RADIATION PROTECTION IN MEDICINE: WHEN AND HOW STAFF AND PATIENTS ARE RECEIVING THE HIGHEST DOSES?

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Abstract

In medicine, there are two practices of concern about doses received by patients and staff: interventional radiology and CT exams. The increased complexity and numbers of interventional procedures applied by multidisciplinary teams are imparting significant exposures to patients and involved workers. Occupational radiation risk could be rather high and tissue reaction effects are appearing on patients, since dose could be higher than the thresholds of deterministic effects. Since CT scans are increasing constantly and organ exposures are larger than those from conventional radiology, cancer risk could increase, especially in young people. Pediatric CT results in increased lifetime radiation risk over adult one, also because of procedure settings. An efficient use of imaging modalities using complex apparatuses requires deep knowledge of the influence of equipment settings on patient and staff doses as well as about the effects of ionizing radiation exposure. On the contrary, is appearing an inadequate doctors' knowledge about imparted doses and patient and staff protection. There is also an evidence of unnecessary radiological examinations required by physicians. All these facts ask for the Medical Physics Experts presence inside health institutions, for an adequate Quality Assurance program and, last but not least, for collaborating with physicians to individuate proper ALARA procedures. Specific training is also useful to aware them about risks and effects of ionizing radiation exposure.

Keywords: radiation protection, patient doses, workers dose, interventional radiology, computed tomography

Introduction

Ionizing radiation has been used in medicine since the beginning of the last century, being an essential tool for medical diagnosis and therapy. Radiological practices have experienced marked increase and new technologies, such as computed tomography (CT) and interventional radiology have become widespread (IR, i.e. fluoroscopy-guided interventional procedures including cardiac and angiographic practices). The associated radiation exposure could be high and has to be assessed and monitored considering its potential to cause harmful health effects: stochastic and, in case of IR, tissue reactions too. Moreover, radiological pediatric procedures are one of the fastest growing areas in the last decade (Pearce et al, 2012). Pediatric procedures are of special concern because, compared to adults, children have a higher risk from detrimental effects and a potential increased incidence of cancer in childhood has been reported in recent years (UNSCEAR, 2018).

In Europe, the per caput effective dose of medical imaging (X-rays + nuclear medicine procedures, NM) is 1.10-1.12 mSv, while the contribution (%) to the European collective dose of CT, plain radiography, fluoroscopy, IR and NM procedures is about 52, 22, 13, 8 and 5%, respectively (Figure 1). Comparing the results with an earlier estimation, there seems to be a trend upwards, in particular of CT and IR practices (EU RP 180, 2015). It is important to note there is a big variability on the imparted doses (second –range- and third column –ratio- of Table 1).

In fact, there are procedures which ratio between maximum and minimum dose values goes up to 40! This means that, in Europe, for the same exam, patient exposure could be up to 40 times more than the minimum, depending on the health institution. Consequently, there is an evident need of radiation protection improvement and of Quality Assurance programs (QA) in a lot of medical bodies.

Due to the limitation of epidemiological studies, there isn't an indisputable evidence of cancer risk related to radiological procedures (Boice et al., 2015; Berrington et al, 2016). However, international organizations (IAEA, ICRP) and professional associations emphasize the importance of the basic principles of justification and optimization of medical practices, in particular in the pediatric area.

This work briefly focus on the two practices all consider of concern about doses received by patients and the involved staff: IR and CT.

Interventional radiology, IR

The patient benefits of IR are widely acknowledged, and, in the past decade, the number of procedures and their complexity has enlarged strongly. The increased complexity applied by multidisciplinary teams, not always expert about the practical aspects of radiation protection, are imparting significant doses to patients and involved workers. Interventional physicians (i.e., cardiologist, urologists, etc.) are the most exposed to ionizing radiation, as they perform their interventions inside the radiological room.

