.

Radiation protection for patients and staff is one of the main issues for IR. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA), together with many other international and national organizations and scientific and professional societies have put all their efforts into improving radiation safety in IR over the last years.

2. UNSCEAR data on Interventional Radiology.

The last UNSCEAR report published in 2000 containing data on Medical Exposures [1] includes a full section on angiographic and interventional procedures. The data collected from several countries indicated that in 1990, nearly 60% of such procedures fell within the broad category of angioplasty (dilatation), with significant applications also in biopsy/drainage (11%), pain therapy (11%), embolization (7%), genitourinary (7%) and biliary (5%) interventions. IR was already considered as an established part of mainstream medicine and was expected to expand with the continuous development and adoption of new procedures, particularly in countries endowed with well-developed health care systems.

In IR, the combination of prolonged localized fluoroscopy, multiple radiographic exposures, and repeated procedures can cause patient doses to reach levels producing acute coetaneous radiation injury. Procedures of particular concern in this respect include radio-frequency cardiac catheter ablation, PTCA, vascular embolization, stent and filter replacement, thrombolytic and fibrinolytic procedures, percutaneous transhepatic cholangiography, endoscopic retrograde cholangiopancreatography, transjugular intrahepatic portosystemic shunt, percutaneous nephrostomy, and biliary drainage or urinary/biliary stone removal.

However, there may be underreporting of skin injuries given the time delay between exposure and manifestation of damage. According to UNSCEAR [1] from 1992 to 1995 in the United States, there were 26 reports to the Food and Drug Administration (FDA) of radiation-induced skin injuries from fluoroscopy. By 1999, the FDA documented some 50 cases of radiation-induced burns, many involving cardiological procedures. The analysis of neurological procedures on 426 patients showed long-term erythema in 1- 2% of embolizations, a potential for temporary erythema in 11% of both carotid procedures and cerebral angiograms and also in 3% of nerve block procedures, in 7% of lumbar procedures, and in 23% of embolization procedures [1].

Values of dose-area product (DAP) and effective dose for interventional procedures are typically larger than those used for common diagnostic x-ray examinations; for example, DAP product values of up to 918 Gy.cm^2 were reported during embolization procedures [1]. The maximum effective doses reported was 57 mSv for PTCA, 13 mSv for PTA, 180 mSv for TIPS (transjugular intrahepatic portosystemic shunt), 25 mSv for radiofrequency ablation, 29 mSv for valvuloplasty, 43 mSv for embolization, and 38 mSv for biliary drainage [1].

During the 2008 annual UNSCEAR meeting, a new draft document on medical exposures was discussed. UNSCEAR considered interventional radiology as part of diagnostic radiology practices and estimated that around half of the collective effective dose due to diagnostic radiology originated from three procedures: CT, angiography examinations and IR. The aspects of radiation injuries in IR were highlighted and the increasing concern about the high skin dose levels in cardiology and other IR procedures were mentioned in Publication 85 of the ICRP [2]. The two main causes mentioned for radiation injuries were: a) the use of suboptimal equipment, and b) procedures performed by individuals inadequately trained in radiation protection.

The age and sex distributions collected by UNSCEAR (i.e. average values obtained from a few countries reporting these data) are shown in table 1.

During the 2008 annual meeting of UNSCEAR, some sessions were also dedicated to the health effects due to radiation from the Chernobyl accident and new information on radiation-induced cataracts was presented as well.

Several new studies among the Chernobyl survivors tend to show that cataracts may form after doses of less than 1 Gy. Though most of these refer to lower grade cataracts, a recent study of the Japanese atomic bomb survivors suggests that there may be an increased incidence of higher grade cataracts at these dose levels [3]. While a specific type of cataract (i.e. posterior subcapsular cataract) is characteristic of radiation exposure, several sets of data suggest that broader categories (i.e. posterior cortical cataracts) may also be regarded as radiation-associated [4-5].

