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REVIEW

STATE-OF-THE-ART PAPER

Radiobiology in Cardiovascular Imaging

Pat Zanzonico, PhD, Lawrence Dauer, PhD, H. William Strauss, MD

ABSTRACT

The introduction of ionizing radiation in medicine revolutionized the diagnosis and treatment of disease and dramatically improved and continues to improve the quality of health care. Cardiovascular imaging and medical imaging in general, however, are associated with a range of radiobiologic effects, including, in rare instances, moderate to severe skin damage resulting from cardiac fluoroscopy. For the dose range associated with diagnostic imaging (corresponding to effective doses on the order of 10 mSv [1 rem]), the possible effects are stochastic in nature and largely theoretical. The most notable of these effects, of course, is the possible increase in cancer risk. The current review addresses radiobiology relevant to cardiovascular imaging, with particular emphasis on radiation induction of cancer, including consideration of the linear nonthreshold dose-response model and of alternative models such as radiation hormesis.
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The use of ionizing radiation in medicine has revolutionized the diagnosis and treatment of disease. Radiation-based imaging techniques continue to improve the quality of health care. As a result of the documented value of diagnostic imaging, the use of these techniques has grown dramatically over the last several decades (1). A recent American College of Radiology white paper (2) reported that the annual number of nuclear medicine procedures saw a 3-fold increase (from 7 million to 20 million) and that the annual number of computed tomography (CT) procedures was increased 20-fold (from 3 million to 60 million) between 1985 and 2005 in the United States. This increase has led to an increase in exposure of the population to radiation, which in turn, raises concern over the radiogenic risks associated with medical imaging. Reports of such risks, some alarmist in tone (3), in both the scientific and the lay media have led to thoughtful critical evaluation of imaging procedures, with technical optimization, justification (i.e., elimination of truly unnecessary procedures), and minimization of imaging doses without compromising the diagnostic information being sought. However, the excessive emphasis on radiogenic cancer risk can create the misconception that not only is radiation the only risk to be considered in medical imaging but also that the benefit of imaging procedures may be outweighed by the risk. It is in this context that the current review addresses radiobiology relevant to cardiovascular imaging, with particular emphasis on radiation induction of cancer, including consideration of the linear nonthreshold dose-response model and of alternative models such as radiation hormesis. Additional recent articles on the radiobiologic effects of cardiovascular imaging are included in the references (4–6).

STOCHASTIC AND DETERMINISTIC EFFECTS OF RADIATION

The radiobiologic effects of radiation are often distinguished as either stochastic (i.e., statistical) or nonstochastic (i.e., deterministic). The distinction between stochastic and deterministic effects is perhaps best understood in terms of their respective probability-dose and severity-dose relationships, as

From the Memorial Sloan Kettering Cancer Center, New York, New York. The authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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illustrated in Figure 1. A stochastic effect is characterized by the absence of a threshold, meaning that any radiation dose above background is associated with a corresponding finite (or non-zero) increase in the probability above background of the effect occurring. As the dose increases above background, this excess probability also increases. However, the severity of the effect does not increase with dose; that is, the severity of a stochastic effect is independent of dose. Stochastic effects include radiation-induced carcinogenesis and germ cell mutagenesis and are generally associated with low-level (e.g., diagnostic) exposures. A deterministic effect is characterized by a well-defined threshold dose, meaning that the probability of the effect occurring does not increase above the background probability until the threshold is exceeded. However, once the threshold dose is exceeded, the severity as well as the excess probability of the effect increase with dose, with essentially all irradiated individuals exhibiting the effect (i.e., the probability reaches 100%) at sufficiently high doses; the dose-dependent probability increases in a sigmoidal fashion typical of pharmacological dose-response curves. The range of effects of radiation on skin typifies deterministic effects, as discussed below. Deterministic effects are generally associated with high-level (e.g., therapeutic) radiation exposures.

At the cellular level, stochastic effects presumably result from nonlethal genetic mutations, and in principle, the clonogenic proliferation of a single mutated cell may progress to a tumor. Although it is a gross oversimplification (and one which ignores immunosurveillance and other homeostatic functions), this effect is mechanistically consistent with the presumed absence of a threshold dose for a stochastic effect such as cancer induction. Induction of a deterministic effect, on the other hand, requires elimination by apoptosis or other cell-killing mechanisms of a critical mass of cells within 1 or more functional cell compartments in order to induce a demonstrable clinical effect. This is consistent with a non-zero threshold for such an effect and with the dose dependency of the severity as well as the probability of deterministic effects.

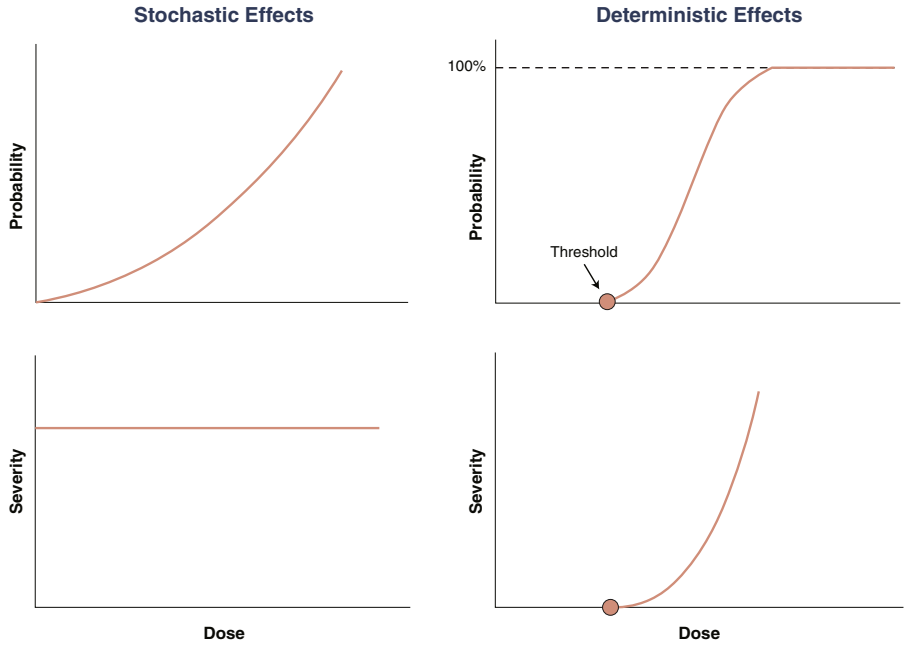
For cardiovascular imaging, the radiation doses, expressed in terms of effective dose, are typically <10 mSv (1 rem); organ absorbed doses range from 10 to 50 mGy (1 to 5 radiation dose [rad]), with most organ doses at the lower end of this range (6) (Figure 2). For cardiovascular imaging, as for

ABBREVIATIONS AND ACRONYMS

ICRP = International Commission on Radiological Protection

NCRP = National Council on Radiation Protection and Measurements

FIGURE 1 Radiation Effects



Stylized probability-dose and severity-dose relationships for stochastic and deterministic effects.