

---

# Foreword: *Radiology* Select Volume 5—Radiation Dose and Dose Reduction

---

Dear *Radiology* Select Reader:

When we chose Radiation Dose and Dose Reduction as the topic for the fifth volume in the *Radiology* Select series, we were very excited about offering a compilation of articles on a theme of utmost importance to all radiologists and health care providers. The concept of the right radiation dose for the right study, at the right time, is central to optimizing care for those patients who require imaging that uses ionizing radiation. Radiation Dose and Dose Reduction are topics that have stimulated a large amount of research and have engendered a great deal of public interest, as well. Industry, our professional organizations, and government regulatory agencies all have a vital interest in this topic.

We chose the team of Denis Tack, MD, PhD, and Cynthia McCollough, PhD, to be the guest editors of this volume to combine their expertise in clinical aspects of radiation dose management and medical physics. Dr Tack received his PhD degree from the Université Libre de Bruxelles, Belgium, in 2005. His thesis was entitled *Radiation Dose Reduction in Adult CT*. Dr McCollough is a professor of medical physics and biomedical engineering at the Mayo Clinic in Rochester, Minnesota, where she has been a member of the faculty since she received her PhD in medical physics from the University of Wisconsin–Madison in 1991. Each of our guest editors have interests that revolve around techniques to reduce radiation dose from CT without compromising diagnostic performance.

Our guest editors had the difficult tasks of reviewing original research and reviews recently published in *Radiology* and selecting those that are included in this compilation. They have compiled an overview of research in this area that spans challenges associated with the safe use of ionizing radiation in medical imaging to quantifying radiation exposure, patient dose, and risk from medical imaging, as well as topics of dose optimization and dose management in selected subspecialty imaging. We are limited to the number of articles we can include to achieve a compilation of reasonable size, so the final list of articles is, of necessity, subjective. The contents of this volume reflect a somewhat personal view of which are the key articles and are not the result of a quantitative determination. Furthermore, it must be recognized that *Radiology* has published many more fine articles on the subject area than can be condensed into this 35-article volume. Many excellent and clinically important articles, therefore, had to be passed over and not included.

We believe that this collection of key articles will be a valuable resource for all radiologists and for a variety of medical practitioners who use ionizing radiation for diagnostic imaging or request such examinations in their patients, since it behooves all of us—even those of us who practice only imaging without

ionizing radiation, such as ultrasonography and magnetic resonance imaging—to have an understanding of the benefits and risks of imaging-related ionizing radiation.

Continuing medical education (CME), in the form of both CME credits and self-assessment CME (SA-CME) credits, is an important aspect of clinical practice in radiology. Recent American Board of Radiology diplomates, in addition to needing CME, also need SA-CME for recertification. We believe that *Radiology* Select offers a perfect vehicle to provide up-to-date SA-CME activities for our readers and will help them better understand how research evolves and translates into clinical practice. Therefore, Drs Tack and McCollough identified key articles for SA-CME. The articles' corresponding authors were then contacted and asked to supply questions for CME and SA-CME activities. In this volume, readers can obtain up to 13 CME/SA-CME credits on radiation dose and dose reduction.

The online era provides multimedia opportunities for publications. We exploit this capability by providing audio and video conversations with authors to explore their views on the effect of their work and the work of others in the field. These conversations also allow experts to share their thoughts on future developments and the impact of their work on these. In this volume of *Radiology* Select, Drs Tack and McCollough have conversations with several groups of authors to discuss the pertinent topics in dose and dose reduction.

In keeping with the trend of increasing reliance on electronic publishing, we are offering *Radiology* Select in three formats: HTML on the Internet, a digital tablet edition, and print on demand. Print on demand is a printed compilation of the articles for those who prefer reading hard copy. The tablet edition is an electronic multimedia document that combines the electronic articles with audio and video; the articles have been formatted to allow viewing on tablet computers such as the Apple iPad and the numerous Android-powered devices. Images can be resized and compared in this format. We also offer an HTML version for viewing with a Web browser. Individual PDFs can also be downloaded, and readers can listen to and view the audio and video conversations. The CME and SA-CME activities are available only through the online version.

We thank Drs Tack and McCollough for reviewing and selecting the articles collected in this volume. We are especially grateful to the authors of the articles, without whom *Radiology* Select would not be possible.

Sincerely,

Deborah Levine, MD, Series Editor, *Radiology* Select  
Herbert Y. Kressel, MD, Editor, *Radiology*



#### Video

Online Educational Edition and Tablet Edition of *Radiology* Select include a video with series editor Deborah Levine.