Table 1: Age and sex distribution for patients submitted to interventional procedures obtained from the last UNSCEAR surveys.

	Age distribution (%)			Sex distribution (%)	
Procedure	0-15 y	16-40 y	>40 y	Male	Female
Angiography (non cardiac)	2	7	91	58	42
Cardiac angiography	4	6	90	53	47
Percut. transluminal coronary angiograhy PTCA	0	6	94	49	51
Cerebral angiography	2	20	78	62	38
Other interventional	1	11	89	55	45

3. International Commission on Radiological Protection (ICRP) recommendations on Interventional Radiology.

The new 2007 ICRP Recommendations [6] addressed different aspects especially relevant for IR. ICRP recognized three kinds of medical exposure of patients: diagnostic, interventional and therapeutic procedures (paragraphs 181 and 322 [6]). Interventional procedures are a practice in between diagnostic and therapeutic procedures.

3.1 Justification and staff doses

For the justification criteria, it is said (paragraph 330 [6]), that “the principal aim of medical exposures is to do more good than harm to the patient, subsidiary account *being taken of the radiation detriment from the exposure of the radiological staff* and of other individuals”. This recommendation to include the exposure of radiological staff during the justification process is a relevant issue in IR as in some hospitals, very ill patients (e.g. with colon cancer) are sent to IR units to be treated percutaneously. This process requires long and complex procedures with a significant occupational radiological risk for the interventionists involved.

3.2 Diagnostic reference levels and interventional

Diagnostic reference levels (DRL) are considered as a useful tool to help optimize IR (paragraph 334 [6]). ICRP Publication 105 [7] gives more details on the use of DRL in IR procedures (paragraph 89 [7]): “For fluoroscopically guided interventional procedures, diagnostic reference levels, in principle, could be used to promote the management of patient doses with regard to avoiding unnecessary stochastic radiation risks. However, the observed distribution of patient doses is very wide, even for a specified protocol, because the duration and complexity of the fluoroscopic exposure for each conduct of a procedure is strongly dependent on the individual clinical circumstances. A potential approach is to take into consideration not only the usual clinical and technical factors, but also the relative ‘complexity’ of the procedure”.

3.3 Deterministic risks to the eyes

Concerning deterministic risks to the eyes, ICRP stated (paragraph 249 [6]) that “Dose limits (to the eyes) remain unchanged. However, new data on the radiosensitivity of the eye with regard to visual impairment are expected. The Commission will consider these data and their possible significance for the equivalent dose limit for the lens of the eye when they become available. Because of the uncertainty concerning this risk, there should be particular emphasis on optimisation in situations of exposure of the eyes”.

3.4 Specific recommendations for interventional procedures

The main document from ICRP containing recommendations for IR is the Publication 85 on Avoidance of radiation injuries from medical interventional procedures [2]. The Commission recognises that IR (fluoroscopically-guided) techniques are being used by an increasing number of clinicians not adequately trained in radiation safety or radiobiology and that a certain number of patients suffer consequently radiation-induced skin injuries due to unnecessarily high radiation doses and younger patients face an increased risk of future cancer.

Many interventionists are not aware of the potential injury linked with interventional procedures, of their occurrence, or do not know the simple methods for decreasing their incidence using dose control strategies. Many patients are neither being counselled on the radiation risks nor followed up at the onset of injury, when it occurs.

Patient skin doses in some interventional procedures approach the level of those experienced in some cancer radiotherapy fractions. As a consequence, skin injuries may occur in some cases as a result of very high radiation doses during interventional procedures due to the use of inappropriate equipment and more often, poor operational techniques. Injuries to physicians and staff performing interventional procedures have also been observed.

ICRP recommends [2] that in the local clinical protocol for each type of interventional procedure each facility should include, a statement on the radiographic images (projections, number, and technique factors), fluoroscopy times, air kerma rates, and resulting cumulative skin doses and skin sites associated with the various parts of the interventional procedure. Each interventional physician should be trained to use this information, displayed at the operator's position.

