Radiation Risks From Cardiovascular Imaging Tests

Felix G. Meinel, MD; John W. Nance Jr, MD; Brett S. Harris, PhD; Carlo N. De Cecco, MD; Philip Costello, MD; U. Joseph Schoepf, MD

A 62-year-old retired account executive complains of diffuse chest pain with moderate activity. His hypercholesterolemia and hypertension have been well controlled. On treadmill testing, he fatigues at a heart rate of 140 bpm. You discuss the option of a pharmacological stress radionuclide study, but his reaction is concern. When questioned, he divulges that he and his wife had recently read an article in a popular lifestyle magazine that warned that "such tests cause cancer."

The concept of radiation, a physical entity that penetrates the human body yet defies perception, is emotionally laden and triggers archetypical angst in many. In recent years, a considerable number of alarmist reports have raised the specter of cancer risk from commonly prescribed imaging tests.[1–3] These publications have received widespread dissemination in the lay media, often in a sensationalist manner, so medical professionals are increasingly confronted by the above patient scenario and its many variations. Public concerns have prompted the US Food and Drug Administration to devote considerable attention to radiation protection, and some states have mandated reporting of radiation doses from imaging examinations. The purposes of this Clinician Update are to summarize the evidence on stochastic risks from diagnostic cardiovascular imaging tests involving ionizing radiation, to enable a realistic appraisal of risk, and to facilitate a rational dialog between healthcare providers and their patients.

Is There Direct Evidence of Cancer Risks From Imaging Tests Involving Ionizing Radiation?

Direct evidence for an association between radiation from medical imaging and cancer induction is exceedingly scarce. The most convincing evidence is derived from 2 recent, large, epidemiological studies in young, predominantly pediatric populations.[4,5] Based on ≈10 year follow-up of 178 000 and 680 000 children and adolescents, respectively, these studies report an incremental risk of ≈2 to 6 excess cancers per 10 000 children and young adults from computed tomography (CT). Direct evidence of an association between radiation from medical imaging and cancer induction in a general adult population does not exist. Much larger cohorts would likely have to be analyzed to detect any incremental increases in cancer rates because ≈38% of women and 44% of men in the United States will develop cancer during their lifetime.[6]

Cancer Risks From Imaging Tests: Estimates and Extrapolations

The overwhelming majority of recent reports on cancer risks from medical imaging are not based on actual epidemiological observations but are derived from extrapolation of risk estimates to low levels of radiation and multiplication with a large number of exposed individuals. Estimates of cancer risks from diagnostic imaging are most commonly based on the Biological Effects of Ionizing Radiation (BEIR VII) report.[7] Among experiences with other (eg, occupational) sources of radiation exposure, this report chiefly takes into account observations from the atomic bomb blasts in Hiroshima and

From the Department of Radiology and Radiological Science (F.G.M., J.W.N., B.S.H., C.N.D.C., P.C., U.J.S.) and Division of Cardiology, Department of Medicine (U.J.S.), Medical University of South Carolina, Charleston; Institute for Clinical Radiology, Ludwig-Maximilians-University Hospital, Munich, Germany (F.G.M.); Russell H. Morgan Department of Radiology and Radiological Science, Johns Hopkins Hospital, Baltimore, MD (J.W.N.); and Departments of Radiological Sciences, Oncology, and Pathology, University of Rome "Sapienza"--Polo Pontino, Latina, Italy (C.N.D.C.).

