

Risks Related To Fluoroscopy Radiation Associated With Electrophysiology Procedures

Eugenio Picano¹, Emanuela Piccaluga², Renato Padovani³, Claudio Antonio Traino⁴, Maria Grazia Andreassi¹, Giulio Guagliumi⁵

¹CNR, Institute of Clinical Physiology, Pisa, Italy. ²Cardiology Unit, Hospital Sacco, Milan, Italy. ³Medical Physics Department, University Hospital, Udine, Italy. ⁴Division of Health Physics University Hospital of Pisa, Pisa, Italy. ⁵Interventional Cardiology Unit, Ospedale Papa Giovanni XXIII, Bergamo, Italy.

Abstract

The benefits of cardiac imaging are immense, and modern cardiac electrophysiology (EP) requires the extensive and versatile use of a variety of cardiac imaging and radiology-based techniques. In the cardiac electrophysiology lab, doses can range around a reference effective dose (ED) of 15 millisievert corresponding to 750 chest x-rays for a cardiac radiofrequency ablation, ranging from less than 2 to > 60 mSv. The reference dose for a regular pacemaker or ICD implant is 4 mSv (range 1.4-17) and for a CRT implant is 22 mSv (range 2.2-95). Doses on the order of magnitude of 10-100 millisievert (mSv) correspond to a low (albeit definite, not negligible) additional lifetime risk of fatal and non-fatal cancer from between 1 in 1000 (10 mSv) to 1 in 100 (100 mSv). The increasing use and complexity of cardiac electrophysiology techniques have not been matched by increasing awareness and knowledge by prescribers and practitioners. The protection of doctors is just as important as protection of patients. Most experienced (and most exposed) interventional cardiologists and electrophysiologists have an exposure per annum of around 5 mSv, two to three times higher than diagnostic radiologists, with a typical cumulative lifetime attributable risk on the order of magnitude of 1 cancer (fatal and non-fatal) per 100 exposed subjects. Operator dose per procedure correlates somewhat with the patient dose, but may be typically 1000 times lower depending upon the shielding employed (one unit of incidence scatter dose for the operator when 1000 units of incident dose are given to the patient). However, adequate radiation protection training and diligent protection can reduce this radiation exposure by 90%.

The priority given to radioprotection in every cardiology department is an effective strategy for primary prevention of cancer, a strong indicator of the quality of the cardiology division, and the most effective shielding for enhancing the safety of patients, doctors, and staff.

Introduction

Over the last 20 years, interventional electrophysiology (EP) has expanded significantly, in the field of diagnostic studies, ablations, and device implantation. Most of their interventions are performed under fluoroscopic guidance. Therefore, effective dose (ED) to patient of EP procedures can range anywhere from 1 to 100 millisievert (mSv), equivalent to a radiological risk corresponding to 50 to 5000 chest x-rays. The occupational exposure of cardiac electrophysiologists can be two to three times higher than that of diagnostic radiologists.¹ The increasing use and complexity of EP techniques have not been matched by increasing awareness and knowledge by prescribers and practitioners. Most doctors – including cardiac electrophysiologists and invasive cardiologists – grossly underestimate the radiation

doses for most commonly requested tests.^{2,3} However, this knowledge is crucial for several reasons. First, the dose is proportional to long-term cancer risk, and therefore it is necessary to be aware of the dose in order to perform a proper risk-benefit assessment, quintessential for evaluating the appropriateness of any given test or procedure. Second, knowing the dose is necessary in order to apply dose optimization, intended to achieve the desired diagnostic information or therapeutic benefit with the lowest necessary dose. Third, radiation awareness is essential for better protection of cardiac electrophysiologists and staff (technicians and nurses), since simple radioprotection knowledge can reduce occupational exposure by tenfold, making one's professional life longer and healthier. These are three excellent reasons to pursue a policy of radioprotection in the EP lab.

