AJR FOCUS ON:

Challenges in Radiation Protection of Patients for the 21st Century

Madan M. Rehani[1]

OBJECTIVE. The purpose of this article is to presage the upcoming challenges in the area of radiation protection of patients in imaging for different stakeholders, such as dosimetrists, radiation biologists, patients, referring physicians, radiologists, radiographers, medical physicists, and manufacturers.

CONCLUSION. Most of the challenges facing different stakeholders are actually based on the contribution required from industry; thus, manufacturers play the greatest role in making patients safer in this century.

The 21st century has brought along with it newer challenges in radiation protection of patients that never existed before. It is likely that there never was a time in the history of medical imaging when, for thousands of patients, the individual patient dose received through diagnostic imaging exceeded an effective dose of 100 mSv. Skin injury to patients undergoing CT is a new finding of the current century, because there were no such incidents with CT machines, whether due to operator error, machine malfunction, or overuse, from 1972 until 2005. Patients undergoing more than 10 CT scans within a few years was unheard of during the last century. It is no wonder that interest in radiation protection of patients has been unparalleled in recent years.

A few decades ago, radiography was the main technique in radiology departments, along with a small component of fluoroscopy. The usage pattern of CT from its introduction in 1972 until almost 2000 was not what it is today. Earlier practice included thick slices of 10 mm, with an interslice gap of 10 mm or more, and a scan area confined mostly to either the abdomen or the pelvis, rather than the combined abdomen and pelvis. Thin and sometimes overlapping slices, as used today, did not exist previously. The radiation dose involved in any radiographic examination is small and has been reduced by many fold in the last century (Table 1). Even if a patient had undergone a few dozen radiographs, the radiation dose involved was still what he or she would have received in a couple of CT scans.

This century's sea change occurred with the development of MDCT scanners, which enhanced diagnostic capabilities immensely, reduced scanning time substantially to just a single breath-hold for chest CT, and made CT both patient friendly and the physician's preferred tool. CT was also added to nuclear imaging systems to create hybrid scanners (PET/CT and SPECT/CT).

According to the National Commission on Radiation Protection and Measurements estimates for 2006 [1], the percentage contributions to the U.S. population's radiation dose for medical exposure from different imaging modalities are CT (49%), nuclear medicine (26%), interventional fluoroscopy (14%), and conventional radiography and fluoroscopy (11%). Thus, the major radiation dose contribution comes from CT. At the global level, according to the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), CT contributes to about 35% of collective dose, even though it accounts for only 5% of all diagnostic and interventional procedures [2]. CT is also the major contributor at the individual patient dose level. Another significant contributor to individual patient radiation dose is hybrid imaging, with the combined dose from the radiopharmaceutical plus the CT scan reaching an effective dose of 10 mSv or more for each examination.

A new challenge has emerged in recent years with regard to communication with patients and the public about radiation risks associated with medical imaging. This challenge

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[1]International Atomic Energy Agency, Radiation Protection of Patients Unit, Vienna International Centre, PO Box 200, A-1400 Vienna, Austria. Address correspondence to M. M. Rehani (M.Rehani@iaea.org or madan.rehani@gmail.com).

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emerged as a result of the media highlighting radiation incidents [3]. Unfortunately, professionals are speaking with different voices that leave patients confused. Although all international organizations and major national organizations dealing with radiation effects, such as the International Commission on Radiologic Protection, UNSCEAR, the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (the Beir Committee), and the National Commission on Radiation Protection and Measurements, endorse the linear nonthreshold theory, there are other groups with different views [4]. Differences within the profession are fine and are bound to exist in many situations where there cannot be clear evidence, but there is a need to communicate with the public by means of a common voice, stating where there is agreement and where there is not, rather than claiming one's own position as the correct one.

The challenges that face us in this century can best be visualized by thinking "out of the box" and placing oneself in an ideal world, unaffected by current-day predicaments. This article conceptualizes these challenges for different stakeholders.

TABLE 1: Trends in Average Effective Doses Resulting From Selected Diagnostic Medical Examinations in Countries of Health Care Level 1

Examination	Years			
	1970–1979	1980–1990	1991–1996	1997–2007
Chest radiography	0.25	0.14	0.14	0.07
Abdomen x-ray	1.9	1.1	0.53	0.82
Mammography	1.8	1	0.51	0.26
CT scan	1.3	4.4	8.8	7.4
Angiography	9.2	6.8	12	9.3

Note—Data are average effective dose per examination in millisieverts. Data are summarized from [2].

Dosimetrists

There is a need to eliminate the use of multiple units of measurement for radiation dose—that is, millisieverts for effective dose and dose equivalent, and milligrays for organ and surface dose. A unit scheme should be designed such that each unit immediately brings to mind the corresponding dose to which it refers, somewhat like degrees Celsius for temperature, kilometer for distance, and so on.