When the maximum cumulative absorbed dose in skin for an actual procedure appears to approach, equal, or exceed the threshold values for deterministic effects, it should be recorded in the patient's record, along with the location and extent of the skin site: 1 Gy (for procedures that may be repeated); 3 Gy (for any procedure). The patient's personal physician should also be informed of the potential for radiation injury. If the dose is sufficient to cause observable effects, the patient should be counselled after the procedure. A system to identify repeated procedures should also be set up. ICRP recommends (paragraph 89 [2]) that all patients should be informed of the likelihood of radiation effects as part of informed consent.

Concerning education and training, the Commission states [2] that individuals performing IR procedures need to be adequately trained in both clinical techniques and radiation protection. ***A second specific level of training in radiation protection, additional to that undertaken for diagnostic radiology, is desirable.*** Specific additional training should be planned when new x-ray systems or techniques are implemented in a centre. A quality assurance programme for interventional radiology facilities should include radiation protection training and assessment of dose control technique.
The advice of a medical physics expert is also mentioned (paragraph 55 [2]). Advice should be available on patient dosimetry, equipment selection, and quality assurance.

It is recommended that some RP tools be supplied by the manufacturers when installing the x-ray systems (paragraph 63 [2]): Equipment manufacturers should also supply additional protective devices and attachments to equipment for interventional radiology. This includes ceiling-suspended lead acrylic viewing screens, under-table shielding attachments to the x-ray couch, and portable personal shields.

ICRP also gives recommendations for personal dosimetry in interventional laboratories (paragraph 66 [2]): "The high occupational exposures in interventional radiology require the use of robust and adequate monitoring arrangements for staff. A single dosimeter worn under the lead apron will yield a reasonable estimate of effective dose for most instances. Wearing an additional dosimeter at collar level above the lead apron will provide an indication of head (eye) dose. In addition, it is possible to combine the two dosimeter readings to provide an improved estimate of effective dose. ***Consequently, it is recommended that interventional radiology departments develop a policy that staff should wear two dosimeters.*** Doses in departments should be analysed and high doses and outliers should be investigated".

Concerning the archive of patient dose values, the Commission states (paragraph 89 [2]) that ***all interventional procedures should include measurement and recording of appropriate equipment technical factors used in the procedure.***

3.5 Recommendations on digital radiology influencing IR

Another relevant document for dose management in IR is Publication 93 on digital radiology [8]. This document doesn't focus on IR but it contains some useful recommendations for patient dose management in interventional laboratories. ICRP recommends that the industry should promote tools to inform radiologists, radiographers, and medical physicists about the exposure parameters and the resultant patient doses. The exposure parameters and the resultant patient doses should be standardised, displayed, and recorded. In addition, and addressed to IR. It is stated that patient dose parameters should be displayed at the operator console (and inside the x-ray room for interventional procedures) to assist radiographers and medical specialists with dose management.

3.6 Other documents in preparation

The ICRP is presently preparing two other documents concerning RP aspects for IR : One will focus on Cardiology and the second one will deal with Education and Training of RP aspects.

4. Actions of other national and international Organizations promoting radiation safety in IR

In 1994 the US Food and Drug Administration alerted the medical community about “serious X-ray-induced skin injuries to patients during fluoroscopically guided procedures” [9]. In 1995, the British Institute of Radiology promoted a scientific meeting on the topic in cooperation with the European Commission [10]. The European Union Directive on medical exposures [11] considers IR as a “special practice” involving high doses to the patient, which requires the use of appropriate means of protection and insists that special attention be given to the quality assurance programmes, including quality control measures and patient dose assessment.

The World Health Organization (WHO) was also involved in the aspects of radiation safety in IR. This organization promoted a Joint WHO/ISH/CE Workshop on Efficacy and Radiation Safety in Interventional Radiology in Munich-Neuherberg, in 1995 [12] and later, in 2000, published a booklet entitled “Efficacy and radiation safety in interventional radiology” [13] which is still today one of the main references on the topic.

