

The Health Risks of Ionizing Radiation From Computed Tomography

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Concerns have increased about the potential health risks of ionizing radiation from computed tomography (CT) scans. This paper discusses the biological effects of radiation, describes research findings related to CT use, cites strategies for radiation dose reduction, and emphasizes the need to be judicious in ordering CT scans for children.

Since the last decade of the 20th century, the diagnostic power of computed tomography (CT) has exerted a profound effect on the practice of medicine. The strengths of CT are unmatched in a number of clinical scenarios, most notably evaluation of chest disease and major trauma. However, longitudinal follow-up of large populations of patients who have undergone CT examinations have very recently strengthened the position that CT use is associated with a small but statistically significant increase in a patient's risk of cancer.

Significance of Ionizing Radiation From CT Studies

Doses of ionizing radiation from CT scans are usually in the range of 5–50 millisieverts (mSv) to each organ imaged [1]. The biological effects of x-rays are classified as *deterministic* (producing an immediate and predictable change to tissue) or *stochastic* (producing genetic or carcinogenic damage) [2]. Deterministic effects occur when an x-ray dose exceeds a specific threshold; such effects include alopecia, a burning sensation, ulcerative lesions, cataract formation, and cardiovascular disease [3]. Deterministic effects are uncommon at the levels of radiation received by patients undergoing noninvasive imaging procedures, although there have been widely publicized cases of patients undergoing CT angiography/perfusion studies of the brain who received high doses of radiation that caused hair loss [4].

Stochastic effects, which are the main concern with medical imaging tests, depend on the radiation dose received and are generally caused by radiation-induced mutations [3]. Stochastic effects result from the collisions of x-rays with DNA, which results in structural damage to the DNA. The term *stochastic* means probabilistic—stochastic effects do not definitely occur at a specific dose; rather, they occur with a probability that is believed to increase as the dose increases [3]. In general, stochastic effects are thought to dominate in the setting of exposure to low doses of x-rays;

in this setting, it typically takes at least 2 years for leukemia to develop and at least 5 years for a solid cancer to develop [5].

An estimated 80 million CT exams were performed in the United States in 2010, compared with fewer than 3 million in 1980 [6]. Over the past 30 years, the National Council on Radiation Protection and Measurements, a congressionally chartered organization focused on ensuring the radiation safety of the US public, has performed 2 comprehensive reviews of radiation exposure from all sources, including naturally occurring background radiation and medical radiation from diagnostic x-rays and nuclear medicine procedures [3, 7]. The difference between the 2 reports, one covering the period 1980–1982 and the other for 2006, is startling [3, 7]. In the earlier time period, natural radiation sources constituted an average per-capita effective dose of 3.0 mSv per year, whereas medical radiation sources accounted for an average per-capita effective dose of 0.53 mSv per year [3, 7]. Although natural radiation exposure remained essentially constant over the 25-year period, radiation exposure from medical sources increased 600%, to 3.0 mSv per capita per year [3, 7]. CT scans are the greatest contributor to the dramatic increase in population exposure to medical radiation [6].

Spurred by the expansion in CT utilization, research studies have investigated potential increases in future cancer risk. A compelling body of evidence links exposure to low-dose radiation with the development of solid cancers and leukemia [5]. These studies are based on data from 4 patient populations: survivors of the atomic bombs dropped on Hiroshima and Nagasaki, who have been studied by the Radiation Effects Research Foundation; persons exposed to medical radiation; workers in nuclear and radiation industries; and populations exposed to environmental radiation (including those affected by the nuclear accidents at Three Mile Island and Chernobyl) [8].