Correspondence to U. Joseph Schoepf, MD, FAHA, Medical University of South Carolina, 25 Courtenay Dr, Charleston, SC 29425-2260. E-mail schoepf@musc.edu

(*Circulation.* **2014;130:442-445.**)

***Circulation* is available at http://circ.ahajournals.org** **DOI: 10.1161/CIRCULATIONAHA.113.005340**

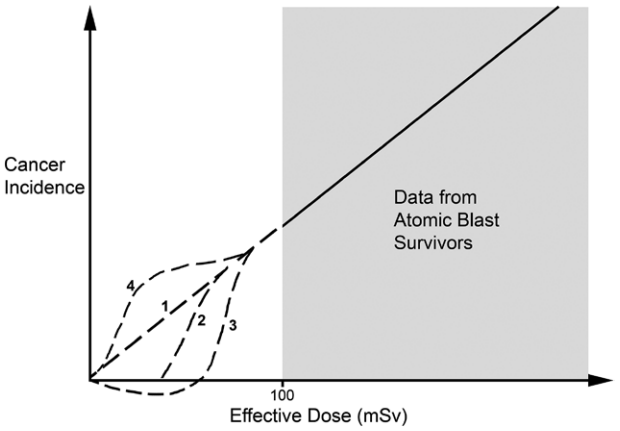

Figure 1. Extrapolating cancer risks from atomic blasts to low radiation doses. There is evidence from atomic blast survivors for a linear relationship between radiation dose and cancer incidence above a radiation dose of 100 mSv (solid line). Various hypotheses for the extrapolation of radiation risk to lower radiation doses are shown as dotted lines. The linear no-threshold model (1) is most widely used, but others have suggested that there may be a threshold dose below which radiation is harmless (2), protective (3), or disproportionately harmful (4).

Nagasaki that describe a statistically significant increase in cancer incidence in Japanese survivors exposed to radiation doses of ≥100 mSv. The BEIR VII report tabulates estimates for the lifetime attributable risk of cancer from exposure to this 100-mSv dose level. The reported confidence intervals are wide, allowing considerable variability in the extrapolation of risk toward the lower or higher limits of confidence.

Diagnostic medical imaging procedures ordinarily are associated with radiation doses well below 100 mSv. The extrapolation of radiation risks to such low levels of radiation is problematic and subject to substantial uncertainties. These extrapolations are based on the hypothesis that cancer risk increases linearly with radiation dose (linear no-threshold model; Figure 1). For lack of better data, the linear no-threshold model currently represents a reasonable, conservative compromise and thus is commonly used in radiation protection policy. However, it remains uncertain whether this model accurately reflects the biological effect of low-level radiation and is suitable for prediction of cancer risks from medical imaging.[8]

Radiation Dose Associated With Cardiovascular Imaging Tests

The effective dose values for diagnostic imaging tests (Figure 2) are most meaningful compared with the annual background radiation from natural sources, which is ≈3 mSv in the United States.