Patient exposure could be significant depending on the intervention, its complexity and on patient conditions. There are many studies showing that tissue reaction effects are appearing on patients, since doses could be higher than the threshold doses of deterministic effects. Figure 2 and Table 2 show the personal doses received by physicians during IR and cardiology procedures (Efstathopoulos et al, 2011). Hands and eyes of interventionist could be at particular risk even when proper procedures for radiation protection have been followed. Eye exposures may cause radiation-induced lens opacities. The International Commission on Radiological Protection (ICRP, 2017) have been lowering the lens dose limit from 150 mSv per year down to 100 mSv in 5 years, since the Commission confirmed that lens radiosensitivity is higher than expected previously. Occupational radiation risk is mainly due to the diffusion of X-rays impinging on the patient. Scatter radiation depends on the beam entering the patient (intensity and energy), his/her dimension, volume of interest and on the irradiated surface (Bartal et al, 2013; Sanchez et al, 2012; Vano et al, 2006; Vano et al, 2009).

Therefore, international recommendations (ICRP, IAEA) and EU regulations (directive 2013/59/Euratom Basic Safety Standards) require that the doses received by patients and involved professionals must be monitored. The “simple” application of basic radiation protection criteria (such as time, distance and shielding) strongly reduces staff and patient doses when the physician have been interviewed properly (Vano et al, 2009). Finally yet importantly, many studies report a relationship between patient dose and staff exposure: this is a positive aspect, since improving patient protection imply also to reduce staff doses. An effective radiation safe policy and training of involved professionals are strongly required for all IR procedures for reducing radiological risk of patients and workers.

Computed tomography, CT

Recent increases in computer tomography have led to significant increase of collective dose to the population (Brenner *et al*, 2007). CT doses could be relevant, in comparison to other radiological procedures (see Table 1). Regular assessments of the magnitude and distribution of this large and increasing source of population exposure is therefore of high importance. On the other end, since CT scans are increasing continuously and organ doses are larger than the ones from conventional radiology, cancer risk could increase, in young people particularly. Figure 3 shows the mean estimated brain dose response relationship for brain tumors from CT scans, in young patients; in the cases with brain tumor-predisposing conditions the excess of relative risk (RR) is slightly higher than in those without (Berrington de G. *et al*, 2016). The risk assessment should have also to consider doses to the irradiated organs, because an evaluation based only on the effective dose could not represent the organ risks (Brenner et al, 2001). As an example, Figure 4 shows the absorbed doses (equivalent dose) for selected organs from CT examinations (Ngaile, Msaki, 2006). A CT head scan could impart to the brain and eyes up to 50 and 60 mSv equivalent dose, respectively, while the effective dose is “only” 2.5-3 mSv. Table 3 reports the organ doses from various radiological studies (Brenner *et al.*, 2007). A correct assessment of all doses is crucial for planning the radiological practices properly: both effective dose and the involved organ equivalent doses.

On the other end, our understanding of the carcinogenic potential of X-ray low doses has improved substantially, particularly for children. ICRP’s considerations suggest that the estimated risks associated with X-ray exposure are not hypothetical (ICRP, 2013; UNSCEAR, 2010). Pediatric CT results in increased lifetime radiation risk over the adult one, also considering the procedure settings (because of the increased dose per mA*sec and the increased lifetime risk per unit dose). For children, you have to apply low settings without significant loss of information. Although the risk–benefit balance is still strongly tilted toward benefit, radiation risks for children undergoing CT are not negligible and may stimulate active reduction of CT scan (justification) and of exposure settings (optimization) (Brenner *et al,* 2001).

Knowledge and preparedness about radiation protection

While radiological practices are the first anthropic sources of population exposure, recent publications show inadequate physicians' knowledge about the imparted doses in medical practices and lack of their preparedness about patient and staff protection. There is also an evidence of unnecessary radiological exams. Recent studies, show that the physician’s knowledge about ionizing radiation doses and human effects is correct for about 60% of them, with a significantly higher result between radiologist. Around 5% and 13% of the professionals do not know that ultrasonography and magnetic resonance, respectively, do not expose patients to ionizing radiations. Only 5% properly associate cancer risk rate to CT (Campanella *et al*, 2017). The knowledge and understanding of radiologists and interventionists about radiobiology and radiological risks and how optimize exposures in many institutions, appears not adequate when compared with the complexity of the procedures they are applying every day.