Deterministic And Stochastic Risks In The EP Lab

There are two main biological effects of radiation (Table 1): tissue reactions (deterministic effects), which occur when the radiation dose exceeds a specific threshold and become evident days to months after exposure as a predictable change in tissue occurs, and stochastic effects, which relate to the potential for future harm to the tissue and the body.^{3,4}

Deterministic (tissue reaction) effects of most concern for patients and operators include skin injuries (reported in patients during long,

Key Words:

Radiation, Risk, Electrophysiology.

Disclosures:
None.

Corresponding Author:
Eugenio Picano, MD, PhD
CNR, Institute of Clinical Physiology
Via Moruzzi, 1
56124 Pisa.

Table 1: Biological effects of ionizing radiation

	Tissue reactions ("deterministic")	Chance damage ("probabilistic")
Dose level	Medium to high	Any
Latency period	Short (days or weeks)	Long (years)
Threshold dose	Yes	No
Biological mechanism	Predominantly cell death	Cell damage
Sample clinical effects	Skin lesions	Cancer

repeated and complicated interventional procedures). The severity of tissue reactions, rather than probability of occurrence, is proportional to the dose imparted to the tissue. Patient skin injuries may occur when fluoroscopic procedures exceed 20 min, using high-contrast fluoroscopy mode, or 60 min in low-level fluoroscopy. Tissue injury following fluoroscopic guided procedures remains asymptomatic and is often unrecognized as it occurs weeks after the procedure. They usually occur on the patient's back (where the x-rays are delivered) and many severe cases come to light only through litigation. A case is filed in the US courts every 4 to 5 weeks by patients who have suffered such injuries.

The lens is a radiosensitive tissue, and thus cataract formation is the primary ocular complication associated with ionizing radiation exposure for both patients and doctors. Until recently, the dose threshold for radiation-induced lens opacities was considered 2 Gy for a single dose or 5 Gy for fractionated dose. Currently, radiation-induced cataract, previously thought to be deterministic (tissue reaction), is now recognized to be possibly stochastic in nature, occurring at a much lower radiation exposure level than previously thought. Indeed, several epidemiological studies showed an increased incidence of lens opacities at doses below 0.5 Gy. Accordingly, on April 21, 2011 the International Commission on Radiological Protection (ICRP) slashed the earlier dose limit of 150 mSv in a year for the lens of the eye, to the present 20 mSv in a year, averaged over a defined period of 5 years, with no single year exceeding 50 mSv. Eye cataracts, with the radiation-specific type of posterior sub-capsular opacities, can be observed in one-third of staff after 30 years of work – as a consequence of lack of specific protection and too-permissive limits allowed for the current generation of workers up to 2011.⁵

The stochastic effect of most concern is a carcinogenic effect (in both exposed patients and doctors). It occurs when the cell is modified by damage to its DNA but remains viable, the harm eventually being expressed through cell proliferation. Ionizing radiation damag-

Table 2: Doses of common examinations in the EP lab

Cardiac electrophysiology	Effective dose (mSv)	Equivalent CXRs
Diagnostic EP studies	3.2 (1.3–23.9)	160
Ablation procedure	15.2 (1.6–59.6)	760
AF	16.6 (6.6–59.2)	830
AT-AVNRT-AVRT	4.4 (1.6–25)	220
VT	12.5 (3 to ≥45)	625
Regular PM or ICD implant	4 (1.4–17)	200
CRT implant	22 (2.2–95)	1100

AF: atrial fibrillation; AT: atrial tachycardia; VT: ventricular tachycardia; CRT: Cardiac Resynchronization therapy

Table 3: Biological effects of ionizing radiation

Radiology	
KAP in adults	$mSv = KAP (Gy\ cm^2) \times 0.2$
KAP in 15-year-olds	$mSv = KAP (Gy\ cm^2) \times 0.4$
KAP in 5-year-olds	$mSv = KAP (Gy\ cm^2) \times 1.0$
KAP in 1-year-olds	$mSv = KAP (Gy\ cm^2) \times 1.9$
KAP in newborns	$mSv = KAP (Gy\ cm^2) \times 3.7$

KAP: Kerma Area Product

es DNA molecules either directly (though ionization of DNA molecule) or indirectly (through generation of free radicals and reactive oxygen species in the surrounding medium). Cancer may occur after a latency period of many years. Reducing the risk of cancer is at the core of the radioprotection system for patient and staff.

