Exposure to Ionizing Radiation and Estimate of Secondary Cancers in the Era of High-Speed CT Scanning: Projections From the Medicare Population

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Purpose: The aims of this study were to analyze the distribution and amount of ionizing radiation delivered by CT scans in the modern era of high-speed CT and to estimate cancer risk in the elderly, the patient group most frequently imaged using CT scanning.

Methods: A retrospective cohort study was conducted using Medicare claims spanning 8 years (1998-2005) to assess CT use. The data were analyzed in two 4-year cohorts, 1998 to 2001 ($n = 5,267,230$) and 2002 to 2005 ($n = 5,555,345$). The number and types of CT scans each patient received over the 4-year periods were analyzed to determine the percentage of patients exposed to threshold radiation of 50 to 100 mSv (defined as low) and >100 mSv (defined as high). The National Research Council's Biological Effects of Ionizing Radiation VII models were used to estimate the number of radiation-induced cancers.

Results: CT scans of the head were the most common examinations in both Medicare cohorts, but abdominal imaging delivered the greatest proportion (43% in the first cohort and 40% in the second cohort) of radiation. In the 1998 to 2001 cohort, 42% of Medicare patients underwent CT scans, with 2.2% and 0.5% receiving radiation doses in the low and high ranges, respectively. In the 2002 to 2005 cohort, 50% of Medicare patients received CT scans, with 4.2% and 1.2% receiving doses in the low and high ranges. In the two populations, 1,659 (0.03%) and 2,185 (0.04%) cancers related to ionizing radiation were estimated, respectively.

Conclusions: Although radiation doses have been increasing along with the increasing reliance on CT scans for diagnosis and therapy, using conservative estimates with worst-case scenario methodology, the authors found that the risk for secondary cancers is low in older adults, the group subjected to the most frequent CT scanning. Trends showing increasing use, however, underscore the importance of monitoring CT utilization and its consequences.

Key Words: Ionizing radiation, CT, cancer

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INTRODUCTION

As medical imaging technology has become more sophisticated, the risks and benefits of imaging have garnered increasing attention and scrutiny in the medical literature, as well as in recent health policy debates. Imaging has attracted particular interest because it has become central to diagnosis and management in modern medical care and, along with other medical technologies, is often viewed as an important driver of health care costs [1]. Expanded use of modern high-speed CT imaging has raised additional concerns about radiation exposure [2,3].

Despite valid concerns, advances in medical imaging offer important opportunities to improve health care. More than 75% of leading physicians assert that CT and MRI technologies are the most important medical innovation of the past decade, outranking blockbuster drugs and medical devices [4]. Improved imaging technology can facilitate faster and more accurate diagnoses, which

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have been linked to lower costs [5], as well as fewer unnecessary surgeries [6] and hospitalizations [7]. Many new imaging procedures can replace more invasive diagnostic methods with higher morbidity and mortality rates [8]. Advancing imaging can also open the door to more use of minimally invasive therapies. With regard to CT, the turn of this past century marked an inflection point with the increasing use of multidetector CT (MDCT) technology. A reduction in scan times from single-slice CT to multidetector scanners has benefited many trauma [6] and pediatric [9] patients. Increased scan ranges are conducive to cancer staging, as well as pulmonary and cardiac angiography [10].

However, there are also important concerns due to ionizing radiation from CT. Although radiation doses vary, the average abdominal-pelvic CT scan has been reported to deliver 100 to 250 times as much radiation as a conventional x-ray [11]. Consequently, although CT examinations only account for an estimated 10% of diagnostic imaging in most large American hospitals, the scans disproportionately contribute nearly 70% to the collective radiation dose [12]. Furthermore, the increasing availability of scanners, coupled with their medical benefits, has increased the number of examinations performed in the United States, rising >20-fold from 2.8 million in 1981 [13] to more than 62 million in 2006 [2]. Many other developed countries have also experienced growth in CT use [14].