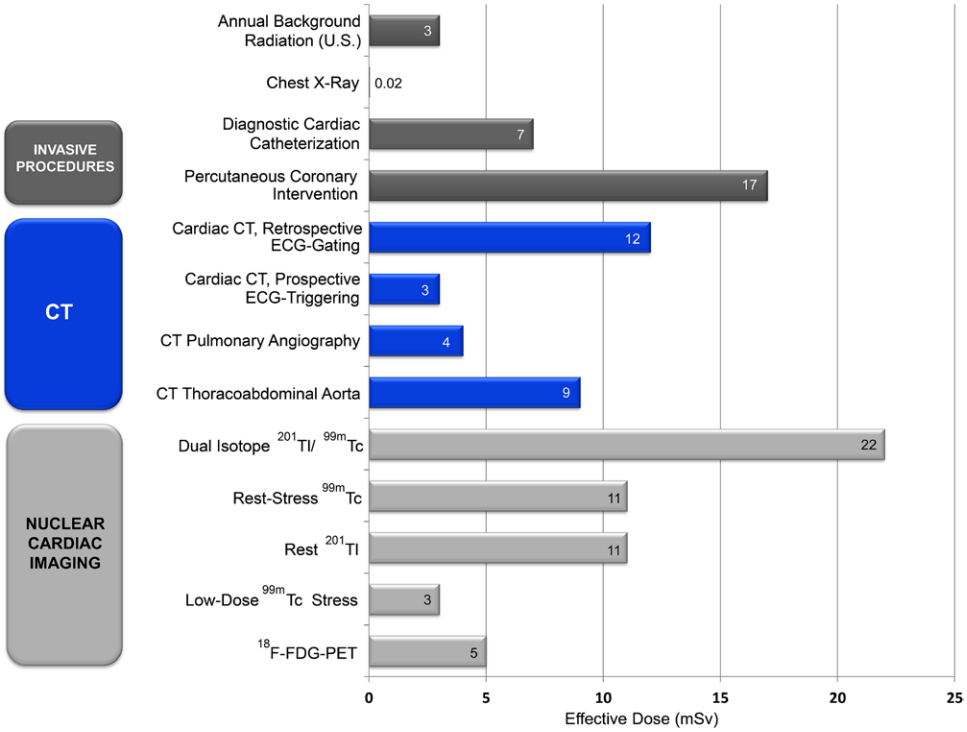

Figure 2. Effective radiation doses associated with common cardiovascular imaging tests. The average effective radiation doses of common cardiovascular imaging tests with current instruments and techniques are shown in relation to the average background radiation exposure from natural sources in the United States. CT indicates computed tomography; and ^{18}F-FDG-PET, ^{18}F-doxyglucose positron emission tomography.

The imaging techniques used in clinical practice for suspected cardiovascular disease have undergone substantial technological improvements in recent years, which have markedly reduced the associated radiation dose. In cardiac CT, average radiation doses fell from 10 to 20 mSv to ≈3 mSv,[9] for example, by restricting the application of radiation to diagnostically meaningful cardiac phases. The radiation dose from CT for suspected pulmonary embolism was reduced from 15 mSv[10] to 2 to 5 mSv,[11] for example, by algorithms that automatically adapt the radiation output to the respective portion of the chest along the scanned anatomic volume. Single-photon-emission CT for myocardial perfusion imaging has seen similar reductions. In many situations, a low-dose ^{99m}Tc-stress-only protocol provides sufficient diagnostic information at an effective dose of 3 mSv compared with the 22-mSv dose of a classic stress-rest dual-isotope protocol.[10,12] The average radiation dose of cardiac[18] Fluorodeoxyglucose positron emission tomography has decreased from 14 mSv[10] to 5 mSv,[12] for example, by more stringent application of weight-based radiotracer dosing and more sensitive detector technologies.

Patients with cardiovascular disease frequently undergo repeated tests and procedures, and the cumulative radiation exposure has been estimated to average 16 mSv for a 3-year follow-up period and 64 mSv over a 20-year period.[13] When interpreting these numbers, one must consider that the effective dose is a useful measure to compare radiation dose between imaging modalities but is not intended to estimate the risk of a specific test in an individual patient.[14]

Radiation Risks for Patients Undergoing Cardiovascular Imaging Examinations

When general estimations of radiation risks are applied to cardiovascular imaging examinations, both the characteristics of the patient population and the spectrum of cardiovascular diseases have to be considered. The majority of cardiovascular imaging tests are performed in adults >50 years of age. The potential harm from radiation in these individuals is substantially lower than in children and young adults because of both decreased vulnerability to radiation of mature tissues with increased age and a shorter life expectancy, allowing less time for cancers to manifest.

Suspected or known coronary, cerebrovascular, or peripheral artery disease, pulmonary embolism, and aortic pathologies, all disorders with substantial morbidity and mortality, are among the most common indications for cardiovascular imaging tests. The radiation risks from these tests have to be weighed against the risks of missing or delaying the diagnosis of such conditions or inaccurately assessing their distribution or severity. Even in young patients, the risk of death resulting from underlying morbidity is more than an order of magnitude greater than the estimated risk of death resulting from long-term radiation-induced cancer.[15] Thus, this consideration is likely even more relevant in older patients with known or suspected cardiovascular disease. Cardiovascular imaging tests have excellent diagnostic accuracy for the detection of these pathologies, and effective therapeutic options exist. In the setting of an appropriate indication, not performing a cardiovascular imaging test places the patient at substantial risk by withholding the clinical benefits of imaging for guiding therapeutic management. Furthermore, the latency period for projections of radiation-induced malignancies can span several decades, whereas suspected cardiovascular disease regularly poses an imminent threat to the patient.