Radiation Doses

The radiation doses of common EP examinations are reported in Table 2. As a reference dose, a conventional chest radiography (single

Table 4: Factors modulating doses in the cardiac EP lab

		Lower doses	Higher doses
Operator-dependent	Operator background	Expert	Beginner
	Training with the simulator	Yes	No
	Awareness	Radiation aware	Radiation unaware
	Written report	Includes KAP	Omits KAP
	Projection	RAO	AP or LAO
	Pulsed fluoroscopy	Low rate (≤ 6 fps)	High rate (> 12.5 fps)
	Cine duration	Short	Long
	Cine substitution by stored fluoroscopy	Yes	No
	Fluoroscopy during catheter withdrawal	No	Yes
	Collimation	Optimized, and adapted	Wide open, and fixed throughout the procedure
Pelvic radiation	Avoided	During introduction and removal of the catheters	
	Anesthesiologists/AP	Allowed to halt the procedure	Also exposed when in close proximity
Patient-dependent	Body habitus	Lean	Obese
	Arrhythmic lesion to be ablated	Supraventricular tachycardia	Atrial fibrillation or VT
Technology-dependent	X-ray system	Tuned for the EP, inspected for QC and maintained	No specific EP settings, not tested, not maintained
	Combination with the CT (pre-procedural/rotational)	No	Yes
	Non-fluoroscopic mapping systems	Yes (Ensite; Carto; and Mediguide)	No
	Shielding	Above and below the table; cabin	Minimal, only above the table

RAO: Right Anterior Oblique projection; LAO: left Anterior Oblique projection; KAP: Kerma Area Product; QC: quality control

Risk to patient

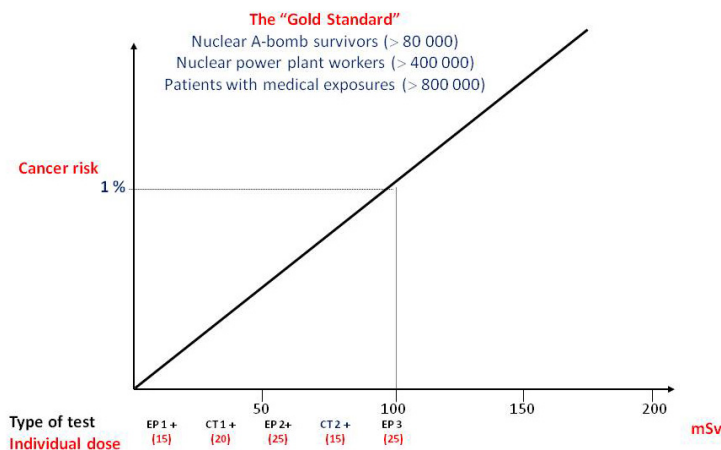


Figure 1:

The dose-effect relationship between radiation exposure and cancer risk over background levels. The solid line indicates the epidemiological evidence, which is conclusive for doses > 50 mSv, and recently expanded with the publication of two medical cohorts of over 800,000 children who underwent CT in Australia and UK. The cumulative dose of 100 mSv corresponds to a 1% extra-risk of cancer over baseline and can be reached after three serial EP procedures and two CTs.

postero-anterior projection) corresponds to 0.02 mSv; a diagnostic coronary angiography to 7 mSv (range 2-16); a percutaneous coronary angioplasty to 15 mSv (7-57); a 64-slice coronary CT to 15 mSv (3-32) and a Sestamibi Myocardial Perfusion Scintigraphy to 9.4 mSv.

On the display of the equipment, values are usually reported as a dose-area product (DAP) or Kerma-area products (KAP) indicating total energy impacting the patient for a given EP procedure. As a general rule, ED can be estimated approximately as follows: ED (mSv) = DAP (Gy x cm²) x 0.2 (mSv/Gy cm²). The conversion factor (from DAP to mSv) is age-specific, and increases with decreasing age (Table 3). Consequently, DAP quantity represents a relevant dosimetry index, the value of which should be optimized against the diagnostic reference level, which varies for each procedure and can be used as a tool to comply with the ALARA (As Low As Reasonably Achievable) principle.