To date, many of the larger studies of the impacts of increased radiation doses from CT have focused on theoretical calculations and have assumed that radiation risk is evenly spread across large populations. However, because radiation risk is a cumulative variable across the patient population, it is critical to determine not simply the numbers of scans and patients, but also the distribution of scans across the patient population. In this study, we sought to examine precisely that distribution of types of scans within the Medicare population from 1998 to 2005. Through Medicare, CMS is the single largest payer for health care services in the United States, covering >40 million Americans. Moreover, it is this population that harbors the vast majority of chronic diseases, which are the diseases whose diagnosis and management are most dependent on CT scanning and other radiologic studies. This is thus an important population to study if we are to understand the overall impact of radiation risk from CT utilization. The purposes of this study were to analyze the distribution of types of CT scans, as well as the amount of ionizing radiation delivered by CT scans, and to estimate the cancer risk from these examinations, focusing on patients in the age group most frequently imaged.

METHODS

We conducted a retrospective cohort study using Medicare claims for a 20% sample of traditional (fee-for-service) Medicare beneficiaries for the 8 years from 1998 through 2005. The data set includes, among other details, information about all physician-billed services performed for these beneficiaries. The analysis was conducted in a way that protected the identities and privacy of all individuals whose data were analyzed. The study was initiated by the investigators and conducted without external funding.

First, we identified all individuals aged 65 to 120 years and enrolled in traditional Medicare as of January 1, 1998 (n = 6,731,895). We retained 5,267,230 individuals after we excluded all individuals who joined Medicare health maintenance organizations at any point during the next 4 years because their claims records may have been incomplete. Similarly, we identified a cohort of individuals aged 65 to 120 years and enrolled in traditional Medicare as of January 1, 2002 (n = 6,890,945). After excluding 1,335,600 persons who had joined Medicare health maintenance organizations in the subsequent 4 years, this sample retained 5,555,345 individuals. Choosing two 4-year cohorts allowed us to analyze the change in CT radiation over time, while achieving reasonable estimates of protracted radiation exposure. As opposed to single-year cohorts, 4-year cohorts provide a more robust aggregation of imaging data. We chose to separate the cohorts between 2001 and 2002 because that was the midpoint of our data. It also coincided with the time at which use of MDCT began to increase more rapidly.

For all individuals in our cohorts, we used the claims data to count the number of CT imaging procedures received over the relevant 4-year period (for the 1998 cohort, January 1, 1998, through December 31, 2001; for the 2002 cohort, January 1, 2002, through December 31, 2005). Medicare provides comprehensive coverage for medically necessary imaging, so these data should reliably capture all, or very nearly all, CT examinations performed on the study population. We counted CT procedures on the basis of claims for scan interpretation (ie, claims for the "professional component" of a scan or a "global fee," which include both the technical and professional components together). We did not count claims for "technical components" of scans, to ensure that we did not double-count scans when separate bills were submitted for the technical and professional components. We also excluded claims that Medicare refused to reimburse because these are often duplicate bills.

Roughly 12% of the patients in the 1998 to 2001 cohort, and about 11% in the 2002 to 2005 cohort, died during the respective 4-year periods. In our analyses, we included all individuals regardless of whether they survived the 4-year spans.

Our data count the total number of scans received and also use procedure codes to separately identify different types of scans, including the following categories: head CT, neck CT, chest CT, spinal CT, pelvic CT, extremity CT, abdominal CT, bone scans and PET scans. We also coded CT angiographic procedures separately from other CT procedures.

Using accepted values from published literature, and in an attempt to set an upper limit of acquired dose, we used the average effective dose for each type of CT procedure [15,16]. This is the most commonly used and accepted method to estimate the total dose applied to a human exposed to radiation taking into account the specific organs and areas of the body that are exposed. Body organs are not equally sensitive to the possible adverse effects of radiation, and therefore, a predetermined tissue weighting factor is assigned to each body organ on the basis of its sensitivity to radiation. Effective doses can then be calculated using the following equation:

$$\text{effective dose}\left(\text{Sv}\right) = \text{absorbed dose}\left(\text{Gy}\right) \times \text{tissue weighting factor}$$

In our study, we used commonly accepted and published values for average effective doses for various CT modalities [15]. It should be noted that there is variance that arises from CT technique, differences in individual CT scanners, and patient body habitus that could affect these doses, and is not accounted for in the Medicare population's claims data. On the basis of the doses, we computed the total 4-year radiation dose each patient received from CT imaging. Unlike prior retrospective cohort analyses [3], which have used annual data, we aggregated examinations over 4-year periods to more accurately reflect exposure to radiation. From the 4-year data, we arrived at average annual exposures.