---

# Introducing *Radiology* Select: Radiation Dose and Dose Reduction

## 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



### Video

Online Educational Edition and Tablet Edition of *Radiology* Select include videos with guest editors Denis Tack, MD, PhD and Cynthia H. McCollough, MD.

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.

## References

- Mettler FA Jr., Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources—1950–2007. *Radiology* 2009;253(2):520–531.
- National Council on Radiation Protection & Measurements. Ionizing radiation exposure of the population of the United States. NCRP report no. 160. Bethesda, Md: National Council on Radiation Protection & Measurements, 2009.
- Hricak H, Brenner DJ, Adelstein SJ, et al. Managing radiation use in medical imaging: a multifaceted challenge. *Radiology* 2010;258(3):889–905.
- ICRP publication 105: radiation protection in medicine. *Ann ICRP*. 2007;37(6):1–63.
- Boone JM, Hendee WR, McNitt-Gray MF, Seltzer SE. Radiation exposure from CT scans: how to close our knowledge gaps, monitor and safeguard exposure—proceedings and recommendations of the Radiation Dose Summit, sponsored by NIBIB, February 24–25, 2011. *Radiology* 2012;265(2):544–554.
- McCollough CH, Chen GH, Kalender W, et al. Achieving routine submillisievert CT scanning: report from the Summit on Management of Radiation Dose in CT. *Radiology* 2012;264(2):567–580.
- Harvey HB, Pandharipande PV. The federal government's oversight of CT safety: regulatory possibilities. *Radiology* 2012;262(2):391–398.
- Mettler FA Jr., Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology* 2008;248(1):254–263.
- McCollough CH. Automated data mining of exposure information for dose management and patient safety initiatives in medical imaging [editorial]. *Radiology* 2012;264(2):322–324.
- McCollough CH, Leng S, Yu L, Cody DD, Boone JM, McNitt-Gray MF. CT dose index and patient dose: they are *not* the same thing [editorial]. *Radiology* 2011;259(2):311–316.
- Brink JA, Morin RL. Size-specific dose estimation for CT: how should it be used and what does it mean? [editorial]. *Radiology* 2012;265(3):666–668.
- Christner JA, Braun NN, Jacobsen MC, Carter RE, Kofler JM, McCollough CH. Size-specific dose estimates for adult patients at CT of the torso. *Radiology* 2012;265(3):841–847.
- Bankier AA, Kressel HY. Through the looking glass revisited: the need for more meaning and less drama in the reporting of dose and dose reduction in CT [editorial]. *Radiology* 2012;265(1):4–8.
- Little MP, Wakeford R, Tawn EJ, Bouffler SD, Berrington de Gonzalez A. Risks associated with low doses and low dose rates of ionizing radiation: why linearity may be (almost) the best we can do. *Radiology* 2009;251(1):6–12.
- Tubiana M, Feinendegen LE, Yang C, Kaminski JM. The linear no-threshold relationship is inconsistent with radiation biologic and experimental data. *Radiology* 2009;251(1):13–22.
- Hendee WR, International Organization for Medical Physics. Policy statement of the International Organization for Medical Physics [editorial]. *Radiology* 2013;267(2):326–327.