The International Electrotechnical Commission (IEC) published in 2000 a standard entitled ‘‘Particular requirements for the safety of X-ray equipment for interventional procedures’’ [14], which includes general safety and RP aspects and details on how to measure and display patient doses at the interventional suites. IEC is working with the DICOM committee on a standard on “Radiation dose documentation” [15]. The document defines the relevant radiation quantities and establishes equipment compliance levels. Compliance level 1 is intended for equipment that produces dose levels below significant deterministic thresholds for all intended uses. Compliance level 2 is intended for equipment used for procedures that could cause significant deterministic injuries. Compliance level 3, while not described in the document, will eventually contain specifications for advanced dose modelling on individual patients. This information is gathered into a Radiation Dose Structured Report (RDSR) designed to be stored in a PACS system, in a medical informatics system, in a freestanding dose management workstation, or in the imaging equipment itself.

IR has also been a relevant topic for the International Radiation Protection Association (IRPA http://www.irpa.net/) through all its congresses and publications.

The International Atomic Energy Agency (IAEA) is leading an International Action Plan on the radiological protection of patients and IR is one of its priorities. Training interventional cardiologists to RP has represented an important effort over the last years [16]. A simple programme of two days' training has been developed, covering possible radiation effects observed among patients and staff, international standards, dose management techniques, examples of good and bad practice and examples illustrating prevention of likely injuries thanks to a good practice of radiation protection. The training material is freely available on CD from the IAEA and on the website (http://rpop.iaea.org/RPoP/RPoP/Content/index.htm). Some research actions carried out under the International Action Plan have already produced important results on the use of reference levels in interventional cardiology [17].

The European Commission (EC) has funded several research actions dealing with IR in the last framework programmes. DIMOND [18] and SENTINEL [19] are probably the two research actions that most focussed on the topic and obtained a relevant number of results and publications. The European Guidelines on Education and Training RP for medical exposures [20] contains a list of educational objectives and a recommendation of 20 hours' training in RP for IR. Free educational material for RP in IR has also been produced with the support of the EC [21].

Most of the medical IR societies have included radiation safety aspects as part of their quality programmes. A list of the most relevant IR societies throughout the world can be found at: http://www.sirweb.org/about-us/IRSocietiesAroundTheWorld.shtml.

The Society of Interventional Radiology (SIR) in US, provides a specific position statement on radiation safety (http://www.sirweb.org/patients/radiationSafetyStatements.shtml) and has produced several important documents on radiation safety: Society of Interventional Radiology Position Statement on Radiation Safety 2003 (www.sirweb.org/clinical/cpg/S387.pdf), Quality Improvement Guidelines for Recording Patient Radiation Dose in the Medical Record 2004 (www.sirweb.org/clinical/cpg/15-423.pdf), etc.

The Cardiovascular and Interventional Radiological Society of Europe (CIRSE) (www.cirse.org) declares as its mission: to provide continuing education and training to physicians and scientists with an active interest in Interventional Radiology or cardiovascular imaging techniques and to promote the exchange of ideas and information to further define the role, direction and goals of cardiovascular and Interventional Radiology as a subspecialty of radiology. CIRSE offers a webpage for patients and public on radiation safety (http://www.cirse.org/index.php?pid=153) and its Standards of Practice Committee is considering including more aspects on radiation protection in its documents.

5. Radiation risks in interventional radiology. Patient and staff dose values.

Interventional procedures are the medical imaging exposures imparting the highest radiation doses to the patients. Medical specialists and other health professionals working in interventional suites are submitted to high level of scatter radiation. Measured dose rates range from 1 to more than 100 mSv/h [22] and some cases of radiation injuries (mainly cataracts) have been reported [23-24] among professionals who have worked for several years without the appropriate RP conditions [23].