The findings show the need of sensitization programs for the involved physicians about the risk linked to radiation exposure in medicine. There is also a necessity for specific courses addressed to general practitioners and family pediatricians, who are the first to order radiation imaging tests. The purpose is to minimize unnecessary radiation exposure of the population with improving appropriateness of examinations.

Quality Assurance Programs, QA

The Quality Assurance program (QA) is necessary for reducing and controlling medical radiation exposure. One of the most important tools of QA is the assessment of diagnostic reference levels (DRLs). They are recommended by ICRP and IAEA and are required also by European Council (directive 2013/59/Euratom). DRLs are a useful tool for optimizing patient doses (EU RP 180, 2014c; EU RP 185, 2018). All examinations resulting in high collective doses should have DRLs.

This can include both the most common low dose examinations and the less common high dose ones. Particular attention should be paid for establishing and using DRLs in pediatric radiology. Specific training is also an important part of QA: it is useful to aware physicians about risks, effects of ionizing radiations in medical practices and how to reduce patient and staff doses, in each radiological practice. The application of DRLs is the responsibility of X-ray imaging providers, while their assessment is a Medical Physics Expert’s task.

You cannot plan and perform any QA without the collaboration of a Medical Physics Expert (MPE). This professional is expert about ionizing radiation exposure, dose assessment and the application of radiation physics in the medical field is part of her/his specialty (EU RP 174, 2014a). The MPE presence is required at health institutions, for assessing DLRs and also for collaborating with physicians to individuate, case by case, proper ALARA procedures.

One way for getting the best radiation protection is by having the MPE's collaboration. Unfortunately, his/her presence is still missing in many European health institutions.

Last but not least, the European imaging referral guidelines are important for helping physicians to decide when an exposure would be useful and to identify the most appropriate examination for each patient. Developed in UK (late 1980s) and adopted by European Commission (EU RP 174, 2014b), they are an active tool for reducing the exposures, for improving the safe use of radiation procedures. Unlikely, many physicians do not know their existence.

Conclusions

There is evidence of the need of raising awareness about risk associated to ionizing radiation in medical procedures. It is imperative to find the best modalities for supporting a widespread knowledge about radiation protection between physicians and to promote the integration of referral guidelines into clinical practice.

Radiographers, IR physicians and MPEs play an essential role in the safe use of ionizing radiations in medical practices. They must be trained so that they can assume this role. Physicians must be educated in radiation management, trained about the complexity of fluoroscopy systems they use, and comfortable with the imaging protocols and proper and safe operating modes. They must also be comfortable with imaging modalities that do not require ionizing radiation whenever clinically appropriate.

A QA properly applied in each health institution using ionizing radiations surely lowers the exposures. The Medical Physics Expert is one of the main actor required for a serious approach to radiation protection in medical practices. European Commission is demanding for this figure in all health institutions: where her/his collaboration is effective there is an evident optimization of staff, patient and collective doses.

Tables and figures

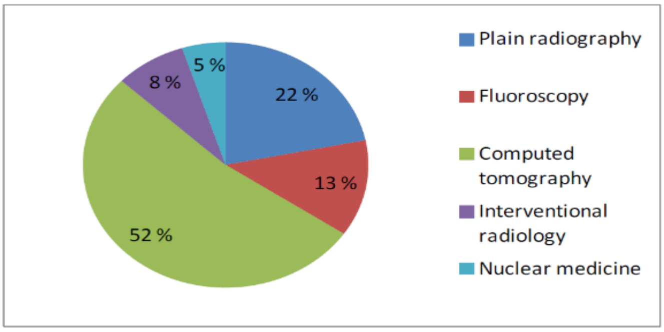


Figure 1. Relative contribution of the main radiation practices to the overall collective effective dose in Europe (EU RP 180, 2015)

