

Radiation dose in imaging of coronary artery disease: current status and perspectives

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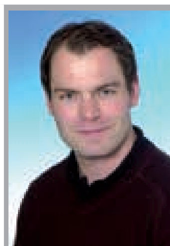
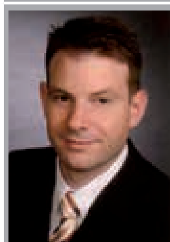


Johannes Rixe
Author for correspondence:
Department of Cardiology/ Cardiac Imaging, Kerckhoff Heart Centre, Benekestrasse 2–8, D-61231 Bad Nauheim, Germany
Tel.: +49 6032 996 2460
Fax: +49 6032 996 2848
j.rixe@kerckhoff-klinik.de



Andreas Rolf
Department of Cardiology/ Cardiac Imaging, Kerckhoff Heart Centre, Benekestrasse 2–8, D-61231 Bad Nauheim, Germany

The number of cardiac diagnostic procedures that make use of ionizing radiation has increased rapidly over the last 20 years. Even though angiographic procedures play a central role in clinical cardiology and have contributed significantly to the decrease in morbidity and mortality from coronary artery disease, it is important to remember that they are not without risk to both patients as well as examiners. Since the average effective dose of a posteroanterior chest x-ray is approximately 0.02 milliSieverts (mSv), the effective doses of cardiac imaging techniques cannot be considered trivial.

In addition, there have been tremendous advances in cardiac imaging in general as well as imaging of coronary artery disease in particular over recent years. Having served as the 'gold standard' for coronary imaging for decades, invasive coronary angiography is actually being challenged by different noninvasive imaging techniques that are suitable for sensitive detection of coronary artery disease and are more precise than ordinary treadmill testing. Next to established techniques, such as myocardial perfusion imaging using nuclear techniques, new modalities are emerging, most importantly the direct visualization of coronary arteries using multidetector-computed tomography. Most of these techniques use ionizing radiation.

Thus, physicians ordering or performing cardiac imaging must be, to at least some extent, familiar with both the dosimetry of radiation from cardiac diagnostic tests and possible methods to minimize dose. This editorial presents an overview of imaging techniques requiring ionizing radiation and identifies possible methods to reduce radiation dose exposure in clinical practice.

Estimation of radiation dose

It should be noted that values of radiation exposure for particular patients or particular studies are always statistical estimates resulting from calculations, since there is no directly measurable quantity that adequately reflects radiation exposure [1,2]. Nevertheless, the most adequate approach to describe risks associated with ionizing radiation is to describe it in terms of dose. Adding up the weighted equivalent doses of all organs, the effective dose (E) is computed. Since it is a single number, E – which is measured in mSv – has become the most frequently used quantity to compare the radiation risks of different diagnostic tests. Nevertheless, the effective dose must be applied with caution: its application is defined for populations, not for the estimation of radiation dose for one examination on one single patient. Accordingly, it is, in itself, not ideally suited to describe the individual estimated cancer risk attributed to an examination using ionizing radiation, as it is always subject to uncertainty [3,4].

Radiation dose from conventional coronary angiography

The mean estimated dose in conventional coronary angiography varies significantly in the literature, ranging from 2.3 mSv to a maximum estimated dose of 22.7 mSv for diagnostic angiography only [5–7]. Coronary angiography and percutaneous coronary intervention together may at least add up to a largely variable estimated dose of 5.4 to 41 mSv [8–10]. The United Nations Scientific Committee on the Effects of Atomic Radiation gives a standard value of 7 mSv for conventional coronary angiography only, but in general it should be noted that in the setting of coronary interventional procedures with long fluoroscopy times, a much higher estimated value may be delivered: an estimated dose of approximately 15 mSv for a percutaneous coronary intervention has been reported by a scientific advisory of the American Heart Association (AHA) [11]. Furthermore, radiation dose in conventional angiography is largely dependant on parameters

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such as personnel experience, use of radiation-reducing techniques such as reducing fluoroscopy and acquisition frame rates, procedural complexity and laboratory equipment [12–16]. Moreover, angiographic procedures performed with a transradial approach tend to result in higher estimated doses than a transfemoral access, and left anterior oblique projections are generally associated with a higher dose than right anterior oblique or posteroanterior views [17].

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The wide variance of estimated dose related to conventional coronary angiography underlines the numerous possibilities to reduce radiation dose in the clinical setting. Amongst these are the employment of the slowest fluoroscopy and fluorography frame rates that maintain diagnostic image quality, the minimization of fluoroscopy/fluorography times, as well as minimizing the distance from patient to image detector and x-ray tube, and the number of views [18].