Comparison With Risks of Everyday Life

In discussions of radiation risks with patients, it can often be helpful to provide perspective vis-à-vis risks of everyday life.[16] The stochastic extrapolated lifetime risk of developing fatal cancer from radiation received during a cardiovascular imaging examination (0.05% or 1 in 2000)[17] is lower than the lifetime risk of drowning (1 in 1112) or dying in a pedestrian accident (1 in 749) and >10-fold lower than the lifetime risk of dying in a motor vehicle accident (1 in 108; Figure 3). Nevertheless, these everyday risks are commonly perceived as very low and

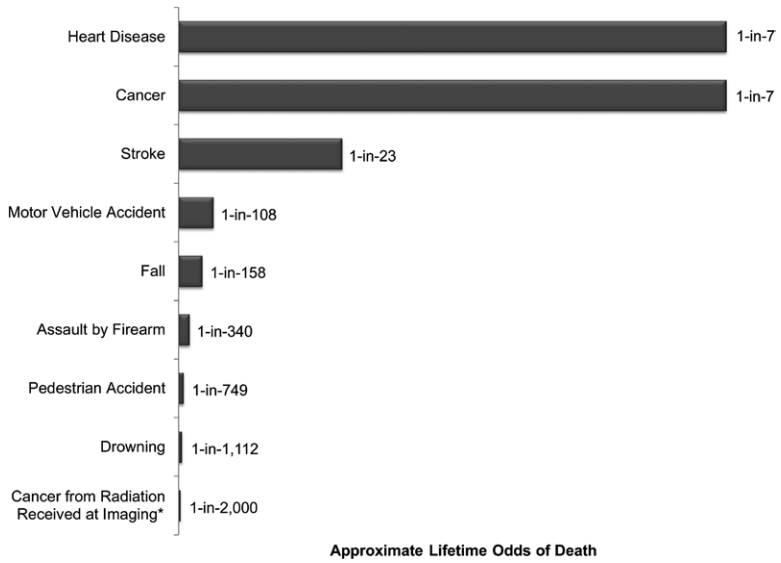

Figure 3. Lifetime odds of dying of selected causes in the United States. Odds of dying as a result of various causes as provided by the National Safety Council[18] are contrasted with the extrapolated stochastic lifetime odds of developing fatal cancer from a diagnostic imaging examination with an effective radiation dose of 10 mSv, assuming a linear no-threshold model.[17]

do not typically prevent an individual from swimming, crossing the street, or getting into a car.

Statements and Recommendation of Professional Associations

The American Association of Physicists in Medicine promulgated a professional statement urging that the discussion of risks related to radiation dose from medical imaging be accompanied by acknowledgment of the benefits of the procedures.[19] In keeping with the BEIR VII assumptions, the American Association of Physicists in Medicine considers risks of medical imaging at effective doses <50 mSv for single procedures or <100 mSv for multiple procedures over short time periods as too low to be epidemiologically detectable and potentially nonexistent. An almost identical position statement has been issued by the Health Physics Society.[20]

Conclusions

Because of our uncertainties about the stochastic effects of radiation, it is reasonable to operate under the assumption that there is risk, however small. Accordingly, we should use all means at our disposal to keep radiation exposure as low as reasonably achievable without compromising the diagnostic information gained from the examination. Fear of radiation should not prevent a patient from undergoing a medically necessary imaging examination.

Acknowledgments

We thank Walter Huda, PhD, for his critical review and helpful comments.

Disclosures

Dr Schoepf is a consultant for or receives research support from Bayer, Bracco, GE, Medrad, and Siemens. The other authors report no conflicts.

