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Management of Medical Radiation: Perspectives from Cardiology

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Abstract Cardiac imaging with ionizing radiation provides immense diagnostic and therapeutic benefits, and also determines a corresponding increase in long-term cancer risk that should be included in the tailored, individualized benefit-risk balance. Cardiologists have a particular responsibility to avoid inappropriate and non-optimized use of radiation, since they are responsible for about 40 % of overall exposure from medical radiation, but they sometimes show suboptimal radiological awareness. The radiological dose of common radiological examinations can range from the equivalent of 1–60 milliSievert (mSv), with a reference dose average of 15 mSv (corresponding to 750 chest x-rays) for a percutaneous coronary intervention, a cardiac radiofrequency ablation, a multidetector coronary angiography, or a myocardial perfusion imaging scintigraphy. The tendency of the previous generation of cardiologists to ignore radiological doses, neglect risks and forget long-term consequences is no longer conscionable considering medical and ethical reasons, but also medicolegal. Institutions, scientific societies and political governance of health care should implement policies to reduce the unacceptablly high rate of inappropriate examinations, not infrequently performed on the wrong patient, with the wrong dose, at the wrong moment. Appropriateness and optimization are a difficult, moving, and elusive target, and there are so many clinical nuances in patient presentation and factors of variability regarding dose determination that it is not easy to have a sharp cut-off between appropriate and optimized vs inappropriate and nonoptimized examinations, but the wrong indication and dose is certainly one that is not audited and remains undisclosed. The 2014 European Society of Cardiology position paper on the use of medical radiation in cardiology provides a simple roadmap for clinical cardiologists to achieve the challenging yet fundamental goal of making our cardiology wards, imaging laboratories, and catheterization suites a safer place for doctors and patients.

Keywords Cancer · Cardiovascular disease · Imaging · Radiation · Radiological protection · Risk

Introduction

During the past 20 years, radiologic imaging procedures have dramatically increased in number and complexity with a corresponding increase in radiation dose to population [1]. The main cause of this increase has been attributed to the advancement of technologies in the field of diagnostic imaging [2]. Additional factors in this growth may be the increased demand from the users themselves, greater accessibility to laboratories and availability of services, and introduction of disruptive new diagnostic techniques such as computed tomography, whose use has grown dramatically over the years from about 3 million in 1980 to 70 million in 2007 [3]. Other growth factors for imaging overuse are the heterogeneous level of competence of the doctors, and their variable and subjective adherence to the guidelines, with increasingly frequent recourse to defensive medicine. The aging of society and

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the consequent greater severity of the clinical condition are also contributing factors to the increasing use of imaging. Most importantly, despite the vast implications for societal costs and population safety, the imaging field remains highly deregulated, and any specialist can prescribe a high-tech, risky imaging procedure, also with non-negligible radiation exposure, as many times as it deems appropriate without being obliged to provide each patient with a log of the imaging procedures they have undergone over the years. The net effect of these complex factors is that the increased quantity of imaging has not been matched by an increase in rationality of its use, with a rise in cost disproportionate to the increase in quality of care.

These procedures have provided not only immense clinical benefit but also an increase in radiation exposures to patients. Medical radiation from x-rays and nuclear medicine is the largest manmade source of radiation exposure in Western countries. The estimated per capita per year dose in the United States increased approximately 600 % in the last 30 years from about 0.53 milliSievert (mSv) in the early 1980 s to about 3.0 mSv (corresponding to 150 chest x-rays) in 2006 [2]—the latter including about 1.5 mSv per capita from CT scans, 0.8 mSv from nuclear medicine procedures, 0.4 mSv from interventional procedures, and 0.3 mSv from standard radiographic procedures. This increase was due mostly to the nearly 100-fold increase in per capita dose from CT scans and the 5-fold and 2.5-fold increases from nuclear medicine and interventional procedures, respectively [4]. Exposure from medical applications is now higher than that due to the sources of natural background radioactivity [4].

This increase in radiation exposure has underlined the need to include long-term consequences such as cancer in the risk–benefit assessment of diagnostic or therapeutic testing. These risks have two different aspects, the population risk and the individual risk. From the population viewpoint, small individual risks multiplied by millions of examinations become significant population risks [5]. It has been estimated that 72 million CT scans performed in the United States in 2007 (of which at least 4 million were children) can produce at least 2 percent of all cancers in the coming decades [6]. The almost 10 million myocardial perfusion scintigraphies performed each year in the USA will cause about 8,000 new cancers years in the future [7]. Overall, the attributable cancer risk from medical radiation rose from 0.5 % in the early 1980s [8] to 2 % in the years 1991–1996 [5] up to an estimated 5–10 % with current volumes of radiological imaging [9, 10]. Also from the perspective of the individual patient, the risk may be far from negligible, especially in light of the cumulative nature of the damage, in which exam adds to exam, dose to dose, and risk to risk. Moreover, the long-term risks are not always weighed against the benefit of immediate diagnostic evaluation of risk–benefit comparison of various methods. This can lead to repeat tests with significant exposure [11], which may be particularly inappropriate in patients with an underlying benign disease such as chronic stable coronary artery disease. Reports describe cumulative doses from cardiological examinations in which 1/4 cases exceed 100 mSv (5000 chest radiographs) for the individual disease [12], sometimes in the setting of a single admission [13], and even for the same type of exam serially repeated, such as myocardial perfusion scintigraphy [14].