According to UNSCEAR data [1] for maximum effective doses for patients during procedures ranging from 13 mSv for PTA to 180 mSv for TIPS, some organ doses may be higher than 100 Gy. Beddetti et al. [25] studied a sample of adult patients (mean age of 67 +/-11 years) who had been admitted to the Institute of Clinical Physiology in Pisa and assessed the cumulative effective dose mainly imparted in cardiology procedures. On average, each patient underwent a median of 36 examinations and the median cumulative effective dose was 60.6 mSv. The median extra-risk of cancer was approximately estimated at 1 in 200 exposed subjects.

Skin doses over several tens of Gy have also been reported [26-28] with important radiation injuries. Stochastic risks for most of the patients (of advanced age) are lower than for other imaging procedures but a certain percentage of IR (between a 5 to 20% depending on the procedures) is carried out on patients under 40.

Thus, estimation of stochastic and deterministic effects is a relevant issue for patients and staff involved in IR.

5.1 Effective dose

ICRP has made an effort to clarify the use and limitations of the quantity effective dose in medical exposures in its new 2007 Recommendations [6]. In any case, when using effective dose to derive the increase of cancer risk, UNSCEAR estimates the inaccuracies to be 2 times higher or lower. [1].

ICRP states (paragraph 340 [6]): “The age distributions for workers and the general population (for which the effective dose is derived) can be quite different from the overall age distribution for the patients undergoing medical procedures using ionising radiation. The age distribution also differs from one type of medical procedure to another, depending on the prevalence of the individuals for the medical condition being evaluated. For these reasons, risk assessment for medical diagnosis and treatment using ionising radiation is best evaluated using appropriate risk values for the individual tissues at risk and for the age and sex distribution of the individuals undergoing the medical procedures. Effective dose can be of value for comparing the relative doses from different diagnostic procedures and for comparing the use of similar technologies and procedures in different hospitals and countries as well as the use of different technologies for the same medical examination, provided that the reference patient or patient populations are similar with regard to age and sex".

The Commission alerts on the limitations (paragraph 341 [6]) in the use of effective dose, saying that: "The assessment and interpretation of effective dose from medical exposure of patients is problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure, which is the case especially with diagnostic and interventional procedures". UNSCEAR adopted a similar criterion (paragraph 14 [1], but presents a more flexible position in paragraph 13 [1]: "Medical exposures to individual patients are summarized most completely in terms of the absorbed dose to each organ or tissue of the body, although this approach is often difficult to realize in practice, particularly for any large-scale dose survey. Weighted-organ dose quantities, such as effective dose, represents convenient indicators of overall exposure in the assessment of diagnostic practice. They broadly reflect in a qualitative manner the risks to health of the stochastic (though not deterministic) effects associated with exposure to ionizing radiation. The Committee has previously used such quantities to evaluate patient doses, with the express purpose of allowing a robust comparison of practice between, inter alia, types of procedure, countries, health-care levels, time periods, and sources of radiation".

5.2 Dose and dose-rate effectiveness factor (DDREF)

ICRP has adopted the LNT (linear non threshold) model combined with a value of 2 for the DDREF and considers it a prudent basis for the practical purposes of radiological protection, i.e., the management of risks from low-dose radiation exposure. Publication 99 [29] states (paragraph 235) that: "The ICRP recommended a DDREF of 2 for radiation protection purposes ... the chosen DDREF should be applied to chronic exposures at dose rates less than 6 mGy/h averaged over the first few hours, and to acute exposures at total doses less than 0.2 Gy", quoting UNSCEAR data. ICRP refers (paragraph A62 of the 2007 recommendations) that: "When dose rates are lower than around 0.1 Gy/hour there is repair of cellular radiation injury during the irradiation".

For some IR procedures, dose and dose rates can be much higher than the quoted values. During an interventional cardiology procedure, a cine frame may involve a skin dose of 1 mGy imparted in 10 ms. This means an instantaneous dose rate of 360.000 mGy/h (360 Gy/h). Thus, during some interventional cardiology procedures, the radiation risk factors could be higher than expected.