Radiation dose from nuclear cardiac imaging

The effective radiation dose administered in a nuclear myocardial perfusion scan is fundamentally dependant on the protocol chosen for the individual patient and the tracer or radiopharmaceutical agent used for the examination. Since there is no locally fixed source of ionizing radiation used in this setting, it becomes even more difficult to estimate the radiation dose for a nuclear scan: in fact, the estimation is performed by compilation of different dose coefficients, determined by biokinetic models quantifying the distribution and metabolism of ionizing agents in the (human) body. These models use organ- and radionuclide-specific activity data over time, as well as data on absorption of energy in selected target organs [19]. Nevertheless, certain assumptions on radiation dose of nuclear studies can be made: the AHA reports an average dose of approximately 9 mSv for a sestamibi 1-day stress/rest myocardial perfusion scan and 41 mSv for a thallium stress/rest myocardial perfusion scan [11]. However, current guidelines of the American Society of Nuclear Cardiology report levels of approximately 11 mSv for a ^{99m}Tc sestamibi stress/rest protocol and an estimated dose of 32 mSv for a ^{201}Tl stress/reinjection protocol [20]. Therefore, effective doses used in myocardial perfusion studies using nuclear techniques are by no means trivial, and they vary significantly: single-injection protocols achieve the lowest dose estimates, whereas dual-isotope studies, which are relatively common for outpatient settings, usually have the highest effective dose estimates of approximately 29 mSv. The lowest doses can be achieved with positron emission tomography protocols using ^{13}N ammonia and ^{15}O water, for which the estimated dose values are approximately 2.4 and 2.5 mSv [8]. Although the estimated dose for nuclear techniques appears to be relatively high, there are not so many possibilities to reduce the radiation burden in these studies: the most evident one is the use of stress-first or even stress-only scanning protocols for selected patients with a low pretest probability for coronary artery disease. Unfortunately, only 9% of sites performing nuclear cardiology in the USA offer single-injection protocols, and only 4% of nuclear studies actually use a single-injection protocol of a ^{99m}Tc agent [8].

Radiation dose from cardiac computed tomography

Coronary computed tomography angiography (coronary CTA) is the most recently developed technique in cardiac imaging. However, its application in clinical routines has so far not only been limited by the ongoing question of reimbursement, but also by reports suggesting that the radiation dose associated with a coronary CTA examination is potentially extensive.

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In fact, there have been relatively poor data records on radiation dose estimates of cardiac CT. However, the recently published international survey including 50 study sites worldwide, the PROTECTION I study, has changed this situation: in this study including almost 2000 patients, the median effective dose associated with coronary CTA was 12 mSv, which is at a slightly higher level than conventional angiography, but at the same level as a ^{99m}Tc sestamibi stress/rest protocol [8,21]. The spectrum of median radiation dose estimates reported in this study – which is 5 to 30 mSv – is striking, since it reflects a phenomenon also found in conventional coronary angiography as well as nuclear cardiac imaging: estimated effective doses vary significantly, no matter what kind of imaging technique is chosen. However, for coronary CTA it can be said that there are very effective tools to substantially reduce the dose.

These include, amongst others, electrocardiographically controlled tube current modulation or so called 'ECG pulsing', the use of 100-kV scanning protocols for nonobese patients or even sequential scanning using prospective ECG-triggering for patients with a stable and low-frequent sinus rhythm. Studies could prove that these techniques have great potential to significantly reduce the estimated dose down to less than 4 mSv for patients routinely examined with a 100-kV protocol and retrospectively gated coronary CTA, or even down to 2.1 mSv or lower using prospectively ECG-triggered coronary CTA [22–25]. Further on, the PROTECTION I trial could show that the implementation of dose-saving algorithms does not have any relevant influence on image quality. Nevertheless, there is one major limitation of these effective techniques: only 73% of the PROTECTION I population were examined using ECG-pulsing, and the subgroups of patients undergoing coronary CTA using a 100-kV protocol or prospective ECG-triggering were even smaller: 5 and 6%, respectively [21]. This shows, in spite of many possibilities to reduce radiation dose in coronary CTA, that there are very few investigators who know how to apply these techniques.

Conclusion

Radiation dose exposure to patients varies significantly not only among different cardiac imaging modalities, but also between different protocols of one and the same imaging technique. While dose in conventional coronary angiography is largely dependent on parameters such as operator experience and procedural complexity, it varies with different tracers in nuclear imaging and with the simple and effective implementation of dose-saving scanning techniques for selected patients in coronary CTA.

"Understanding the dosimetry of cardiac imaging protocols is therefore a first step towards minimization of risk to patients while still providing optimal diagnostic accuracy."

Even if the effect of a certain exposure to ionizing radiation may be extremely difficult to determine, it nevertheless should be emphasized that careful attention to technique, including the use of dose-reduction strategies, can minimize dose to patients as well as to investigating personnel. Thus, selection of individual protocols for individual patients must always be determined from an approach guided by the ALARA philosophy ('As Low As Reasonably Achievable'). Understanding the dosimetry of cardiac imaging protocols is therefore a first step towards minimization of risk to patients while still providing optimal diagnostic accuracy.

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Bibliography

1 Amis ES Jr, Butler PF, Applegate KE *et al.*: American College of Radiology white paper on radiation dose in medicine. *J. Am. Coll. Radiol.* 4, 272–284 (2007).

2 Stabin MG: Developments in the internal dosimetry of radiopharmaceuticals. *Radiat. Prot. Dosimetry* 105, 575–580 (2003).