The National Academy of Sciences has commissioned a

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series of reports, the Biological Effects of Ionizing Radiation (BEIR) reports, which draw on data from all 4 of these populations to examine the health risks from exposure to low levels of ionizing radiation. The latest of these reports, BEIR VII [5], provides comprehensive risk projection estimates for cancer resulting from exposure to low-dose ionizing radiation, which the BEIR VII report defines as radiation in the range from near zero to approximately 100 mSv. On average, assuming an age and sex distribution similar to that of the entire US population, the BEIR VII lifetime risk model predicts that approximately 1 individual in 1,000 will develop cancer from exposure to a single, 10-mSv dose of radiation (the amount of radiation received during a routine CT scan of the abdomen) [5].

Considering that an individual has about a 1 in 3 lifetime risk of developing cancer, the risk from imaging-based radiation may appear small. From a public health perspective, however, this small individual risk must be multiplied by the large and ever-increasing population of individuals undergoing CT scans [9, 10]. Estimates suggest that approximately 29,000 future cancers could be related to CT use in the United States in 2007 [11]. A retrospective cross-sectional study by Smith-Bindman and colleagues describes the effective radiation doses from 11 common types of diagnostic CT

studies and estimates the lifetime risk attributable to those scans [12].

The radiation doses delivered by CT scans are much higher than those of conventional radiography. For instance, a single CT scan of the chest delivers an effective dose that is 100 to 1,000 times greater than that received during a chest radiograph [10]. Not only is radiation exposure from CT scans higher than the radiation delivered during other medical imaging studies, it is further increased by the common practice of ordering multiple CT exams on the same patient. A retrospective analysis of 31,462 patients revealed that 33% of these patients had undergone 5 or more CT studies during the 22-year study period [13]. The cumulative CT radiation exposure that results from such practices adds incrementally to the patient's baseline cancer risk [13].

In addition, pronounced variations in radiation doses are common. A recent multi-institutional analysis of common CT examinations in the San Francisco Bay Area found substantial variation in radiation doses within and between institutions, with a mean 13-fold difference between the highest and lowest doses for identical CT procedures [12]. Hence, depending on where and when an individual received a CT study, the effective dose for a particular patient could substantially exceed the median.

Even though the US Food and Drug Administration (FDA) in 2010 created a road map for reducing and standardizing the radiation doses associated with CT scans [14], there are no federal mandates governing the standardization of radiation dosages delivered by medical imaging [15]. Instead, the responsibility for standardization has been shifted to medical societies and professional groups. The American College of Radiology (ACR) states that doses should be “as low as reasonably achievable” (ALARA), meaning that providers should use the minimum level of radiation needed to achieve an image of satisfactory diagnostic quality. Providers need to be cognizant of the fact that the highest-quality images, which expose patients to the highest levels of radiation, are not always required to make a diagnosis. In many cases, lower-resolution scans are diagnostic [16]. The ACR is a founding participant in the Image Gently campaign for dose reduction in pediatric imaging [17] and has also launched Image Wisely, a radiation-reduction endeavor for adult patients [18].

Are We Protecting Children?

Between 5 million and 9 million CT examinations are performed annually on children in the United States [16]. A recent population-based study of more than 350,000 chil-

dren across 5 large health care markets in the United States showed that exposure to ionizing radiation from medical imaging may occur frequently among children [19] and that the average child in this study population will have received more than 7 diagnostic imaging studies using low-dose ionizing radiation by the time he or she reaches 18 years of age. A 2013 study in *JAMA Pediatrics* [20] culled data from a large research network of 6 major health maintenance organizations in the United States and quantified trends in the use of pediatric CT scans and the associated radiation exposure and cancer risk. The study found that many children received high radiation doses from CT scans. The authors attribute this finding both to the greater use of higher-dose CT examinations, such as scans of the abdomen and pelvis, and to substantial variability in radiation doses. They project that if radiation doses nationwide reflect the doses they observed for CT scans of the head, abdomen/pelvis, chest, and spine for children younger than 15 years, then the scans performed in 1 year in the United States might cause 4,870 future cancers [20]. The authors suggest that if the highest 25% of doses can be reduced to the median dose, then 43% of those cancers might be prevented [20].