17. Hendee WR, O'Connor MK. Radiation risks of medical imaging: separating fact from fantasy. *Radiology* 2012;264(2):312-321.
18. Brenner DJ, Hall EJ. Cancer risks from CT scans: now we have data, what next? [editorial]. *Radiology* 2012;265(2):330-331.
19. Thrall JH. Radiation exposure in CT scanning and risk: where are we? [editorial]. *Radiology* 2012;264(2):325-328.
20. Brenner DJ, Shuryak I, Einstein AJ. Impact of reduced patient life expectancy on potential cancer risks from radiologic imaging. *Radiology* 2011;261(1):193-198.
21. Pandharipande PV, Eisenberg JD, Lee RJ, et al. Patients with testicular cancer undergoing CT surveillance demonstrate a pitfall of radiation-induced cancer risk estimates: the timing paradox. *Radiology* 2013;266(3):896-904.
22. 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(2):460-469.
23. Yaffe MJ, Mainprize JG. Risk of radiation-induced breast cancer from mammographic screening. *Radiology* 2011;258(1):98-105.
24. Eisenberg JD, Harvey HB, Moore DA, Gazelle GS, Pandharipande PV. Falling prey to the sunk cost bias: a potential harm of patient radiation dose histories. *Radiology* 2012;263(3):626-628.
25. Kim SY, Lee KH, Kim K, et al. Acute appendicitis in young adults: low- versus standard-radiation-dose contrast-enhanced abdominal CT for diagnosis. *Radiology* 2011;260(2):437-445.
26. Lee KH, Lee JM, Moon SK, et al. Attenuation-based automatic tube voltage selection and tube current modulation for dose reduction at contrast-enhanced liver CT. *Radiology* 2012;265(2):437-447.
27. Deák Z, Grimm JM, Treitl M, et al. Filtered back projection, adaptive statistical iterative reconstruction, and a model-based iterative reconstruction in abdominal CT: an experimental clinical study. *Radiology* 2013;266(1):197-206.
28. Hack K, Pinto PA, Gollub MJ. Targeted delayed scanning at CT urography: a worthwhile use of radiation? *Radiology* 2012;265(1):143-150.
29. Lee EY, Tse SKS, Zurakowski D, et al. Children suspected of having pulmonary embolism: multidetector CT pulmonary angiography—thromboembolic risk factors and implications for appropriate use. *Radiology* 2012;262(1):242-251.
30. Oba Y, Zaza T. Abandoning daily routine chest radiography in the intensive care unit: meta-analysis. *Radiology* 2010;255(2):386-395.
31. Singh S, Kalra MK, Shenoy-Bhangle AS, et al. Radiation dose reduction with hybrid iterative reconstruction for pediatric CT. *Radiology* 2012;263(2):537-546.
32. Chen MY, Shanbhag SM, Arai AE. Submillisievert median radiation dose for coronary angiography with a second-generation 320-detector row CT scanner in 107 consecutive patients. *Radiology* 2013;267(1):76-85.
33. Pontana F, Pagniez J, Duhamel A, et al. Reduced-dose low-voltage chest CT angiography with sinogram-affirmed iterative reconstruction versus standard-dose filtered back projection. *Radiology* 2013;267(2):609-618.
34. Balter S, Hopewell JW, Miller DL, Wagner LK, Zelefsky MJ. Fluoroscopically guided interventional procedures: a review of radiation effects on patients' skin and hair. *Radiology* 2010;254(2):326-341.
35. Yamao Y, Yamakado K, Takaki H, et al. Optimal scan parameters for CT fluoroscopy in lung interventional radiologic procedures: relationship between radiation dose and image quality. *Radiology* 2010;255(1):233-241.
36. Neriishi K, Nakashima E, Akahoshi M, et al. Radiation dose and cataract surgery incidence in atomic bomb survivors, 1986-2005. *Radiology* 2012;265(1):167-174.
37. Wang J, Duan X, Christner JA, Leng S, Grant KL, McCollough CH. Bismuth shielding, organ-based tube current modulation, and global reduction of tube current for dose reduction to the eye at head CT. *Radiology* 2012;262(1):191-198.
38. Smith AB, Dillon WP, Lau BC, et al. Radiation dose reduction strategy for CT protocols: successful implementation in neuroradiology section. *Radiology* 2008;247(2):499-506.

**Denis Tack, MD, PhD**



**Denis Tack, MD, PhD**, is a radiologist subspecialized in CT at the EPICURA Hospital in Baudour, Belgium. In 2005, he received his PhD degree from the Université Libre de Bruxelles, Belgium. His thesis was entitled “Radiation Dose Reduction in Adult CT.” He was editor of the first (2007) and second (2012) editions of the medical books entitled *Radiation Dose from Multidetector CT*. He joined the thoracic imaging section of the Radiology Editorial Board in 2012.

**Cynthia H. McCollough, PhD**



**Cynthia H. McCollough, PhD**, is a professor of medical physics and bio-medical engineering at the Mayo Clinic in Rochester, Minn, and a fellow of the American Association of Physicists in Medicine and the American College of Radiology. Her clinical and academic contributions are focused on CT imaging, particularly on developing techniques to reduce radiation dose without compromising diagnostic performance. As director of the multi-disciplinary CT Clinical Innovation Center at the Mayo Clinic, she works with numerous co-investigators on projects seeking to detect and/or quantify disease using CT imaging. She has served as an associate editor for both *Radiology* and *Medical Physics* and is active in numerous national and international organizations in the areas of CT imaging and radiation dose management.

*Radiology Select* is a continuing series of *Radiology* articles chosen by a guest editor for their importance in radiologic science with each volume focusing on a specific subspecialty topic. The series is available to

members and nonmembers for a fee and is offered in three formats: online, tablet, and print. Both *Radiology* and *Radiology Select* are owned and published by the Radiological Society of North America, Inc.

For more information on the *Radiology Select* series, please contact RSNA Publications, 630-590-7770 or [subscribe@rsna.org](mailto:subscribe@rsna.org). © RSNA 2014