Radiation Dose and Risk of Cancer from CT Scans

Smith-Bindman R, Lipson J, Marcus R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med 2009;169:2078–86.

Study Overview

Objective. To estimate the amount of radiation exposure associated with computed tomography (CT) examinations; to estimate variation across examination types, patients, and institutions; and to use these data to estimate the lifetime attributable risk (LAR) of cancer associated with CT examinations.

Design. Retrospective cross-sectional study.

Setting and participants. Data were collected at 4 large hospitals in the San Francisco Bay area. The most frequent CT study types were determined through querying the radiology information system at the University of California, San Francisco, for all CT examinations performed in a single month. The 11 most common study types not performed in association with a therapeutic procedure were selected. At each hospital, 20 to 30 consecutive patients age 18 years or older were sampled for each study type between 1 Jan 2008 and 31 May 2008 for a total sample of 1119 patients. For each patient, the technical parameters and dose report data were abstracted from the CT images.

Main outcome measures. Radiation exposure associated with each CT examination was measured using the "effective dose" measurement. This measurement accounts for the amount of radiation to exposed organs and each organ's sensitivity to developing cancer from radiation exposure. Effective dose was estimated using the dose-length product (DLP) recorded as part of each CT scan, an approximation of the total energy a patient absorbs from the scan. The DLP was combined with details of the area imaged to take into account the sensitivities of different organs to developing radiation-induced cancer. Descriptive statistics of the effective doses were calculated for each CT study type, and differences within and across institutions were assessed using analysis of variance (ANOVA). To put the dose estimates in context, the effective dose for each CT study type was compared with the effective doses for the 2 most common conventional radiology studies in the United States—a frontal and lateral chest x-ray (0.065 millisieverts [mSv]) and a screening mammography series (0.42 mSv). The LAR was estimated using a method provided by the Biological Effects of Ionizing Radiation (BEIR VII) 2006 report, based on the magnitude of a single radiation exposure and the patient's age at the time of that exposure. The LAR is defined as the additional cancer risk above and beyond a patient's baseline cancer risk. The age- and sex-specific LAR for all cancers combined was calculated for the median and interquartile range (IQR) of effective doses for each type of study.

Main results. The 11 CT study types examined included 3 head and neck studies (routine head, routine neck, and suspected stroke); 4 chest studies (routine chest without contrast, routine chest with contrast, suspected pulmonary embolism, and coronary angiogram); and 4 abdomen and pelvis studies (routine abdomen-pelvis without contrast, routine abdomen-pelvis with contrast, multiphase abdomen-pelvis, and suspected aneurysm or dissection). Together these studies comprise approximately 80% of all CT scans performed. The mean patient age was 59 years and 48% of patients were female. The median effective dose varied widely between study types. For head and neck studies, the median effective dose varied from 2 mSv (IQR, 2–3 mSv) for a routine head study to 14 mSv (IQR, 9–20 mSv) for a suspected stroke CT. For chest scans, the median effective dose varied from 8 mSv (IQR, 5–11 mSv) for a routine chest study to 22 mSv (IQR, 14–24 mSv) for coronary angiography. For abdomen and pelvis scans, the median effective dose varied from 15 mSv (IQR, 10–20 mSv) for a routine scan without contrast to 31 mSv (IQR, 21–43 mSv) for a multiphase scan. The median effective dose delivered through a single multiphase abdomen-pelvis CT scan was equivalent to 442 chest radiography series and 74 mammography series.

Even within each study type, radiation dose varied substantially both within and across institutions. There was a mean 13-fold variation between the highest and lowest dose for each study type (range 6- to 22-fold difference across different study types), with the greatest variation occurring in the abdomen and pelvis studies. The mean dose varied 2-fold across institutions, with no consistent pattern observed for which institution had the highest radiation dose (each site had the highest dose for at least 1 of the study types).

