The Role of the Medical Physicist in Managing Radiation Dose and Communicating Risk in CT

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OBJECTIVE. This article discusses the discrepancy between the public's perception of radiation risk and the actual risks from low doses of ionizing radiation. Resources from the medical physics community that can be used to manage dose levels in CT examinations are reviewed. An approach is described for presenting information about radiation risks and benefits to patients that supports dose management and acknowledges that risks from the low doses of radiation used in medical imaging either are too low to be reliably detected or do not exist.

CONCLUSION. When asked by a patient or a patient's family about the risk of radiation, it is incumbent on each of us to remember the tenet of justification first and foremost: If the examination is needed, the benefit will outweigh any small or potentially nonexistent risk. The next responsibility is to image the patient with care by adjusting the delivered dose to the patient size and to the diagnostic task.

Although there is a perception among some physicians and patients that the low doses of ionizing radiation associated with medical imaging examinations, particularly with CT, are dangerous, this inaccurate perception is not consistent with current consensus opinions from radiation protection and medical physics organizations [1–5]. Hence, imaging professionals are left with a dilemma: If we emphasize the ALARA (as low as reasonably achievable) principle (which we should) and focus on dose management, we inadvertently reinforce the perception that CT doses are dangerous; after all, why would we work so hard to reduce CT doses if they are not dangerous? The goals of this article are to discuss this topic, review resources from the medical physics community that exist to manage dose levels in CT, and suggest approaches for presenting radiation risk and benefit information that support the ALARA principle and acknowledge the overall low or nonexistent risk of CT.

Public Perceptions of Radiation

Conveying information to medical personnel and patients about the small or nonexistent risks associated with low doses of radiation can be difficult, in part because of their unfamiliarity with radiation dose measurement units (e.g., millirads [mrad], milligrays [mGy] and, millisieverts [mSv]) and also in part because of the general belief in society that radiation is to be feared. Even our comic books reinforce the perception that the invisible forces of radiation can do strange and powerful things to the human body. This perception that all radiation is dangerous is negatively impacting patient care. For example, patients ask medical providers on a routine basis about the safety of CT, and physicians and radiology departments are increasingly encountering patients who are unwilling to undergo a medically appropriate CT examination because of their fear of the radiation. Clear and accurate scientific information is needed regarding the radiation doses used in medical imaging and any associated potential for adverse health effects. An in-depth review of these topics can be found elsewhere [6].

Risks From Low Doses of Ionizing Radiation

Most people are unfamiliar with the radiation dose that each of us is exposed to simply by living on Earth. In the United States, the effective dose from natural sources in our environment (e.g., radon gas, cosmic rays, building materials) ranges from 1 to 20 mSv/y, with an average of approximately 3 mSv/y. However, there is no direct evidence of harm from these radiation dose levels. In

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fact, residents of states with higher background radiation have lower cancer rates relative to those from states with lower background radiation levels [7], and residents of regions in the world with very high background radiation levels (100–260 mSv/y) have been shown to have no increase in cancer risk compared with people living in areas with lower background dose levels [8].

Cohorts of individuals exposed to radiation, including workers in the nuclear power industry and the atomic bomb survivors, have been studied extensively to estimate the effects of low doses of radiation. The largest study evaluated a cohort of approximately 500,000 occupationally exposed workers across 15 countries who received cumulative effective doses in the range of 30–60 mSv. No increase in cancer mortality compared with the general population was found after the Canadian data, which were found to be inaccurate, were removed from the study [9, 10]. In atomic bomb survivors, analyses of cancer incidence and mortality have also not shown an increased risk from acute radiation doses below 100 mSv [11, 12] (Fig. 1).

Because of the lack of documentation of the long-term effects in the low-dose range (< 100 mSv), U.S. and international radiation protection organizations have repeatedly cautioned that risk estimates below 100 mSv have huge uncertainties. Similarly, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), in their 2012 report to the United Nations General Assembly, specifically noted that an increase in the incidence of adverse health effects in populations cannot be attributed to exposure to radiation doses at levels that are typical of global background levels of radiation—that is, 1–20 mSv/y [2]. In response to concerns raised by some authors that the large numbers of CT examinations performed each year will result in a measurable increase in cancer incidence, UNSCEAR, the International Commission on Radiological Protection (ICRP) [3], the National Council on Radiation Protection and Measurements (NCRP), the Health Physics Society (HPS) [4], and the American Association of Physicists in Medicine (AAPM) [5] explicitly stated that it is inappropriate to multiply highly uncertain risk estimates for radiation doses comparable to natural background levels by the millions of individuals undergoing CT and other imaging studies to predict radiation-induced health effects. Unfortunately, this inappropriate arithmetic is precisely what was done in several articles published in prestigious medical journals [13, 14], and alarmist reporting on these articles by major media outlets has caused great concern for medical professionals and for patients and their families.