Radiation Exposure Dose in Cardiology Practice

The cardiologists prescribe or directly perform over 50 % of all imaging tests and cardiological practice using high-impact/high radiation exposure dose technology for diagnostic and/or interventional techniques. The median radiation exposure of four very common cardiology examinations (myocardial perfusion imaging, cardiac CT, PCI, cardiac arrhythmia radiofrequency ablation) is 15 mSv, with a wide variation between 3 and 50 mSv [1, 15••].

A decade ago, the “radiation issue” was raised in cardiology, which refers to the need to include long-term cancer risks due to ionizing radiation in the risk–benefit assessment of diagnostic or therapeutic testing in cardiology. It was initially focused on the area of non-invasive diagnosis of coronary artery disease, where the high volume of stress imaging per year, the high dose of perfusion imaging and the availability of competitive non-ionizing techniques highlighted the problem of avoidable long-term cancer risk [16]. This position was disruptive for the imaging practice of cardiology which de facto ignored radiation risks as merely theoretical or insignificant [17], but the reinforcement of an appropriate and justified prescribing attitude was already well rooted in European law [18] and European Commission medical imaging referral guidelines [19].

Within the last 20 years, cardiologists have become modern imaging specialists, responsible for at least 40 % of the radiation exposure dose delivered in medical diagnostics [1, 15••]. Unfortunately, more intensive use is not necessarily correlated with better knowledge, or better outcomes, and the awareness of doses and risks of common cardiological imaging testing is still very limited among cardiologists, interventional cardiologists, radiologists and nuclear cardiologists who prescribe and/or perform these exams [20, 21, 22••]. An important reason for this is that information on the radiation dose of various studies is often difficult to find and—once found—not easy to understand, given the variety of largely exotic measurement terms used (milliampere and megabecquerel, millicuries and rad, dose-area product and centigray) and described with obscure wording [23, 24••]. Poor knowledge among cardiac healthcare professionals suggests that current training in the field is insufficient. However, it should also be easily correctable, with targeted training mediated by communication experts [25] and with the support of user-friendly software [26].

A consequence of the lack of knowledge is that inappropriate aspects to imaging in cardiology is unacceptably high, especially worrisome for procedures with high radiation exposure [1, 15••, 27, 28], and that patient information is vague and insufficient, resulting in an undermined informed consent process.

For all these reasons, the cardiology community can no longer ignore responsible management of radiation imaging. The “linear-no threshold” model of radioprotection accepted by all major scientific societies states that no safe dose exists and the risk increases linearly with increasing radiation dose, and all doses are additive in determining cancer risk [29].

The radiation dose for common cardiological imaging examinations is shown in Table 1, which we also express as multiples of chest radiographs to provide a basis for Ref. [15••]. The dose can be significant: 500 chest x-rays for a stress scintigraphy with sestamibi, 750 chest x-rays for a coronary CT angiography or for an angioplasty with stenting, with large variations from 100 to 2,500 radiographs according to patient type, age of the equipment, protocol, expertise and especially, the awareness of the radiological operator [4]. It is not surprising that in patients with ischemic heart disease a common radiological cumulative average dose reaches 60 mSv (3000 chest X-rays) [12], and is steadily increasing [13] (see Fig. 1).

Radiation Exposure of Interventional Cardiologists

Interventional cardiologists who perform angioplasty and ablations experience a high occupational exposure per year, about three times higher than that of diagnostic radiologists [30]. The high level of radiation exposure for the patient during a single procedure (from 5 to 50 mSv) implies a significant professional exposure for the interventional cardiologist, who needs to operate near the patient and the radiation source. The single dose per procedure of the operator is 1000 times lower than the exposure of the patient, depending upon the shielding employed [31]. Effective occupational doses per procedure range from 0.02 to 38 microSv for a diagnostic catheterization, 0.2–31.2 microSv for a percutaneous coronary intervention, 0.2–9.6 microSv for an ablation, 0.3–17.4 microSv for pacemaker or intracardiac defibrillation implantations [32]. The operator dose may reach even higher values per procedure, up to 50 microSv for dilation of chronic total coronary occlusion and up to 100 microSv for a transcutaneous aortic valvuloplasty [33]. Although the exposure per exam is limited, each operator can perform hundreds (sometimes thousands) of procedures per year, and thus the cumulative dose in a professional lifetime is not negligible. After 30 years of work, an experienced interventional cardiologist in high-volume cath labs with an annual exposure equivalent to around 5 mSv (below apron) per year cumulates a projected professional lifetime attributable excess cancer risk of 1 in 100 [34]. The left side of the operator is more exposed than the right side due to the usual way of working at the right side of the patient [30]. Scattered radiation from the patient can reach the physician’s head, which is often unprotected since the brain was (erroneously) considered in the past radio-resistant, due to its low mitotic activity [35•]. Unfortunately, in the past interventional cardiologists had suboptimal perception of radiation risk and a negligent use of radiation protection tools [36]—with little protection of the body and no protection at all of the head. We now know that radioprotection awareness by operators is effective at reducing professional exposure by 90 % [37]—but until recently this radioprotection was low. The unfortunate consequence has been that the professional exposures of cardiologists and radiologists was unprecedented, exposing this unique cohort of workers (rapidly expanding in number of practitioners since the mid-1980s) to largely avoidable health damage.