Children are especially vulnerable to the harmful effects of radiation. For example, risk projections suggest that for an

abdominal or pelvic CT scan, the lifetime risks for children are 1 cancer per 500 scans, regardless of age at exposure [11, 21]. There are several unique considerations regarding radiation exposure in children: Children are at greater risk than adults from a given dose of radiation because of the enhanced radiosensitivity of developing organs [22]; children have a longer life expectancy than adults and more remaining years of life during which a radiation-induced cancer could develop [22]; children may receive a higher radiation dose than necessary if CT settings are not adjusted for their smaller body size [23]; and, as a result of the surge in use of medical imaging [24], today's children are likely to eventually receive higher cumulative lifetime doses of medical imaging-related radiation than will individuals who are already adults [25].

Recently, the evidence base for increased cancer risk associated with CT scans has been fortified by 2 retrospective direct analyses of data from large cohorts of children in the United Kingdom [21] and Australia [1], both of which had a mean duration of follow-up after exposure of 10 years. Results of these studies were similar, showing the overall cancer incidence to be 24% greater for children who had been exposed to CT scans versus those who were unexposed [26].

Strategies for CT Radiation Dose Reduction

Although it is difficult to imagine modern medicine without CT, there is convincing evidence that a substantial fraction of the approximately 80 million CT exams performed annually in the United States are ordered without sound medical justification. Appropriateness criteria for CT scans are critically important, because authoritative sources, including the Radiological Society of North America (RSNA) and the ACR, suggest that 20%-50% of such scans could be replaced by another type of imaging, or not performed at all [27, 28]. Computerized radiology order entry with embedded decision support, which was included in federal policy via recent meaningful use regulations [29], has shown promise in reducing the growth rate of CT imaging [30, 31]. Furthermore, alternative imaging modalities such as ultrasound or magnetic resonance imaging (MRI) should always be considered [32]. Because ultrasound does not involve exposure to radiation or use of sedatives, it is a useful and versatile modality in many pediatric clinical settings, such as the evaluation of abdominal pain or acute appendicitis [33]. Also, for many patients, a well-performed and well-interpreted MRI is as good as, or perhaps better, than a CT scan performed in the same clinical context [33].

As part of the impetus for patient-centered care and safety, new CT machines feature dose-reduction tools, which are now mandated by the FDA [34]. The latest CT scanners incorporate tools such as automatic exposure control, iterative reconstruction, safety cutoffs to prevent excessive doses, and prompts for coupling protocols to patient size (which are especially important when perform-

ing CT scans on pediatric patients) [35]. Recent iterative reconstructive techniques have been a boon to radiation dose-reduction efforts because they make it possible for CT scans to be performed with significantly decreased radiation doses while preserving diagnostic quality [35]. Future goals include reducing CT effective doses to less than 1 mSv, which is less than the average annual dose from naturally occurring sources of radiation [36].

Looking Forward

CT has inarguably exerted a tremendous impact on diagnostic radiology over the past few decades, but serious concern exists that the radiation associated with CT scans may pose significant health risks, on both individual and public health levels. Despite the diversity of opinions regarding the exact nature of this health risk, the mantle of responsibility to protect patients ultimately rests on the shoulders of health care providers. As Semelke and Elias stated in a recent textbook on radiology and health care, "if we assume there are radiation risks when there are none, we will be expending effort and resources to minimize nonexistent risks; however, if there truly are radiation risks that we chose to ignore, we will have subjected our patients to long-term detrimental consequences" [37].

As a step toward the standardization and optimization of radiation doses in pediatric CT, UNC Hospitals and its community hospital affiliates have recently launched a collaborative learning quality improvement project. Leaders from Blue Cross and Blue Shield of North Carolina, the Cecil G. Sheps Center for Health Services Research, the UNC Gillings School of Global Public Health, and Chatham Hospital Imaging Center have helped to make this project visible to others as a way of effecting positive change. NCMJ

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