5.3 Changes in some risk and weighting factors.

In the 2007 ICRP Recommendations [6] the weighting factor for breast has increased by a 140% in comparison to the 1990 ICRP value [30] (0.12 in 2007 versus 0.05 in 1990). This factor has decreased for gonads by a 60% (0.07 in 2007 versus 0.20 in 1990). The group of tissues considered as "remainder" has now a weighting factor of 0.12 versus 0.05 in 1990, thus resulting in a 140% increase. The (fatal) risk factor for breast cancer in 1990 [30], was 40 per million and mSv, equivalent to 20 for the full population (1 mSv could be equivalent to a mammography examination). In the 2007 Recommendations [6], this value was increased to 127 per million and mSv (62 for the full population, considering 50% females) (table A.4.1 [6]). The increase in the risk factor for breast cancer induced by radiation has reached a 210%.,The values for lung cancer have changed from 85 per million and mSv in 1990, to 113 (table A.4.1 [6]) in 2007 which represents an increase of 33%.

These changes should be taken into account when comparing the radiological risk for different imaging techniques, e.g. a cardiac catheterization versus a computed tomography cardiac angiography. The estimation of effective doses can sometimes result in similar values, but the effect of organ doses and cancer risks can prove very different especially for (young) women. The age and sex of the patient is a critical issue. The mortality factor for lung cancer for 20 year old women (BEIR VII [31]) is 50% higher than for 30 year old ones receiving the same radiation dose. For breast cancer, this increase is a 100% between the age of 20 and 30. Eistein et al. have recently published results [32] showing that some diagnostic cardiac CT (computed tomography) studies involved lung doses from 42 to 91 mSv and from 20 to 80 mSv for breast. The estimation of the increase in cancer probability due to radiation was 1 in 143 for 20 year old women and 1 in 3261 for 80 year old men.

5.4 Patient and staff dose values.

A large number of publications have appeared over the last years on patient and staff doses in IR. ICRP [2] and UNSCEAR [1] reports have summarized most of the results. A significant improvement has resulted thanks to various initiatives such as the European Commission research programmes (DIMOND [18]and SENTINEL [19]) the EC preparation of Guidelines (DOSE DATAMED [33]), the actions and national surveys of some IR societies (SIR at USA [34-35], European [36] and SERVEI in Spain [37]) or even (Switzerland [38]). The IAEA and the International Action Plan of Protection of Patients have also contributed with the publication of relevant results for cardiology [17].

Today, thanks to these studies, patient dose reference levels are available for IR and interventional cardiology. These values can be used to optimize programmes and to help improve radiation safety.
It has been recognised [39] that some of the official data published for staff doses in IR and cardiology could underestimate the real occupational risk deriving from the lack of a regular use of personal dosimeters and the use of a single dosimeter under the apron. Dose values to the non- protected organ or tissues (e.g. lens of the eyes) are unknown to most of the IR professionals.

6. Conclusions

Today IR is safe from the radiation protection point of view and highly beneficial to patients. But we cannot deny that the levels of radiation are among the highest used in medical imaging. Medical doctors employing fluoroscopically-guided procedures need to be trained and certified in RP for this practice and the effort in training actions should be maintained in the years to come. Scientific societies should promote this training. X-ray systems used for IR should be submitted to a strict acceptance and commissioning process in order to optimize initial settings in agreement with the users. Industry should continue to implement dose saving options for the interventional systems and aim at standardizing the patient dose reports, at archiving and processing them automatically using the existing RIS and PACS systems. They should also develop software to estimate skin dose distribution and organ doses: such data would facilitate the selection of the patients in need of a clinical follow-up. Occupational dosimetry should be improved and intenventionists should be convinced of the benefits of having good personal dose records. Patient dose surveys and the use of reference levels should be extended and considered as an indicator of good practice.

Acknowledgements

This work has been partly supported by the Spanish grant FIS2006-08186 (Ministry of Science and Innovation) and by the Spanish Ministry of Health.

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