Several studies indicated that chronic low doses of ionizing radiation can lead to significant somatic DNA damage in professionally exposed physicians [38, 39]. The recent report of a cluster of 31 brain cancers in interventional cardiologists involving the left side 7 times more frequently than the right side is a striking, albeit as yet small scale, evidence of how patterns of asymmetrically received doses may translate into lateralized cancer risk for exposed professionals [40••]. In general, there is a striking lack of systematically collected data in exposed medical professionals. In 2006 the National Academy of Sciences BEIR VII committee identified as one of the top ten research needs “future occupational radiation studies”, which should include highly exposed populations with full record of exposure [29]. High and unprecedented levels of radiation exposure in the contemporary population of interventional cardiologists and paramedical staff working at the catheterization laboratory clearly represent a challenge and an opportunity, and several studies are now ongoing (in Italy and the USA) on exposed cohorts of interventional cardiologists to assess cancer and non-cancer effects via a classic epidemiology and a more advanced molecular epidemiology approach. Among non-cancer effects, of particular concern are eye cataract [41, 42],

Table 1 Standard average reference doses of common cardiological examinations

Diagnostic procedures	Effective dose (mSv)	Equivalent CXRs	Background radiation (years)
Conventional radiography			
CXR (PA)	0.02	1	2–3 days
Invasive fluoroscopy			
Diagnostic coronary angiography	7 (2–16)	350	2.9
PCI	15 (7–57)	750	6.3
Thoracic angiography (pulmonary or aorta)	5 (4–9)	250	2.1
Abdominal angiography or aortography	12 (4–48)	600	5.0
Pelvic vein embolization	60 (44–78)	3000	25.0
TIPS placement	70 (20–180)	3500	29.3
Aortic valvuloplasty	39	1950	16.2
Dilation chronic coronary occlusion	81 (17.194)	4050	33.7
ETAAAR procedure	76–119	3800–5950	31.6–49.5
Renal angioplasty	54	2700	22.5
Iliac angioplasty	58	2900	24.1
Cardiac electrophysiology			
Diagnostic EP studies	3.2 (1.3–23.9)	160	1.2
Ablation procedure	15.2 (1.6–59.6)	760	5.7
AF	16.6 (6.6–59.2)	830	6.9
AT-AVNRT-AVRT	4.4 (1.6–25)	220	1.8
VT	12.5 (3–$\geq$45)	625	5.2
Regular PM or ICD implant	4 (1.4–17)	200	1.6
CRT implant	22 (2.2–90)	1100	9.1
CT			
64-slice coronary CTA	15 (3–32)	750 (150–1,600)	6.25
Calcium score	3 (1–12)	150	1.25
Nuclear cardiology			
PET F-18 FDG rest (350 MBq, viability)	7	350	2.9
PET Rubidium-82 stress-rest (3700 MBq)	4.6	230	1.9
PET N-13 ammonia stress-rest (1100 MBq)	2.4	120	1
PET $^{15}O–H_2O$ stress-rest (2200 MBq)	2.5	125	1.04
^{99}Tc-labeled erythrocytes (1110 MBq, cardiac function)	7.8	390	3.25
SPECT-^{201}Th stress/redistr. (130 MBq, single injection)	22	1100	91.6
^{201}Thallium stress/rest reinj. (185 MBq, double injection)	40.7	2035	16.9
^{99}Tc-Sestamibi (1100 MBq, 1 day) stress-rest	9.4	470	3.9
^{99}Tc-Tetrofosmin (1500 MBq, 1 day) stress-rest	11.4	570	4.7
Lung Scintigraphy			
^{99}Tc-MAA (185 MBq, lung perfusion)	2	100	0.8
^{133}Xenon (740 MBq, lung ventilation)	0.5	25	0.2
Technegas (50 MBq, lung ventilation)	0.75	40	0.3

