Introducing *Radiology* Select: Radiation Dose and Dose Reduction

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Introduction

As a consequence of the success of medical imaging over the past decades for aid in accurately diagnosing disease or injury and guiding therapy, the collective radiation dose delivered to the U.S. population from medical imaging has increased six-fold since the 1980s (1,2). This has resulted in substantial concern from physicians, patients, and regulators. Consequently, radiation dose management and reduction have become one of the most important challenges facing medical imaging providers (3). Radiation protection in medicine is based on two guiding principles: *(a)* the examination or procedure must be medically indicated, and *(b)* the examination or procedure must use doses that are as low as reasonably achievable—the ALARA principle—without compromising the diagnostic task (4).

However, these simple principles can be difficult to apply in clinical practice, because quantification of either the risks or the benefits associated with exposures to ionizing radiation is not always straightforward. Even the standard metrics for describing the amount of radiation dose delivered to a patient and the optimal methods for dose reduction are still a matter of debate, as is the role of industry, professional organizations, and regulatory agencies. In addition, the rapidly improving technology and the ever increasing number of articles published on the topic of radiation dose reduction every year indicate that we are far from a stable situation from which the medical community could develop universal consensus on best practices for radiation dose management. The aim of this edition of *Radiology* Select was, therefore, to collect the best articles published in *Radiology* from 2008 to mid-2013 that address these important and rapidly evolving issues.

We reviewed articles with the general topic of radiation dose, defined major categories for subtopics, and selected five to eight articles for each subtopic. The category and the number of articles within each category were greatly influenced by the extent to which the articles addressed the challenges facing the imaging community with regard to radiation exposure and risk from medical imaging, as well as by the quality of the respective articles. The selected categories include *(a)* Challenges Associated with the Safe Use of Ionizing Radiation in Medical Imaging, *(b)* Quantifying Radiation Exposure and Patient Dose from Medical Imaging, *(c)* Quantifying Radiation Risk From the Low Doses Used in Medical Imaging, *(d)* Quantifying Radiation Risk in a Medical Population, *(e)* Dose Optimization in CT of the Abdomen, *(f)* Dose Optimization in CT of the Heart and Lungs, and *(g)* Dose Management in Interventional Radiology and Neuroradiology.

Although a majority of the publications are related to dose issues arising from medical uses of computed tomography (CT) (probably because CT is responsible for the largest part of collective dose delivered by medical imaging, followed by nuclear medicine and interventional radiology), we have also included articles related to radiography, mammography, and interventional

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and nuclear medicine examinations or procedures. Radiation protection in interventional radiology has special importance, as these procedures are known to deliver some of highest doses in the radiology department and have unfortunately caused a number of deterministic patient injuries, including skin injuries and hair loss. Selected articles also address issues specific to the care of pediatric and young adult patients.

The volume begins with three special reports exploring the challenges that we face with respect to dose management in medical imaging (3) and priority areas for research to close existing gaps in our knowledge and routinely achieving submillisievert CT scanning (5,6). The role of the federal government in overseeing safety in medical imaging, particularly in CT, is also considered (7). These articles set the stage for the more specific discussions that follow.

In the second section, the magnitude of radiation exposures in medical imaging is reviewed (8) and automated methods for extracting exposure parameters from patient records discussed, such that individual practices could extract and evaluate their own dose data for use in quantitative dose management and patient safety initiatives (9). Specific to CT imaging, the differences between scanner radiation output and patient dose are reviewed (10), and a recently introduced method to calculate size-specific dose estimates (11,12) is described. The section closes with an editorial in which Bankier and Kressel (13) suggest the use of well-defined quantitative metrics for CT "dose" in the peer-reviewed literature and the avoidance of relative terms such as "low dose." Because of the many misconceptions regarding the meaning of the quantity effective dose, in particular its frequent misuse as a patient-specific measure of dose or risk, use of the term is discouraged except when comparing the population risk (averaged over both sexes and all ages) associated with different types of imaging examinations (eg, chest radiograph vs cardiac CT angiogram vs coronary catheterization vs nuclear cardiac stress test) (10,13).

For decades, the magnitude of risk associated with low doses of ionizing radiation has been debated. This highly controversial question is critical to the topic of dose management in medical imaging, as the amount of effort expended in radiation protection efforts should be commensurate with the level of risk from the associated exposures. In the third section, we present two review articles that summarize the radiation epidemiology and biology arguments on each side of this controversy (14,15), as well as editorials in which caution is advised in accepting the prediction of future cancers from low doses of ionizing radiation (16,17) and one arguing quite the opposite—that these increases in cancer risk are not hypothetical and have begun to be measured (18). Because this debate is unlikely to be settled anytime soon, Thrall (19) proposes that the most promising approach to this complex issue lies in neither biology nor epidemiology but rather in technology, utilization management, and best quality practices.