The introduction of non-radiology-based methods of cardiac mapping and co-registration of CMR images of the target structures (for instance, the left atrium) could dramatically reduce these doses. The many factors modulating the dose in the EP lab are summarized in Table 4 and can reduce the dose by a factor of 10 to 100.

Protection Of Personnel

Protection of doctors is just as important as the protection of patients. Most experienced (and most exposed) cardiac electrophysiologists have an exposure per annum of around 5 mSv, two to three times higher than diagnostic radiologists, with a typical cumulative lifetime attributable risk on the order of magnitude of 1 cancer (fatal and non-fatal) per 100 exposed subjects.^{6,7} The excess cancer risk may involve more exposed and less well protected organs, such as skin cancer, leukemia, breast cancer in females, and brain cancer.⁸ More dose corresponds to greater cancer risk, and recent observational case series described a disproportionate number of tumors in the left side of the brain,⁹ the region of the head known to be more

exposed to radiation – twice as much compared to the right side.¹⁰

Operator dose per procedure correlates somewhat with the patient dose, but may be typically 1000 times lower depending upon the shielding employed (one unit of incidence scatter dose for the operator when 1000 units of incidence dose are given to the patient). However, adequate radiation protection training and diligent protection can reduce this radiation exposure by 90%.¹⁰

The Order Of Magnitude And Risks

A cumulative ED of 100 mSv may be reached by a patient after four ablation procedures plus two or three CT's, with an extra-risk of cancer of 1 in 100 (Fig. 1). The same cumulative dose of 100 mSv can be reached by an experienced EP after 30 years of work (Fig. 2). This is a "population" risk, and the true individual risk is dictated – as always in medicine – by genetic and environmental factors. For instance, the average dose of 15 mSv confers a risk of one extra-cancer in every 750 exposed 50-year old male patients, but the risk is 38% higher in women, must be multiplied by 4 in children, and reduced by 50% in an 80-year-old man. The risk is higher in presence of some unfavorable polymorphisms of genes involved in DNA repair and in presence of other environmental carcinogens such as smoking. The risk can probably be reduced with chemoprotective strategies, for instance with anti-oxidant cocktails,¹¹ although the cost-benefit assessment of these strategies remains unsettled.

The use of fluoroscopy during invasive fluoroscopy intervention (such as catheter radiofrequency ablation) is likely to result in a small increase in the lifetime risk of a fatal malignancy, and the most likely malignancies will be lung, bone marrow (leukemia) and the breast, the organs exposed to the maximum amount of radiation.¹²

The risk may be acceptable when flanked with a documented or expected benefit, but it is not negligible, and should be spelled out in

Risk to EP doctor – 20 years of work, 5 mSv (below apron) per year

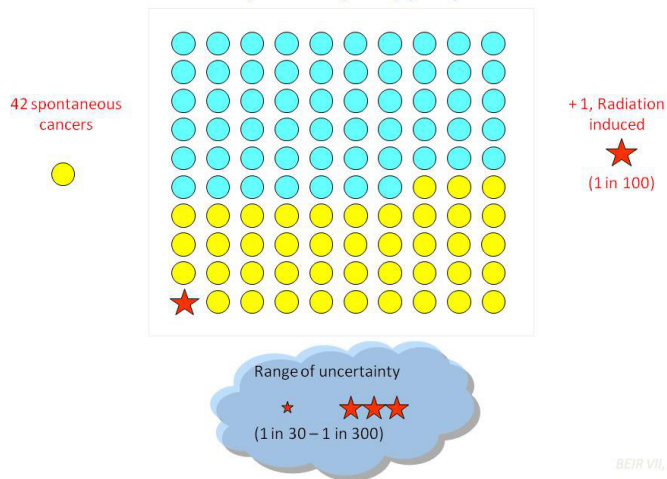






Figure 2:

The risk model for the Biological Effects of Ionizing Radiation Committee VII for exposure to low-level radiation predict that about one (red star) out of 100 people would likely develop solid cancer or leukemia from an exposure of 100 mSv above background. About 42 additional people (yellow circles) in the same group would be expected to develop solid cancer or leukemia from other causes. Roughly half of these cancers would result in death. This dose of 100 mSv is reached by 5% of patients in a single cardiac ablation or coronary angiography procedure. [Modified and adapted from ref 6: BEIR VII Health Risks from Exposure to Low levels of Ionizing Radiation, Phase 2. dels-old.nas.edu/dels/rpt_briefs/beir_vii_final.pdf.]

Table 5: Terminology that should be used

Investigation (example)	Effective dose range	Additional lifetime risk of fatal and non-fatal cancer	RCR symbolic representation	Proposed risk term
CXR	<0.1 mSv	1 in 1 million to 1 in 100 000		Negligible
Abdominal X-ray	0.1-1 mSv	1 in 100 000 to 1 in 10 000		Minimal
Chest CT	1-10 mSv	1 in 10 000 to 1 in 1 000		Very low
PCI	10-100 mSv	1 in 1 000 to 1 in 100		Low

RCR: Royal College of Radiology. Adapted and modified from ref. ¹

the informed consent form before the procedure (Table 5). After the examination, the actual delivered dose should be stored in the patient's and laboratory's records. This simple process will gently force the doctor to learn what he/she should already know, enabling him/her to make more responsible choices.

Novel Opportunities In The EP Lab

The challenges of radioprotection in the EP lab opens exciting new opportunities for the clinician, the researcher, and the pharma and technology industries, in a perspective that will rapidly positively impact on both patients and doctors.

For the clinician, the advent and diffusion of near-zero fluoroscopy techniques will soon lead to a dramatic reduction in delivered doses to patients and also to the operator.

For the researcher, it is essential to move from the current evidence-poor to an evidence-rich milieu, with data directly linking radiation exposure to cancer and non-cancer (including arterial and brain premature aging) effects in our patients and in ourselves as exposed population. In particular, the EP community should play a proactive role in collecting new evidence. In the USA, the Multispecialty Occupational Health Group network triggered a cohort mortality study comparing cancer and other serious disease outcomes (including cardiovascular disease) in 44,000 physicians performing fluoroscopically guided procedures (including interventional cardiologists, cardiac electrophysiologists, radiologists, neuroradiologists and others). In Italy, the Healthy Cath Lab study is organized by the Italian National Research Council – Institute of Clinical Physiology with endorsement by the Italian Society of Invasive Cardiology.⁴ The

Table 6: Ongoing studies on interventional cardiologists and electrophysiologists

Main funding	NIH and NCI	Italian CNR National Research Council – IFC, Institute of Clinical Physiology
Scientific Societies endorsement	Multispecialty Occupational Health Group	Italian Society of Invasive Cardiology (GISE)
Enrolled population	<ul style="list-style-type: none"> • 44,000 fluoroscopists (interventional cardiologists, radiologists, neuroradiologists) • 49,000 non-interventional radiologists • 100,000 non-exposed physicians 	<ul style="list-style-type: none"> • 500 exposed interventional cardiologists (nurses, technicians) • 500 non-exposed clinical cardiologists (nurses, technicians)
Endpoint	Epidemiological clinical endpoints (cancer, cataract, vascular events)	Surrogate biomarkers of genetic, vascular, reproductive, neurocognitive effect

NIH: National Institute of Health; NCI: National Cancer Institute

Italian study population will involve 500 exposed interventional cardiologists and staff (technicians and nurses) evaluated by a molecular epidemiology approach to assess “early warning signs” of brain and vascular aging (Tab. 6). The EP community might decide to join in, since the safety issue is vital for EP doctors and patients.

For the industry, there is growing interest not only in new techniques with near-zero exposure based on non-fluoroscopic navigation, but also for new textile materials for better and more ergonomic shielding for patients and doctors, also based on novel alloys and nano-technology.