AF atrial fibrillation, *AT* atrial tachycardia, *ASD* atrial septal defect, *AVRT* atrio-ventricular reciprocal tachycardia, *CXRs* chest x–rays, *CRT* cardiac resynchronization therapy, *ETAAAR* endovascular thoraco abdominal aortic aneurysm repair, *FDG* fluorodeoxyglucose, *MAA* macro-aggregated albumin, *PA* antero-posterior, *PCI* percutaneous coronary intervention, *TIPS* transjugular intrahepatic portosystemic shunt

brain aging [43] and—of special interest to cardiologists—atherosclerosis. In particular, atherosclerosis has been linked to radiation exposure by considerable epidemiological evidence from hundreds of thousands of subjects [44, 45] and by mechanistic studies showing under controlled in vitro setting a pro-inflammatory effect of very low doses of radiation on endothelial cells [46, 47].

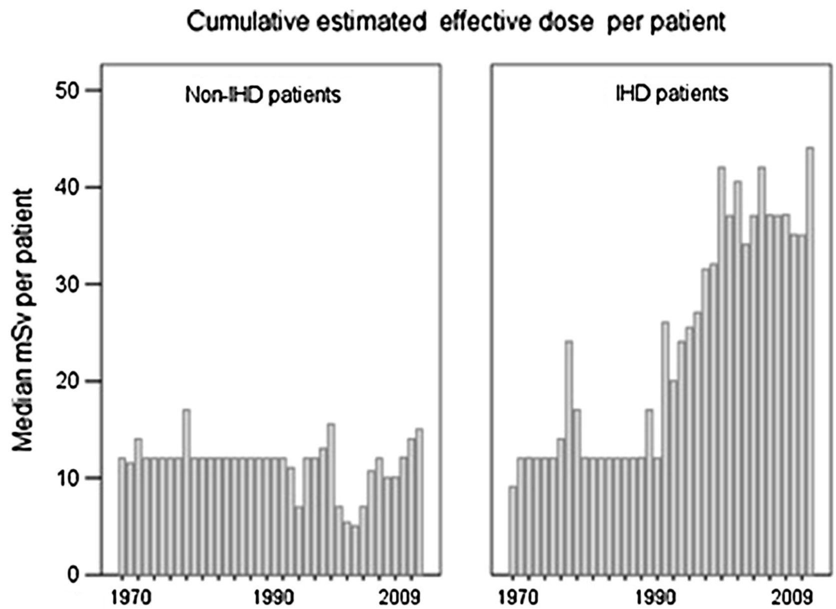

Fig. 1 Secular trends of cardiovascular medical radiation exposure over the last 40 years in in-hospital patients admitted for cardiovascular disease. Radiation exposure is expressed as cumulative estimated effective dose/patient. On the *left* panel the trend of non-ischemic (non-IHD) patients, and on the *right* the one of ischemic (IHD) patients. Modified from Carpeggiani et al., Ref. 13

What Cardiologists have Done

Scientific Societies have a central, proactive role in promoting what is necessary to raise the cultural level of doctors, administrators and patients. Several initiatives were proposed at the international and national level to assess the needs, review standards, and foster clinical research relating to several aspects of radiation issues. In the United States, the social marketing campaign “Choose Wisely” was developed to emphasize the importance of appropriateness in medical practice and interventions to be implemented, especially in the field of imaging, and to limit the practice of inappropriate services, which can be clinically of little value and potentially dangerous [47].

Several software programs have been developed to educate professionals about radiation dose and cancer risk associated with medical imaging procedures, to keep track of radiology and imaging-related exams and procedures, and to provide an estimate of the risk of developing cancer secondary to this radiation [48••].

Innovative dose reduction and dose management solutions and applications have been set by leading providers [49]. Web-based patient radiation dose monitoring software was implemented to capture and report radiation dose directly from any imaging device or PACS and track patients’ cumulative dose over time. These applications could foster awareness and transparency for patients and staff with quantifiable dose value reports. Limited exposure for users and automated system settings and controls can be obtained with the aim of managing and reducing dose while still producing diagnostic quality images.

In January 2014, the European Society of Cardiology joint working group on cardiovascular imaging, interventional cardiology and electrophysiology, published the Joint Position Paper on medical radiation [15••], whose primary purpose is the reduction of image testing required in an inappropriate manner and/or performed with unoptimized x-ray dose. A catalogue of updated reference doses of the most common cardiac exams was provided.

Before prescribing an examination with ionizing radiation the doctor should establish the expected benefit to the patient, and whether the information can be obtained through other radiation-free procedures such as magnetic resonance or ultrasound, particularly in patients at high risk for radiation exposure as children, as well as women during pregnancy.