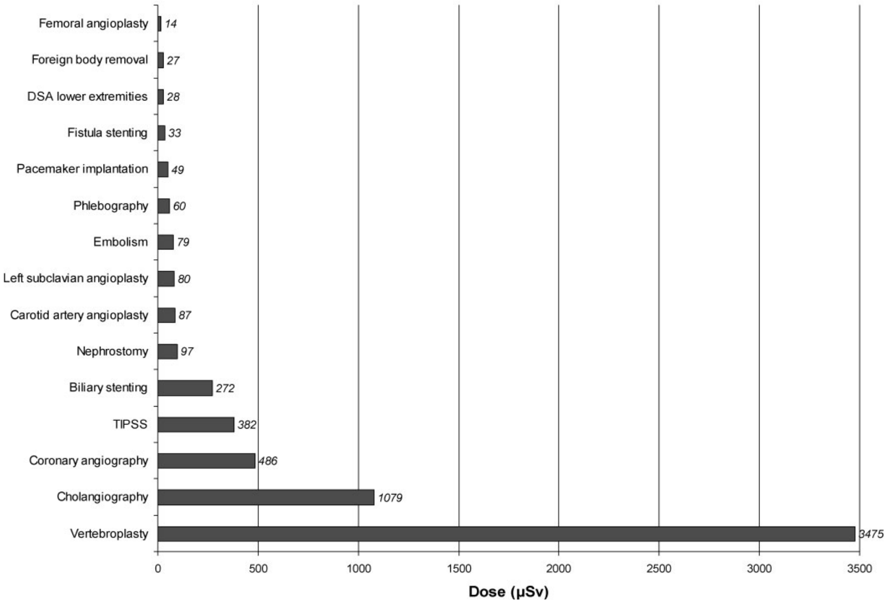


Figure 2. Average dose per procedure recorded by the left wrist dosimeter (location of the highest recorded dose). DSA= digital subtraction angiography; TIPSS= transjugular intrahepatic portosystemic stent shunt (Efstathopoulos *et al*, 2011)

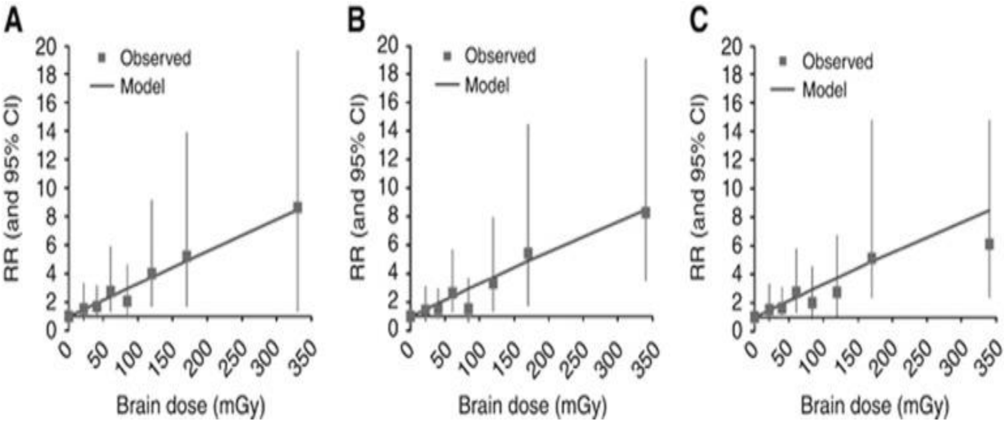


Figure 3. Excess relative risk (RR)-dose response relationship for brain tumors in relation to brain dose from CT scans. (A) No one predisposing condition excluded. (B) Excluding underlying cancer-predisposing conditions. (C) Excluding previous cancers (Berrington de G. et al, 2016)