The median adjusted LAR of cancer ranged from 0.23 cancers per 1000 patients from a routine head CT scan (range, 0.03–0.70 cancers per 1000 patients) to 4 cancers per 1000 patients from a multiphase abdomen and pelvis CT (range, 0.8–11.1 cancers per 1000 patients). The estimated number of patients undergoing CT that would lead to the development of 1 radiation-induced cancer, by age at exposure and sex, was lowest for coronary angiogram (among 40-year-old women, 1 cancer would be expected to occur among approximately 270 women as a result of the radiation exposure [IQR, 1 in 250 to 1 in 420]) and highest for routine head CT (among 40-year-old women, 1 cancer would be expected to occur among approximately 8100 women as a result of the radiation exposure [IQR, 1 in 6110 to 1 in 9500]). The number of CTs that would result in 1 radiation-induced cancer was much lower among women than among men (reflecting the higher cancer risk of radiation among women) and much lower among younger patients than among older patients.

Conclusion. Radiation doses from common CT studies are higher and more variable than previously estimated, highlighting the need for greater standardization across institutions and coordinated efforts to limit unnecessary CT examinations.

Commentary

Since its invention in the early 1970s, the CT scan has become one of the most widely used medical diagnostic tests in the United States. In fact, use of CT scans has increased dramatically in recent years, from approximately 3 million annual scans in 1980 to over 70 million scans in 2007 [1,2]. In a study of nearly 1 million nonelderly adults between 2005 and 2007, 70% underwent an imaging procedure over the 3-year study period [3]. In this important article, Smith-Bindman et al caution that such widespread use of CT scans is not without attendant risk. Their findings highlight that while CT scans may be "noninvasive," fast, and painless, they involve higher and more variable amounts of radiation exposure than previously thought, and may be associated with a significantly increased LAR of radiation-induced cancer.

Quantifying the risks of radiation exposure from CT scanning poses a challenge. As Smith-Bindman et al report, the magnitude of radiation delivered varies widely even within a single CT study type at a single institution. What seems clear from their calculations, however, is that the LARs of cancer are often much higher than previously reported, particularly for younger women. For example, while the FDA estimates that a CT scan is associated with an increased cancer risk of approximately 1 in 2000 [4], Smith-Bindman et al calculate that a 20-year-old woman who underwent a CT scan for suspected pulmonary embolism and received the highest effective dose of radiation could have an increased risk of developing cancer as high as 1 in 80. The authors note that the doses of radiation documented in their study may be higher than those typically reported because previous studies have assessed radiation doses received in idealized settings (ie, by plastic models placed in scanners for research purposes) or failed to account for variation between different types of CT scans or scanning protocols, or across institutions.

Given the evidence that actual effective radiation doses may be more harmful than previously recognized, the authors and an accompanying editorial [5] offer several suggestions for needed change. First, efforts are needed to standardize and limit the amount of radiation associated with individual scans. While several European countries have adopted more aggressive standards for monitoring and limiting CT radiation doses, the FDA does not currently monitor or regulate the dose associated with clinical CT examinations. Second, efforts should be taken to minimize the number of CT examinations performed. While there has been some attention to the inappropriate use of CT studies as full-body screening exams in asymptomatic patients, few guidelines exist to limit the overuse of CT studies in other settings (ie, the repeated use of CT for patients with undocumented renal stones). Finally, the authors raise the possibility of tracking detailed dose information at the patient level in a systemwide manner to help both educate patients and physicians about the risks and benefits of scanning and minimize radiation-associated risks among the subset of patients who receive repeated studies over a lifetime.

Several limitations should be considered in the interpretation of these results. First, while the study pointed to significant variation in radiation dose, the sample was not large enough to evaluate the reasons for this variation (including the technologist's experience, the physician's experience, geographic variation, and the availability or use of dose-modulating algorithms). Second, further work is needed to characterize the association between the image quality and radiation dose. Third, this study likely underestimated the actual variation in doses across sites because all included scans were performed by a single manufacturer's scanner. Fourth, the LAR should be viewed as an approximation and not an exact risk of cancer. Multiple variables (including the patient's life expectancy) may alter this estimation.

Applications for Clinical Practice

This study provides evidence that radiation exposure from commonly performed CT examinations is both higher and more variable than previously recognized, contributing to a substantially increased risk of cancer, particularly among younger women. These findings highlight the need for systemic changes to ensure than the benefits of CT examinations outweigh the risks. In particular, attention is needed to standardize and minimize the amount of radiation received from each study, decrease unnecessary imaging, and ensure that physicians and patients are aware of the risks and benefits of CT examinations.

—Review by Yael Schenker, MD

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