The communication of doses and risks is often based on a highly specialized technical language, difficult to understand even for practitioners and cardiologists. In radiological informed consent, communication of doses and risks is often absent or difficult to understand even for practitioners and radiologists. As a result, both patients and doctors often are unaware of what they are doing, in terms of doses and radiation risks. The informed consent form should spell out, in tabular form and possibly with a figure, the specific reference dose [14]. After the examination, the dose actually delivered should be stored in the patient’s record. The radiation dose should be reported in mSv, and comprehension may be aided using equivalent number of chest radiographs, with a straightforward numerical description of the cancer risk (Table 2).

Table 2 Terminology that should be used

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

RCR Royal College of Radiology, *CXR* chest x ray, *PCI* percutaneous coronary intervention, *CT* computed tomography

Several rules are provided to improve the imaging clinical practice as listed in Table 3.

All other considerations being equal, it is not recommended to perform tests involving ionizing radiation when the desired information can be obtained with a non-ionizing test with comparable accuracy.

Unnecessary tests should be avoided, such as the ones indicated for cardiac patients from 'Choose Wisely' (such as coronary CT and myocardial perfusion scintigraphy in healthy, asymptomatic, low-risk subjects).

If a test is performed that utilizes ionizing radiation, choose the one with the lowest dose and be aware of the many factors modulating dose.

The radiation delivered dose should be always known and reported in the final report that is delivered to the patient. This is particularly important in cardiology, where the dose for each individual invasive test can vary by a factor of 10 (from 10 to 100 mSv) and where patients often perform the same procedure several times over the course of a remaining lifetime (such as stress myocardial scintigraphy once a year after percutaneous coronary revascularization).

Due to the numerous sources of variability, there is no clear threshold between acceptable and unacceptable exposure for any given examination, but any dose that is not necessary is certainly unacceptable. The dose should be expressed clearly in understandable terms, and we employ multiple x-rays of the chest.

X-rays and g-rays used in radiology and nuclear medicine are proven (class 1) carcinogens, and cardiologists should make every effort to give 'the right imaging exam, with the right dose, to the right patient'.

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 to enhance the safety of patients, doctors, and staff. An informed cardiologist cannot be afraid of the essential and often life-saving use of medical radiation, but must be very afraid of radiation unawareness.

What to do Next

A simple way to improve cardiology management of radiation imaging is to make sure that cardiologists adhere to the indications supported by the world's largest professional association of cardiology, the European Society of Cardiology [15••]. This includes understanding the long-term risk of cancer, proportional to the delivered dose, in the risk–benefit balance.

Collaborative initiatives such as Choose Wisely [48••] and the European Slow Medicine [47] campaigns should be fostered to change imaging practice by increasing awareness, with the goals of eliminating unnecessary imaging exams and lowering doses in those exams that are necessary.

Formal training in radioprotection is a part of the interventional cardiology curriculum and even required by law in many European countries as a prerequisite for entering the cardiac catheterization laboratory. In practice, at least one-fifth of interventional cardiologists did not receive any formal training in radioprotection and, with or without training, their radiation awareness is disappointingly low.

The Interventional Cardiology Society should require invasive cardiologists to be familiar with radiation safety issues in order to obtain Board Certified medical imaging professionals. Radiation management should be a component of their board certifying examinations.

All cardiac cath labs should have a periodic radiation safety program with active participation from the

Table 3 Simple rules to increase the quality of radiation imaging

1. Avoid performing unnecessary radiation imaging procedures
2. Use a non-ionizing comparable test when the desired information can be obtained
3. If you perform a test that utilizes ionizing radiation, choose the one with the lowest dose
4. Be aware of the many factors modulating radiation dose
5. The actual delivered dose should always be recorded and included in patients' records
6. The informed consent form should spell out, in tabular form and possibly with a figure, the specific reference dose and risks
7. There is no clear threshold between acceptable and unacceptable exposure for any given examination, but a dose that is not even considered is certainly unacceptable
8. Systematic clinical audits are necessary to avoid inappropriateness and to increase awareness
9. Applying radioprotection rules is the best way to increase staff and patient safety and is a strategy to reduce cancer risk
10. A good cardiologist cannot be afraid of lifesaving radiation, but must be afraid of radiation unawareness and negligence

physicians, staff and physicists. All interventional cardiologists should apply two basic principles of radiation protection to their practice: reduce radiation exposure to "as low as reasonably achievable" (ALARA); and ensure procedure justification, so that no patient receives radiation without potential benefit. Courses on radioprotection should also be implemented for general practitioners and cardiologists. A limited (one-day) teaching program can dramatically improve awareness regarding radiation dose and risks; it is not necessary to have in-depth knowledge of health physics and radiobiology to become familiar with the essential information needed for the responsible practice of medicine [48••].

Accreditation programs from Cardiology Societies, such as those offered by the American College of Radiology, have to be organized to accredit cardiology facilities that have established their imaging competence, adherence to guidelines, and personnel qualifications, and have also demonstrated their awareness of the need for ongoing quality control involving their equipment and personnel. Facilities must perform audit activity and show that their doses do not exceed established levels.