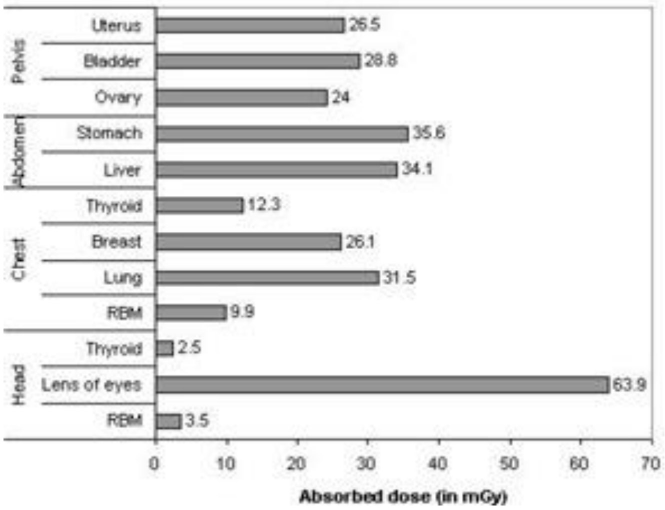
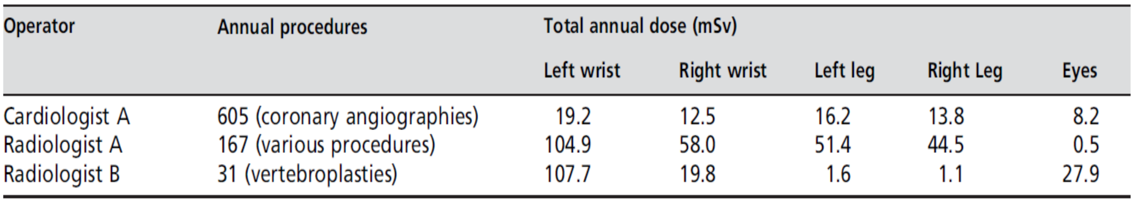


Figure 4. Absorbed dose for selected organs from CT examination type (Ngaile, Msaki, 2006)

X-ray procedure	E, mSv	Range, mSv	Max/min
Chest/Thorax	0,1	0,014-0,26	18,6
Cervical spine	0,2	0,02-0,7	41,2
Thoracic spine	0,6	0,14-2,0	14,2
Lumbar spine (inc.LSJ)	1,2	0,29-3,15	10,9
Mammography	0,3	0,02-0,6	35,3
Abdomen	0,9	0,11-2,9	27,9
Pelvis & hip	0,7	0,21-2,0	9,7
Ba meal	6,2	0,8-15.0	18,8
Ba enema	8,5	2,2-25,2	11,5
Ba follow-through	7,2	0,63-24,5	38,9
IVU	2,9	0,43-5,63	13,0
Cardiac angio-graphy	7,7	3,25-11,25	3,5
CT head	1,9	0,28-3,98	14,3
CT neck	2,5	0,42-5,38	13,0
CT chest	6,6	2,03-20,4	10,0
CT spine	7,7	2,38-16,3	6,9
CT abdomen	11,3	2,61-28,7	11,0
CT pelvis	7,3	0,8-14,5	18,1
CT trunk	14,8	2,35-50,5	21,5
PTCA	15,2	4,0-29,0	7,3

Table 1. Average typical effective doses (E) in European Countries (EU RP 180, 2015).



Operator	Annual procedures	Total annual dose (mSv)				
		Left wrist	Right wrist	Left leg	Right Leg	Eyes
Cardiologist A	605 (coronary angiographies)	19.2	12.5	16.2	13.8	8.2
Radiologist A	167 (various procedures)	104.9	58.0	51.4	44.5	0.5
Radiologist B	31 (vertebroplasties)	107.7	19.8	1.6	1.1	27.9

Table 2. Calculated annual doses for the interventionists with the highest workloads (cardiologist A and radiologist A) and the interventionist for whom maximum doses per procedure were recorded (radiologist B) (Efstathopoulos et al, 2011)

Study Type	Relevant Organ	Organ Dose* (mGy or mSv)
Dental radiography	Brain	0.005
Posterior–anterior chest radiography	Lung	0.01
Lateral chest radiography	Lung	0.15
Screening mammography	Breast	3
Adult abdominal CT	Stomach	10
Barium enema	Colon	15
Neonatal abdominal CT	Stomach	20

Table 3. Typical Organ doses from various radiological studies (Brenner et al, 2007)

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