If there is one point on which all authors in the third section agree, it is that the potential benefits of a medically appropriate CT scan (or other medical imaging examination using ionizing radiation) would, in almost all cases, outweigh the potential risks. The statistical risks computed from other exposed cohorts, such as the atomic bomb survivors, assume an otherwise healthy population. For medical cohorts, the potential risks are mitigated by the reduced lifespan of individuals suffering from various conditions due to the underlying morbidity and mortality associated with their conditions (20–22). In asymptomatic individuals, the benefit-to-risk ratio can also be sufficient to justify widespread use of imaging examinations, such as in the case of mammographic screening (23). Because it is the potential benefit to the patient that primarily drives the benefit-to-risk ratio, Eisenberg et al (24) argue that the justification of a medical examination depends only on the patient's current medical status, regardless of the magnitude of past exposures.

Having determined that a medical imaging examination is indeed justified, how can providers maximize the benefit-to-risk ratio? In the fifth, sixth, and seventh sections, this question is examined for abdominal, cardiac, and thoracic examinations; interventional procedures; and neurologic examinations, respectively. Two primary approaches are generically obvious—avoid unnecessary examinations or scanning phases and use only as much radiation as is needed to answer the clinical question accurately or treat the patient effectively. However, the specific details as to how implement these strategies in daily practice are anything but obvious. We thus aimed to select articles addressing such implementation issues.

A number of important considerations must be evaluated when proposing a decrease in radiation dose from what has typically been accepted in the past. Dose optimization must consider the adequacy of images with higher noise levels for specific diagnostic tasks (eg, appendicitis [25]), as well as how changes in image contrast (26), image texture (27), or number of scanning phases (28) due to the use of dose reduction strategies affect diagnostic performance. Dose reduction strategies that result in decreased diagnostic performance reduce the benefit to the patient and, therefore, may not result in an increase in the benefit-to-risk ratio.

In the thorax, appropriate use of pulmonary CT angiography in children suspected of having pulmonary embolism is recommended (29), while abandoning daily routine chest radiography in the intensive care unit is supported by a robust meta-analysis (30). The ability of iterative reconstruction to reduce patient dose without compromising diagnostic performance has also begun to be demonstrated; in the sixth section, we include an example of pediatric chest CT (31). For cardiac CT, where some of the greatest reductions in patient dose have been observed over the past decade (6), we see that submillisievert imaging of the coronary arteries has already been achieved (32), in part through the use of lower tube potential settings and/or iterative reconstruction approaches (33).

In the final section, we have included articles related to the risks of deterministic patient injuries, such as hair loss, skin erythema, or skin burns (34); the trade-offs between dose and image quality in CT fluoroscopic procedures (35); and the risks of CT scanning to the eye lens and possible solutions for reducing these risks (36, 37). We conclude our discussion of clinical implementation strategies with a report on the successful implementation of CT radiation dose reduction strategies in a neuroradiology section (38).

Although we have each worked for many years with scientific data concerning radiation dose issues, whether in our respective clinical practices, research programs, or professional activities, we have benefited considerably from what we have learned through this selection process, and we thank the *Radiology* editorial office for giving us the opportunity to co-edit this volume of the *Radiology* Select series. In particular, we appreciate the appointments of both a clinical radiologist and a medical physicist for this editorial process, as we believe that this provided the broadest possible overview of this important topic.

Our resulting selection has, however, some limitations. First, it is somewhat subjective, having been accomplished by individuals who brought to this project not only specific strengths, but also inevitable weaknesses. Second, we had the unpleasant task of having to choose only a small portion of the many excellent articles considered for inclusion. We made every effort to achieve a balanced overview of the many issues related to radiation dose and risk in medical imaging, covering a range of diverse topics, such as imaging of the head, breast, heart, vessels, chest, and abdomen; imaging of pediatric and adult patients; diagnostic and screening examinations; dose reduction strategies and technologies; controversies regarding dose measurement and risk calculation methods; clinical outcomes; and regulatory and professional issues. We apologize in advance for any imperfections in our final choices. It is our hope, however, that this volume will clarify a number of questions regarding radiation dose and risk in medical imaging, and will increase not only the awareness of the importance of this topic, but also the expertise of the radiology community in matters related to dose management and dose reduction.

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