A repository of national radiation dose-related information should be implemented to provide a mechanism for comparing exams throughout facilities, nationally, regionally and locally. The position statement recommends that patients be given the estimated dose before a procedure, and the actual dose in writing afterwards if they request it. This could become a legal requirement through the European Directive Euratom Law 97/43, with local committee control.

Appropriateness should be mandatory for all prescribers, with a clear understanding of the indications, risks, and costs of the various tests in various clinical situations. A panel of experts could be set up in hospitals in order to establish criteria for access to ionizing and invasive procedures and screening requests, and set priorities. We must prescribe an easier and more harmless exam, avoiding more expensive and risky tests, and provide verification of appropriateness of the prescription. Appropriateness grids, developed by the principal Scientific Societies, accessible in the office, on PC and mobile, should be designed to assist referring physicians in prescribing the best radiology examination for their patients based on guidelines. This will reduce the number of examinations by assuring that the most suitable exam is done first.

Cardiologists should work with manufacturers to obtain innovative technological solutions that reduce doses and risks. Since 2006, all fluoroscopic equipment sold in the United States identifies, records, and displays patient dose during the procedure. This measure should be taken worldwide. Radiological sustainability is becoming a competitive marketing advantage. Standardized open systems using a common standard to display the dose and archive it in digital patient records should be developed. By comparing themselves to others, facilities can determine whether the radiation dose from their procedures is within appropriate ranges.

The responsibility to wear a dosimeter should not be up to the individual but belongs to companies and institutions regarding their employees. At least a single dosimeter should be worn and protective shields used routinely.

The use of ionizing radiation during an imaging procedure should be disclosed to the patients by the ordering provider at the time of ordering, and reinforced by the performing provider team in terms of shared decision-making and should be written in the informed consent.

Radioprotection will be best achieved through close interaction and communication between cardiologists, radiologists, health physicists, radiology technicians, industry and patients.

The implementation of the 3A Intenational Atomic Energy Agency strategy based on: Audit, Awareness, Appropriateness [50••] will lead to redesign the clinical practice in cardiology increasing cardiologists' knowledge. Currently, the employment of this strategy is hampered by a healthcare system that reimburses for volume rather than appropriateness. Action at the political level is fundamental. New models of reimbursement should be implemented to pay for more doctors who prescribe and/or perform the appropriate procedures. A system that pays for quality and not only quantity would be of enormous support to implement appropriateness in clinical practice.

Conclusions

The development of cardiac imaging technologies has changed the practice of cardiology and can save lives. Evaluating patients using medical radiation may be an essential part of modern medicine, but this is not a viable argument for using radiation without wisdom, knowledge, and prudence. Special care should be taken regarding the use of radiation in children, adolescents, and young women, when the radiation risks are higher for any given dose; and in research projects—where radiation should be used only when strictly needed and after detailed information of the associated risk to the patient. It is now imperative within the imaging community to create a framework to safely drive justified and optimized radiation imaging use. Cardiologists have to recognize the importance of radiation management. The concept of minimizing radiation exposure to patients and to practitioners should become standard practice. Improved radiation awareness will lead to a reduction in unnecessary tests and better dose optimization, with consequent reduction of health care costs in cardiology—both direct costs of imaging and indirect, downward costs due to development of avoidable cancers. This process must be accompanied by an innovative model of governance that does not cut health care costs but discourages and underpays inappropriate medicine. The doctor has a duty to know the risks in diagnostic imaging, and the patient has the right to be aware. Better knowledge of radioprotection basics will make our Cardiology wards and imaging laboratories a safer place for both doctors and patients.