References

1. Smith-Bindman R. Is computed tomography safe? *N Engl J Med*. 2010;363:1–4.
2. Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. *JAMA*. 2007;298:317–323.
3. Berrington de Gonzalez A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, Land C. Projected cancer risks from computed tomographic scans performed in the United States in 2007. *Arch Intern Med*. 2009;169:2071–2077.
4. Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, Howe NL, Ronckers CM, Rajaraman P, Sir Craft AW, Parker L, Berrington de González A. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*. 2012;380:499–505.
5. Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, Giles GG, Wallace AB, Anderson PR, Guiver TA, McGale P, Cain TM, Dowty JG, Bickerstaffe AC, Darby SC. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. *BMJ*. 2013;346:f2360.
6. American Cancer Society. Lifetime risk of developing or dying from cancer. http://www.cancer.org/cancer/cancerbasics/lifetime-probability-of-developing-or-dying-from-cancer. Accessed September 19, 2013.
7. National Research Council. *Health Risks From Exposure to Low Levels of Ionizing Radiation: BEIR VII---Phase 2: Committee to Assess Health Risks From Exposure to Low Levels of Ionizing Radiation*. Washington, DC: National Academies Press; 2006.
8. Hendee WR, O'Connor MK. Radiation risks of medical imaging: separating fact from fantasy. *Radiology*. 2012;264:312–321.
9. Fink C, Krissak R, Henzler T, Lechel U, Brix G, Takx RA, Nance JW, Abro JA, Schoenberg SO, Schoepf UJ. Radiation dose at coronary CT angiography: second-generation dual-source CT versus single-source 64-MDCT and first-generation dual-source CT. *AJR Am J Roentgenol*. 2011;196:W550–W557.
10. Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology*. 2008;248:254–263.
11. De Zordo T, von Lutterotti K, Dejaco C, Soegner PF, Frank R, Aigner F, Klauser AS, Pechlaner C, Schoepf UJ, Jaschke WR, Feuchtner GM. Comparison of image quality and radiation dose of different pulmonary CTA protocols on a 128-slice CT: high-pitch dual source CT, dual energy CT and conventional spiral CT. *Eur Radiol*. 2012;22:279–286.
12. Einstein AJ, Knuuti J. Cardiac imaging: does radiation matter? *Eur Heart J*. 2012;33:573–578.
13. Chen J, Einstein AJ, Fazel R, Krumholz HM, Wang Y, Ross JS, Ting HH, Shah ND, Nasir K, Nallamothu BK. Cumulative exposure to ionizing radiation from diagnostic and therapeutic cardiac imaging procedures: a population-based analysis. *J Am Coll Cardiol*. 2010;56:702–711.
14. Laskey WK, Feinendegen LE, Neumann RD, Dilsizian V. Low-level ionizing radiation from noninvasive cardiac imaging: can we extrapolate estimated risks from epidemiologic data to the clinical setting? *JACC Cardiovasc Imaging*. 2010;3:517–524.
15. Zondervan RL, Hahn PF, Sadow CA, Liu B, Lee SI. Body CT scanning in young adults: examination indications, patient outcomes, and risk of radiation-induced cancer. *Radiology*. 2013;267:460–469.
16. McCollough CH, Guimarães L, Fletcher JG. In defense of body CT. *AJR Am J Roentgenol*. 2009;193:28–39.
17. Gerber TC, Carr JJ, Arai AE, Dixon RL, Ferrari VA, Gomes AS, Heller GV, McCollough CH, McNitt-Gray MF, Mettler FA, Mieres JH, Morin RL, Yester MV. 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*. 2009;119:1056–1065.
18. National Security Council. Injury, death, and fatality statistics. http://www.nsc.org/news_resources/injury_and_death_statistics/Pages/InjuryDeathStatistics.aspx. Accessed November 4, 2013.
19. American Association of Physicists in Medicine. AAPM position statement on radiation risks from medical imaging procedures (policy number PP 25-A). 2011. http://www.aapm.org/org/policies/. Accessed June 21, 2013.
20. Health Physics Society. Radiation risk in perspective: position statement of the Health Physics Society. July 2010. http://hps.org/documents/risk_ps010-2.pdf. Accessed September 19, 2013.