Finally, the patient will benefit from these innovations, since in the end radiation doses will drop and the benefit will remain the same, making the EP lab a safer place.⁵

Conclusion:

The advent of radioprotection culture in the EP lab is a unique opportunity for today's generation of professionals, who have the responsibility to change time-honored practices that increase the risk to patients and to us without any benefit. The key messages are simple and direct:

1. Attention to radioprotection is one aspect – and not the least important – of good practice of EP.
2. Protecting the patient from an unjustified or unoptimized dose is the best way to protect yourself and your staff.
3. Before the exam, both you and the patient should know the expected delivered dose (which is directly proportional to the long-term risk).
4. During the exam, make every effort to keep the dose as low as possible.
5. After the exam, write the dose down in the records. You and your patient need to know it, because short-term (weeks or months) deterministic (skin ulcers) and long-term (years or decades) stochastic (cancer) risk depend on it.

And finally: a smart EP cannot be afraid of radiation, but must be very afraid of radiation unawareness.

References:

1. Picano E, Vañó E, Rehani MM, Cuocolo A, Mont L, Bodi V, Bar O, Maccia C, Pierard L, Sicari R, Plein S, Mahrholdt H, Lancellotti P, Knuuti J, Heidbuchel H, Di Mario C, Badano LP. The appropriate and justified use of medical radiation in cardiovascular imaging: a position document of the ESC Associations of Cardiovascular Imaging, Percutaneous Cardiovascular Interventions and Electrophysiology. *Eur Heart J*. 2014 Jan 8. [Epub ahead of print]
2. Correia MJ, Hellies A, Andreassi MG, Ghelarducci B, Picano E. Lack of radio-

- logical awareness among physicians working in a tertiary-care cardiological centre. *Int J Cardiol.* 2005;103:307-11.
3. Kim C, Vasaiwala S, Haque F, Pratap K, Vidovich MI. Radiation safety among cardiology fellows. *Am J Cardiol* 2010;106:125-8
 4. Picano E, Vano E. Radiation exposure as an occupational hazard. *EuroIntervention.* 2012;8:649-53
 5. Heidebuchel H, Wittkamp F, Vano E, Ernst S, Schilling R, Picano E, Mont L. Practical ways to reduce radiation dose for patients and staff during device implantations and electrophysiological procedures. EHRA Position Paper. *Europace.* 2013. doi:10.1093/europace/eut409.
 6. BEIR VII Health Risks from Exposure to Low Levels of Ionizing Radiation, Phase 2. <http://www.nap.edu/openbook.php?isbn=030909156X>. Retrieved: February 17th, 2014
 7. Venneri L, Rossi F, Botto N, Andreassi MG, Salcone N, Emad A, Lazzeri M, Gori C, Vano E, Picano E. Cancer risk from professional exposure in staff working in cardiac catheterization laboratory: insights from the National Research Council's Biological Effects of Ionizing Radiation VII Report. *Am Heart J.* 2009;157:118-24
 8. Linet MS, Kim KP, Miller DL, Kleinerman RA, Simon SL, Berrington de Gonzalez A. Historical review of occupational exposures and cancer risks in medical radiation workers. *Radiat Res.* 2010;174:793-808
 9. Roguin A. *CardioPulse.* Radiation in cardiology: can't live without it!: using appropriate shielding, keeping a distance as safely as possible and reducing radiation time are essential principles for radiation reduction. *Eur Heart J.* 2014;35:599-600
 10. Vañó E, González L, Guibelalde E, Fernández JM, Ten JI. Radiation exposure to medical staff in interventional and cardiac radiology. *Br J Radiol.* 1998;71:954-60
 11. Andreassi MG, Cioppa A, Manfredi S, Neri MG, Foffa I, Picano E. N-acetyl cysteine reduces chromosomal DNA damage in circulating lymphocytes during cardiac catheterization procedures: a pilot study. *Int J Cardiol.* 2012;161:93-6
 12. Kovoov P, Ricciardello M, Collins L, Uther JB, Ross DL. Risk to patients from radiation associated with radiofrequency ablation for supraventricular tachycardia. *Circulation.* 1998;98:1534-40.