3 Einstein AJ, Sanz J, Dellegrottaglie S *et al.*: Radiation dose and cancer risk estimates in 16-slice computed tomography coronary angiography. *J. Nucl. Cardiol.* 15, 232–240 (2008).

4 Martin CJ: Effective dose: how should it be applied to medical exposures? *Br. J. Radiol.* 80, 639–647 (2007).

5 Delichas M, Psarrakos K, Molyvda-Athanassopoulou E *et al.*: Radiation exposure to cardiologists performing interventional cardiology procedures. *Eur. J. Radiol.* 48, 268–273 (2003).

6 Delichas MG, Psarrakos K, Molyvda-Athanassopoulou E, Giannoglou G, Hatziioannou K, Papanastassiou E: Radiation doses to patients undergoing coronary angiography and percutaneous transluminal coronary angioplasty. *Radiat. Prot. Dosimetry* 103, 149–154 (2003).

7 Hunold P, Vogt FM, Schmermund A *et al.*: Radiation exposure during cardiac CT: effective doses at multi-detector row CT and electron-beam CT. *Radiology* 226, 145–152 (2003).

8 Einstein AJ, Moser KW, Thompson RC, Cerqueira MD, Henzlova MJ: Radiation dose to patients from cardiac diagnostic imaging. *Circulation* 116, 1290–1305 (2007).

9 Neofotistou V: Review of patient dosimetry in cardiology. *Radiat. Prot. Dosimetry* 94, 177–182 (2001).

10 Neofotistou V, Tsapaki V, Kottou S, Schreiner-Karoussou A, Vano E: Does digital imaging decrease patient dose? A pilot study and review of the literature. *Radiat. Prot. Dosimetry* 117, 204–210 (2005).

11 Gerber TC, Carr JJ, Arai AE *et al.*: Ionizing radiation in cardiac imaging: a science advisory from the American Heart Association Committee on Cardiac Imaging of the Council on Clinical Cardiology and Committee on Cardiovascular Imaging and Intervention of the Council on Cardiovascular Radiology and Intervention. *Circulation* 119, 1056–1165 (2009).

12 Kuon E, Dahm JB, Schmitt M, Glaser C, Gefeller O, Pfahlberg A: Short communication: time of day influences patient radiation exposure from percutaneous cardiac interventions. *Br. J. Radiol.* 76, 189–191 (2003).

13 Kuon E, Dorn C, Schmitt M, Dahm JB: Radiation dose reduction in invasive cardiology by restriction to adequate instead of optimized picture quality. *Health Phys.* 84, 626–631 (2003).

14 Kuon E, Glaser C, Dahm JB: Effective techniques for reduction of radiation dosage to patients undergoing invasive cardiac procedures. *Br. J. Radiol.* 76, 406–413 (2003).

15 Padovani R, Bernardi G, Malisan MR, Vano E, Morocutti G, Fioretti PM: Patient dose related to the complexity of interventional cardiology procedures. *Radiat. Prot. Dosimetry* 94, 189–192 (2001).

16 Tsapaki V, Kottou S, Vano E *et al.*: Patient dose values in a dedicated Greek cardiac centre. *Br. J. Radiol.* 76, 726–730 (2003).

17 Sandborg M, Fransson SG, Pettersson H: Evaluation of patient-absorbed doses during coronary angiography and intervention by femoral and radial artery access. *Eur. Radiol.* 14, 653–658 (2004).

18 Hirshfeld JW Jr, Balter S, Brinker JA *et al.*: ACCF/AHA/HRS/SCAI clinical competence statement on physician knowledge to optimize patient safety and image quality in fluoroscopically guided invasive cardiovascular procedures: a report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training. *Circulation* 111, 511–532 (2005).

19 Einstein AJ: Radiation risk from coronary artery disease imaging: how do different diagnostic tests compare? *Heart* 94, 1519–1521 (2008).

20 Hendel RC, Wackers FJ, Berman DS *et al.*: American Society of Nuclear Cardiology consensus statement: reporting of radionuclide myocardial perfusion imaging studies. *J. Nucl. Cardiol.* 13, E152–E156 (2006).

21 Hausleiter J, Meyer T, Hermann F *et al.*: Estimated radiation dose associated with cardiac CT angiography. *JAMA* 301, 500–507 (2009).

22 Earls JP, Berman EL, Urban BA *et al.*: Prospectively gated transverse coronary CT angiography versus retrospectively gated helical technique: improved image quality and reduced radiation dose. *Radiology* 246, 742–753 (2008).

23 Hausleiter J, Meyer T, Hadamitzky M *et al.*: Radiation dose estimates from cardiac multislice computed tomography in daily practice: impact of different scanning protocols on effective dose estimates. *Circulation* 113, 1305–1310 (2006).

24 Husmann L, Valenta I, Gaemperli O *et al.*: Feasibility of low-dose coronary CT angiography: first experience with prospective ECG-gating. *Eur. Heart J.* 29, 191–197 (2008).

25 Rixe J, Conradi G, Rolf A *et al.*: Radiation dose exposure of computed tomography coronary angiography: comparison of dual-source, 16-slice and 64-slice CT. *Heart* 95, 1337–1342 (2009).