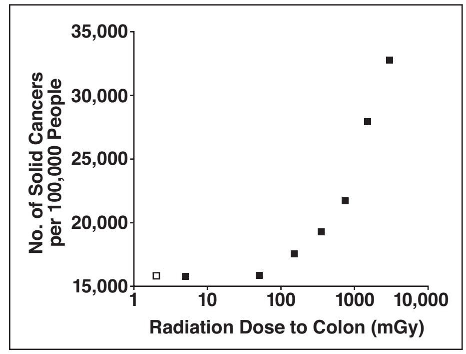

Fig. 1—Solid squares show data from the atomic bomb survivors. Open square shows cancer rates in individuals from Hiroshima and Nagasaki who were not in town at time of bombings. All data from [1]. Increase in cancers above rate of nonexposed individuals was observed only above 100 mSv. Because these were whole-body exposures, 100 mGy = 100 mSv.

Implications for Medical Imaging

Given these circumstances, it is essential that physicians in all specialties are educated regarding the radiation dose levels associated with medical imaging (Table 1) and the lack of evidence for any adverse health effects at these low-dose levels. This understanding will reassure medical providers that they can order and patients that they can undergo a medically appropriate imaging examination without concerns regarding radiation-induced health effects. That is, they will understand that a medically essential examination should always be performed [3].

Roles of the Medical Physicist in Managing Dose and Communicating Risk

A medical physicist is a certified medical professional with education and clinical training in the safe and effective application of radiation in the fields of medical imaging and radiation therapy. They are certified by the American Board of Radiology. Many radiologists, however, do not have the opportunity to work directly with a medical physicist and hence may not be aware of the role that a qualified medical physicist can play in managing radiation doses in medical imaging.

First, a qualified medical physicist is an essential member of the team in an accredited imaging practice. In addition to testing the performance of the equipment, medical physicists are required to participate in protocol review and optimization; and serve as members of a dose management team. Medical physicists routinely monitor a practice's doses against national benchmarks, such as those provided in the Dose Index Registry of the American College of Radiology (ACR) [15]. Medical physicists should be available for consultation with patients or family members, and they often play an active role in the technical and radiation safety education of physicians, including radiologists and radiologic technologists.

Second, many medical physicists are active volunteers in their primary professional organization, the AAPM. With approximately 8400 members, the AAPM works to promote patient safety in medical imaging and radiation oncology through numerous education, research, and professional initiatives.

TABLE 1: Typical Effective Dose Values Associated With Medical Imaging Examinations

Examination	Effective Dose (mSv)
Radiography and fluoroscopy	
Hand radiography	< 0.1
Dental bitewings	< 0.1
Chest radiography	0.1–0.2
Mammography	0.3–0.6
Lumbar spine radiography	0.5–1.5
Barium enema	3–6
Coronary angiography	5–10
CT	
Head CT	0.5–2
Chest CT	2–6
Abdominal CT	2–7
Pelvic CT	2–4
Coronary artery calcification CT	0.1–2
Coronary CT angiography	1–15
Radionuclide imaging	
Lung scanning	2–3
Bone scanning	3–5
Myocardial perfusion scanning	12–14

Alliance for Quality CT

One activity of major relevance to safety in CT is the work of the AAPM's Working Group on the Standardization of CT Nomenclature and Protocols [16], which has recently taken on a more representative name: the Alliance for Quality CT (AQCT). The AQCT's membership includes a core group of medical physicists whose primary expertise is in the field of CT and radiation dosimetry and safety. They are joined by representatives of the ACR, American Society of Radiologic Technologists (ASRT), Society for Pediatric Radiology, U.S. Food and Drug Administration, and DICOM and representatives from seven manufacturers of CT scanners (GE Healthcare, Hitachi Medical Systems, NeuroLogica, Neusoft Medical Systems, Philips Healthcare, Siemens Healthcare, and Toshiba Medical Systems). The AQCT was formed in 2010 in response to growing concerns about the safe and effective use of CT. Since then, the AQCT has published representative CT protocols for a range of common examinations [16], recommendations and educational slides regarding the use of the Dose Check feature [17, 18] mandated by Standard XR-25 of the National Electrical Manufacturers Association (NEMA) [19], and a lexicon of the terminology used by the different manufacturers so that users of one system can understand the parameters' names of a different manufacturer (e.g., scout vs topogram vs preview) [20]. They have also produced educational slides that describe all the parameters that affect the dose delivered from CT. All of these resources are free and are available on the AAPM website [16].