Compliance with Ethics Guidelines

Conflict of Interest Dr. Clara Carpeggiani and Dr. Eugenio Picano each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Picano E. Sustainability of medical imaging. Education and debate. BMJ. 2004;328:578–80.
2. Redberg R. The appropriateness imperative. Am Heart J. 2007;154:201–2.
3. Smith-Bindman Rebecca, Miglioretti Diana L, Larson Eric B. Rising use of diagnostic medical imaging in a large integrated health system. Health Aff. 2008;27:1491–502.
4. Mettler FA Jr, Bhargavan M, Faulkner K, Gilley DB, Gray JE, Ibbott GS, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources—1950–2007. Radiology. 2009;253:520–31.
5. Berrington de González A, Darby S. Risk of cancer from diagnostic x-rays: estimates for the UK and 14 other countries. Lancet. 2004;363:345–51.
6. Berrington de Gonzales A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med. 2009;169:2071–7.
7. BerringtondeGonzalez A, Kim KP, Smith-Bindman R, McAreavey D. Myocardial perfusion scans: projected population cancer risks from current levels of use in the United States. Circulation. 2010;122:2403–10.
8. Doll R, Peto R. The causes of cancer: quantitative estimates of avoidable risks of cancer in the United states today. J Natl Cancer Inst. 1981;66:1191–308.
9. Picano E. Risk of cancer from diagnostic x-rays. Lancet. 2004; 363:345–51 (letter).
10. Mc Manus R. National Cancer Institute' s. Berrington outlines risks of radiation. Amy berrington De Gonzalez lecture on: Medical radiation and cancer risk: assessing the price of progress. 15 Feb 2013.
11. Fazel R, Krumholz HM, Wang Y, Ross JS, Chen J, Ting HH, Shah ND, Nasir K, Einstein AJ, Nallamothu BK. Exposure to low-dose ionizing radiation from medical imaging procedures. N Engl J Med. 2009;361(9):849–57.
12. Bedetti G, Botto N, Andreassi MG, Traino C, Vano E, Picano E. Cumulative patient effective dose in cardiology. Br J Radiol. 2008;81:699–705.
13. Carpeggiani C, Landi P, Michelassi C, Marraccini P, Picano E. Trends of increasing medical radiation exposure in a population hospitalized for cardiovascular disease (1970–2009). PLoS One. 2012;7(e50168):1–6.
14. Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. JAMA. 2007;298(3):317–23.
15. •• 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;35:665–72. *A position paper of all imaging subspecialties of the European Society of Cardiology to present an updated catalogue of doses for all major cardiology imaging tests for cardiologists working in cardiology wards and imaging labs.*
16. Picano E. Stress echocardiography: a historical perspective. Am J Med. 2003;114:126–30, Special Article.
17. Abbott BG, Zaret BL. Contemporary cardiology and hysteric nucleophobia. Am J Med. 2003;114(2):131–4.
18. Council Directive 97/43/Euratom of 30 June 1997 on health protection of individuals against the dangers of ionising radiation in relation to medical exposure, and repealing Directive 84/466/Euratom. Official Journal of the European Communities 1997, L 180:0022-7.
19. European Commission on Radiation Protection 118: Referral guidelines for imaging. http://ec.europa.eu/energy/nuclear/radioprotection/Publication/doc/118_en.pdf. Accessed 21 Sept 2014.
20. Correia MJ, Hellies A, Andreassi MG, Ghelarducci B, Picano E. Lack of radiological awareness among physicians working in a tertiary-care cardiological centre. Int J Cardiol. 2005;103:307–11.