Radiation Biologists

One can envision and presage the development of biologic indicators that can reveal the radiation dose a person has obtained and even the history of exposure, somewhat akin to the hemoglobin A1c test, which indicates the percentage of hemoglobin that has become glycated (stuck to sugar). Similar measures will be needed for organ doses for the eye, breast, and heart, to name a few. The theory behind the hemoglobin A1c test is that our red blood cells live an average of 3 months, so if we measure the amount of sugar stuck to these cells (which is what the hemoglobin A1c test does), it will give us an idea of how much sugar has been in the blood over the previous 3 months. A similar procedure, even though it may currently be wishful thinking, needs to be established as a vision, to achieve progress. Once again, thinking out of the box is needed to solve current-day problems. There could be biologic parameters as risk indicators that may dilute the need for dose assessment. Thus, effect rather than cause could be the focus. With reports emerging about the cancer incidence in children who have undergone several CT scans, there is the need to further establish an authentic rationale on the radiation effects resulting from diagnostic exposures.

Patient

The challenge lies in creating a system that will build confidence in a patient and alleviate worries about the justified use of a radiologic examination that the doctor has just written for the patient. There should be performance indicators accessible to everyone to show that the imaging facility performs the examination with the lowest radiation dose while maintaining diagnostic quality of the image. A card that allows a patient access to his or her radiation exposure history, along with implications of the dose, would provide an added element to confidence building and alleviating patients' worries. The key is confidence-building measures based on outcome (dose and quality) rather than tools.

Referring Physician

Imagine a system where every referral for a radiologic examination is fully justified. Tools needed to achieve this ideal might include a referring physician having access to all previous radiologic examinations a patient has undergone, perhaps even on the physician's mobile telephone. Furthermore, easy access to a system that facilitates making a rational decision on the appropriate examination for a particular individual, somewhat similar to the decision support system that is currently in place, would be needed. Alerts and checks to warn physicians of an inappropriate referral or suggesting the need for consultation with imaging specialists should be built-in features.

Radiologist

One can envisage a system where the request for every radiologic examination has been scrutinized by the electronic referral system such that, when it reaches the radiologist, appropriateness has already been addressed or the need for review and advice is indicated. Radiation dose is mentioned on each examination on images produced by the radiographer. Images of a patient's previous examinations are available in parallel. The report indicates that the dose was within and much lower than the reference level. An integrated grading system for radiologist practice quality could also be in place.

Radiographer

The systems should provide alert messages whenever image quality higher than needed is chosen, whenever the area being exposed is larger than optimal, when a patient has declared pregnancy, and also when there is a need to ascertain pregnancy. The machine should, by default, provide indication-based protocols and an automatic exposure system for all modalities with dose display. Comparison of the dose with reference levels and a feedback mechanism should be in place. Daily statistics of dose performance indicating the number of cases and their doses relative to reference levels should be available routinely.

Medical Physicist

There is a need to make the transition from entrance dose and the dose to a representative phantom to a patient dose. Medical physicists should have the ability to obtain the radiation exposure history of an individual patient at the click of a mouse and the tools to estimate cancer risk for organs, rather than the current whole body dose–based approach. The medical physicist should receive alerts remotely whenever a patient receives a radiation dose that is above a defined level and whenever an imaging machine is not performing within stipulated tolerance levels of exposure parameters. Finally, to assess the level of optimization, medical physicists should have access to daily statistics on dose performance for each imaging examination, indicating the dose (with patient weight accounted for) and, wherever available, the indication for the examination, measured against corresponding reference levels.

Manufacturers

It is encouraging that manufacturers are vying with each other to reduce radiation dose for their imaging systems and that there is momentum to achieve the goal of submillisievert doses for CT of any part of the body, not just cardiac CT [5]. It can be anticipated that developments in detectors and electronics that yield submillisievert-dose CT will also help in reducing patient doses for interventional procedures. Most of the challenges already discussed for all stakeholders are actually based on the contribution required from industry; thus, manufacturers play the greatest role in making patients safer.

Tools for Optimization of Radiation Protection

Diagnostic reference levels have been a practical tool for optimization and should be available for all examinations, not just for frequently performed ones. Although diagnostic reference levels were developed for detecting "outliers" (i.e., the 25% of cases that fall beyond the third quartile), the need for optimization of the 75% of cases that fall within the third quartile should be stressed. The "as low as reasonably achievable" principle is important in this respect, but there will be a need to develop further mechanisms to achieve optimization within diagnostic reference levels. An important aspect that tends to get missed is radiation dose variation as a function of time. If one asks how much was the typical dose that a patient received from CT in the 1980s, 1990s, and 2000s and how much a patient receives now, it is not easy to obtain this information. UNSCEAR is an organization with a mandate to review radiation usage and its effect in the world, and it has provided information that is summarized in Table 1. There is a need to monitor change over time, and an article in an upcoming issue of *AJR* will give an example of such continuous monitoring [6].

There have been successful examples, such as the Image Gently campaign, which promotes radiation protection for children worldwide through awareness, education, and advocacy [7], and those of the International Atomic Energy Agency, in particular its Radiation Protection of Patients website [8]. This website is the world's top website in the area of patient radiation protection, with over 230,000 visits per year resulting in over 15 million hits per year. The impact created by these two organizations has been noted in recent years [9–11]. New initiatives such as Image Wisely, Choose Wisely seem promising in terms of impact. A future direction could be the creation of an alliance of these organizations to develop directions and speak with a common voice and to attend to the issues identified in this article.

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