Radiation Dose in Computed Tomography
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The emergence of CT scanning as a routine diagnostic and radiation therapy planning tool has improved patient care by increasing the anatomic detail and diagnostic information available to clinicians. An increase in patient demand, availability and reimbursement practices have contributed to a dramatic escalation in the number of scans performed each year, and the risk and clinical justification for many of these procedures now is under debate. This Directed Reading reviews recent trends in CT imaging and patient radiation dose, dosimetry, the biological effects of ionizing radiation, the principles of radiation safety and strategies for managing patient dose.

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After reading this article, readers should be able to:

- Identify recent trends in CT utilization.
- Compare and contrast how CT and radiography exams contribute to cumulative patient radiation exposures.
- Explain the role of patient age and gender in modulating the lifetime cancer risks from radiation exposures.
- Describe the role of distance, duration and protection in applying the as low as reasonably achievable principle.
- Summarize competing models of radiation risk.
- Discuss how pencil ionization chambers calculate patient radiation dose.
- Describe the competing imperatives of image quality and minimized radiation dose, along with CT scan variables that modulate dose.

In October 2009, the U.S. Food and Drug Administration (FDA) issued a nationwide alert that advised hospitals to review safety protocols for computed tomography (CT) scans. This warning followed the discovery that a hospital in California had inadvertently exposed 206 patients to elevated CT radiation doses over an 18-month period during scans ordered to assess suspected strokes. Two months later, the FDA announced that additional cases had been identified at the hospital, and that at least 256 patients had received up to 8 times the intended radiation doses.

The magnitude of the radiation overdoses and their effect on patients were described by the FDA as “significant.” At least 82 patients experienced skin burns (reddening) and patchy hair loss, and affected patients face a possible increased cataract risk. In December 2009, the FDA announced that it was investigating similar reports of CT radiation overdoses at undisclosed facilities in other states.

“This situation may reflect more widespread problems with CT quality assurance programs and may not be isolated to this particular facility or this imaging procedure,” the FDA advisory warned. Although early reports indicated that equipment malfunction caused the incidents, the FDA subsequently announced that the overdoses involved CT imaging equipment from more than 1 manufacturer. This fact suggested that human error and lapses in safety practices and protocols, rather than faulty equipment, caused the errors. The FDA urged hospitals to report similar adverse events via its MedWatch Web site (www.fda.gov/Safety/MedWatch/HowToReport/default.htm).
Regulatory Response

In February 2010, the FDA announced a sweeping new regulatory initiative to reduce medical radiation exposures from CT scans and nuclear medicine and fluoroscopy procedures. Citing patients’ increasing lifetime medical radiation doses, the agency declared its goal of eliminating unnecessary imaging procedures and ensuring the “careful optimization” of medically necessary imaging exams. Planned regulations were announced, including new requirements that CT scanners and fluoroscopic equipment record and display settings and dose for each scan performed and that patient doses be documented permanently in electronic health records.

As part of an FDA patient education initiative, the agency also announced development of a patient medical imaging history card, distributed via the FDA Web site, that will allow patients to track their imaging history and present it to referring physicians. The FDA also declared its support for a national dose registry and revised, uniform accreditation for radiology departments.

“Each patient should get the right imaging exam, at the right time, with the right radiation dose,” the agency’s white paper stated. “This registry will help define diagnostic reference levels where they do not yet exist, validate levels that do exist, and provide benchmarks for health care facilities to use in individual imaging studies.”

As a result of the investigation into the unintended high radiation exposures, the FDA also shared several recommendations with the Medical Imaging Technology Alliance, a division of the National Electrical Manufacturers Association (NEMA) representing manufacturers in the medical imaging industry. In October 2012, NEMA published a new CT access control standard to ensure that only authorized operators can alter the controls of CT equipment. The standard includes assigning more specific permissions to users, provisions to lock the user interface manually and quality assurance features, such as recording operator and patient information, and tracking changes made to protocols.

The headlines and response to the radiation overdoses were just the latest chapter in global news media coverage of radiation risks associated with CT scanning. Other recent examples have included warnings about the radiation effects from full-body CT screening sought by “worried well” patients who have no symptoms of disease, and for whom the net clinical benefits of imaging are questionable. Medical literature and the news media have scrutinized the wide variation in radiation doses of routine CT exams and the cumulative dose of repeated CT scans.

CT Proliferation

Since its introduction in 1973, CT scanning technology has dramatically improved the diagnostic quality and clinical utility of images. Slip-ring conductors preceded development of continuous gantry rotation and single-motion helical CT image acquisition. Image postprocessing advances allowed 3-D, volumetric imaging and the ability to generate multiplanar images from 1 data acquisition set. However, sharply increasing patient radiation dose is the cost for these advances and the widespread availability and popularity of CT.

CT scans are increasingly common procedures that constitute a greater proportion of Americans’ annual exposure to ionizing radiation. The modality represents as much as 67% of the medical imaging radiation dose to patients in some facilities. The annual population-wide medical radiation dose in the United States increased by an estimated 750% between 1980 and 2009. Up to 72 million CT scans are performed annually in the United States, based on 2006 and 2007 data. Medical imaging now represents nearly one-half (48%) of Americans’ radiation exposure, compared with less than 2% from occupational exposures. The remaining 50% of radiation exposures come from background, cosmic ray and environmental sources.

Animal and epidemiological studies of occupational and atomic bomb survivors indicate that even relatively low doses of ionizing radiation can cause cancer, particularly leukemia and myeloma, and blood disorders such as aplastic anemia. Guidelines for nuclear industry and health care workers call for monitoring radiation exposures, which are restricted to no more than 50 mSv a year and no more than 100 mSv every 5 years.

Yet patient exposures to medical imaging-related ionizing radiation rarely are monitored or systematically