21. Kim C, Vasaiwala S, Haque F, Pratap K, Vidovich MI. Radiation safety among cardiology fellows. Am J Cardiol. 2010;106:125–8.
22. •• Einstein AJ, Tilkemeier P, Fazel R, Rakotoarivelo H, Shaw LJ, American Society of Nuclear Cardiology. Radiation safety in nuclear cardiology-current knowledge and practice: results from the 2011 American Society of Nuclear Cardiology member survey. JAMA Intern Med. 2013;173(11):1021–3. *Inappropriateness at nuclear-cardiology examinations are guided by a lack of known radiological knowledge*.
23. Picano E. Informed consent and communication of risk from radiological and nuclear medicine examinations: how to escape from a communication inferno. BMJ. 2004;329:849–51.
24. •• Terranova G, Ferro M, Carpeggiani C, Recchia V, Braga L, Semelka RC, Picano E. Low quality and lack of clarity of current informed consent forms in cardiology: how to improve them. JACC Cardiovasc Imaging. 2012;5(6):649–55. *A new informed consent form with a highly sophisticated attempt to inform our patients.*
25. Carpeggiani C, Kraft G, Caramella D, Semelka R, Picano E. Radioprotection (un)awareness in cardiologists, and how to improve it. Int J Cardiovasc Imaging. 2012;28:1369–74.
26. Carpeggiani C, Paterni M, Caramella D, Vano E, Semelka RC, Picano E. A novel tool for user-friendly estimation of natural, diagnostic and professional radiation risk: Radio-Risk software. Eur J Radiol. 2012;81:3563–7.
27. Patel MR, Spertus JA, Brindis RG, Hendel RC, Douglas PS, Peterson ED, et al. American College of Cardiology Foundation ACCF proposed method for evaluating the appropriateness of cardiovascular imaging. J Am Coll Cardiol. 2005;46:1606–13.
28. Carpeggiani C, Marraccini P, Morales MA, Prediletto R, Landi P, Picano E. Inappropriateness of cardiovascular radiological imaging testing in a tertiary care referral center. PLoS One. 2013;8(11):e81161.
29. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, National Research Council, Health risks from exposure to low levels of ionizing radiation BEIR VII phase 2, The National Academies Press, Washington, DC (2006).
30. 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.
31. Kim KP, Miller DL, Balter S, Kleinerman RA, Linet MS, Kwon D, Simon SL. Occupational radiation doses to operators performing cardiac catheterization procedures. Health Phys. 2008;94:211–22.
32. Vano E. Radiation exposure to cardiologists: how it could be reduced. Heart. 2003;89:1123–4.
33. Picano E, Vano E. Radiation exposure as an occupational hazard. EuroIntervention. 2012;8(6):649–53.
34. 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.
35. • Picano E, Vano E, Domenici L, Bottai M, Thierry-Chef I. Cancer and non-cancer brain and eye effects of chronic low-dose ionizing radiation exposure. BMC Cancer. 2012;12:157. doi:10.1186/1471-2407-12-157. *The description of radio-machismo in the cath-lab. Those who need protection most are also often the more negligent in adopting radioprotection defenses.*
36. Watson RM. Radiation exposure: clueless in the cath lab, or sayonara ALARA. Cathet Cardiovasc Diagn. 1997;42:126–7.
37. Vaño E, Gonzalez L, Fernandez JM, Alfonso F, Macaya C. Occupational radiation doses in interventional cardiology: a 15-year follow-up. Br J Radiol. 2006;79:383–8.
38. Andreassi MG, Cioppa A, Botto N, Joksic G, Manfredi S, Federici C, Ostojic M, Rubino P, Picano E. Somatic DNA damage in interventional cardiologists: a case-control study. FASEB J. 2005;19:998–9.
39. Andreassi MG. The biological effects of diagnostic cardiac imaging on chronically exposed physicians: the importance of being non-ionizing. Cardiovasc Ultrasound. 2004;2:25. Review.
40. •• Roguin A, Goldstein J, Bar O, Goldstein JA. Brain and neck tumors among physicians performing interventional procedures. Am J Cardiol. 2013;111(9):1368–72. *Brain tumors are described for the first time in interventional cath lab staff.*
41. Annals of the ICRP: Early and late effects of radiation in normal tissues and organs: threshold doses for tissue reactions and other non-cancer effects of radiation in a radiation protection context.: public draft; 2012. published at ICRP website: www.icrp.org. Description of early and late effects of radiation in normal tissues and organs.
42. Ciraj-Bjelac O, Rehani MM, Sim KH, Liew HB, Vano E, Kleiman NJ. Risk for radiation-induced cataract for staff in interventional cardiology: is there reason for concern? Catheter Cardiovasc Interv. 2010;76:826–34.
43. Tonacci A, Baldus G, Corda D, Piccaluga E, Andreassi M, Cremonesi A, Guagliumi G, Picano E. Olfactory non-cancer effects of exposure to ionizing radiation in staff working in the cardiac catheterization laboratory. Int J Cardiol. 2014;171(3):461–3. doi:10.1016/j.ijcard.2013.12.223 Epub 2014 Jan 10.
44. Little MP, Azizova TV, Bazyka D, Bouffler SD, Cardis E, Chekin S, Chumak VV, Cucinotta FA, de Vathaire F, Hall P, Harrison JD, Hildebrandt G, Ivanov V, Kashchee VV, Klymenko SV, Kreuzer M, Laurent O, Ozasa K, Schneider T, Tapio S, Andrew M, Taylor AM, Tzoulaki I, Vandoolaeghe WL, Wakeford R, Zablotska LB, Zhang W, Lipshultz SE. Systematic review and meta-analysis of circulatory disease from exposure to low-level ionizing radiation and estimates of potential population mortality risks. Environ Health Perspect. 2012;120:1503–11.
45. Darby SC, Ewertz M, Hall P, Darby SC. Ischemic heart disease after breast cancer radiotherapy. N Engl J Med. 2013;368(26):2523–4.
46. Borghini A, Gianicolo EA, Picano E, Andreassi MG. Ionizing radiation and atherosclerosis: current knowledge and future challenges. Atherosclerosis. 2013;230(1):40–7.
47. Cervelli T, Panetta D, Navarra T, Andreassi MG, Basta G, Galli A, Salvadori PA, Picano E, Del Turco S. Effects of single and fractionated low-dose irradiation on vascular endothelial cells. Atherosclerosis. 2014;235(2):510–8.
48. •• Rao VM, Levin DC. The overuse of diagnostic imaging and the Choosing Wisely Initiative. Ann Intern Med. 2012;157:574–76. *An example of a serial marketing campaign to increase radiation awareness in patients and doctors: less is more.*
49. IAEA (2010) Enhances Patient Radiation Safety in Medical Diagnosis and Treatment. Available: http://www.iaea.org/NewsCenter/News/2010/radsafety.html.
50. •• Malone J, Guleria R, Craven C, Horton P, Järvinen H, Mayo J, O'reilly G, Picano E, Remedios D, Le Heron J, Rehani M, Holmberg O, Czarwinski R. Justification of diagnostic medical exposures: some practical issues. Report of an International Atomic Energy Agency Consultation. Br J Radiol. 2012;85(1013):523–38. *The triple A's strategy: Awareness, Audit and Appropriateness to increase sensitization and optimization in wards and imaging labs.*