AAPM's Position Statement on Radiation Risks From Medical Imaging Procedures

Medical physicists assist the medical imaging community in providing safe and effective CT examinations. Their effort to manage dose carefully is consistent with the AAPM's Position Statement on Radiation Risks from Medical Imaging Procedures [5], which states the following:

> The American Association of Physicists in Medicine (AAPM) acknowledges that medical imaging procedures should be appropriate and conducted at the lowest radiation dose consistent with acquisition of the desired information. Discussion of risks related to radiation dose from medical imaging procedures should be accompanied by acknowledgement of the benefits of the procedures. Risks of medical imaging at effective doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be nonexistent. Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged. These predictions are harmful because they lead to sensationalistic articles in the public media that cause some patients and parents to refuse medical imaging procedures, placing them at substantial risk by not receiving the clinical benefits of the prescribed procedures.
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> AAPM members continually strive to improve medical imaging by lowering radiation levels and maximizing benefits of imaging procedures involving ionizing radiation.

The essential elements of the AAPM position statement are a prudent and pragmatic approach to the dilemma discussed earlier; that is, why would one work to reduce radiation dose when low doses of radiation (e.g., < 100 mSv) have not been shown to increase long-term risks? There are five essential elements. The first essential element is to support the radiation safety tenet of justification (i.e., medical imaging procedures should be appropriate). The second essential element is to commit to patient safety in medical imaging by acknowledging the need to keep doses as low as reasonably achievable while also maintaining the diagnostic benefit of the examination or procedure (i.e., ALARA principle). This element supports the radiation safety tenet of optimization. The third essential element is to acknowledge that the risks of medical imaging are small and may, in fact, be nonexistent. This element is consistent with the consensus statements of the International Organization for Medical Physics, UNSCEAR, ICRP, HPS, and AAPM [1–5]. The fourth essential element is to emphasize that the discussion of risk needs to be accompanied by discussion of medical benefit. The fifth essential element is to express concern about the reporting of predicted cancers as though they are fact and, in particular, to express concern that some patients are not receiving appropriate medical care because of their fears of radiation exaggerated by these speculative reports.

Discussion

There have been too many polarizing articles on the topic of radiation dose in CT. These articles serve only to perpetuate the discussion, leaving patients and their families with the impression that this issue is a deeply concerning one. Rather, the correct approach is one that includes the five elements noted earlier. These elements neither brush aside the potential for risk (i.e., do not endorse imaging indiscriminately or without the necessary expertise in dose management) nor propagate the alarmist message that CT is dangerous. The BEIR VII report [21] notes that statistical limitations make it difficult to evaluate cancer risks in humans at doses below 100 mSv and that at such low doses there is uncertainty as to whether a relationship exists between radiation and disease, let alone a causative relationship.

Above the 100- to 200-mSv range, it is known that the risk of long-term effects is real, albeit small. Below these doses, the risk is difficult, if not impossible, to prove. The risk may be real, or it may not exist. Either way, the risk is certainly small compared with the well-documented benefits derived from justified medical imaging.

Walking this middle road—neither being alarmist nor being careless—is what the AAPM and so many other imaging organizations recommend (e.g., AAPM, ACR, ASRT, and Radiological Society of North America). When asked by a patient or a patient's family about the risk of radiation, it is incumbent on each of us to remember the tenet of justification first and foremost: If the examination is needed, the benefit will outweigh any small or potentially nonexistent risk. The next responsibility is to image the patient with care by adjusting the delivered dose to the patient size and to the diagnostic task. The resources made available by the efforts of the AQCT can be of assistance with this latter charge. If imaging professionals have additional questions about this topic, I recommend that they seek out a qualified medical physicist and avail themselves of his or her expertise.

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