The details of radiation-induced carcinogenesis have been extensively reviewed in the literature. Radiation from protracted exposures, such as CT scans over time, is less carcinogenic than from acute exposures such as an atomic bomb explosion [17]. We used currently accepted thresholds of 50 and 100 mSv for protracted exposure over the 4-year period [17,18]. Reasonable evidence shows an increase in cancer risk at doses >100 mSv, and there is suggestion of an increase in risk at >50 mSv [17]. To date, studies have not demonstrated a statistically significant risk for prolonged exposure amounting to <50 mSv. To add some perspective to this figure, workers monitored for occupational radiation risk in the United States are restricted to 100 mSv over a given 5-year period, with a maximum of 50 mSv in a single year [18].

Lifetime attributable risk values of all cancer mortality are 364, 284, and 172 per 100,000 persons exposed to a single dose of 0.1 Gy (equivalent to 100 mSv) when age at exposure is 60, 70, and 80 years [19]. This number reflects both excess solid cancers and leukemia, averaged for both men and women. We took the average of these estimates, 273, to be cancer mortality per 100,000 for our patient population when exposed to 100 mSv. We invoked the currently accepted linear dose response model [17] to determine the number of excess cancers when patients were exposed to <50 mSv as well as between 50 and 100 mSv of radiation. Using this model, we arrived at 68 and 137 as the respective cancer deaths per 100,000 persons for <50 mSv and between 50 and 100 mSv. Although there has been no conclusive evidence of increased cancer incidence between 1 and 50 mSv, we have included an upper bound estimate by assuming that linear dose relationship applies to these lower doses as well.

RESULTS

In our study, the early cohort (1998-2001) included 5,267,230 Medicare patients, of whom 2,236,998 (42%) underwent at least one CT examination. In the later cohort (2001-2005), 2,767,834 of 5,555,345 patients (50%) underwent CT imaging. The increase in scans was statistically significant ($P < .001$). In both groups, CT examinations of the head, abdomen, pelvis, and chest were most commonly performed. Although head CT was the most commonly performed examination, abdominal CT represented the greatest proportion of delivered radiation (Table 1). The radiation doses per examination for the most common CT codes are provided in this table, and the actual ratio of examinations can be back-calculated by dividing the radiation delivered by the radiation per examination. Table 1 reflects the percentage of patients who underwent each type of examination. For example, in the second cohort, 58% of patients who received CT scans underwent head CT. This column allows analysis of frequency without weighting patients who received multiple scans, as in the case of 1 patient in the second cohort who received 72 head CT scans. In both cohorts, the study also showed that patients in the 2 cohorts had a relatively similar spread of these examinations: head (60% and 58%), abdomen (45% and 51%), chest (28% and 36%), and pelvis (36% and 45%).

In the 1998 to 2001 cohort, approximately 0.5% of patients received cumulative radiation doses >100 mSv, and 2.2% received cumulative doses between 50 and 100 mSv (Figure 1). In the 2002 to 2005 cohort, these values increased to 1.2% and 4.2%, respectively. The increase in patients receiving each dosage level was statistically significant ($P < .001$). Correspondingly, approximately 72 cancers were predicted in the earlier cohort and roughly 183 in the later cohort for those exposed to >100 mSv of radiation. Assuming a linear dose response curve, a similar calculation for the 50 mSv threshold predicts additional 156 and 317 cases of cancer in the two cohorts. Thus, for the combined groups, there would be approximately 228 expected CT-induced cancers for the 1998 to 2001 cohort and 500 for the 2002 to 2005 cohort. Although there is no demonstrated increased risk for developing cancer when exposures are <50 mSv, if we include the cancers predicted in the population that

Table 1. Average dose from major CT examinations, percentage of patients receiving CT scans stratified by cohort, and percentage of total CT radiation stratified by cohort

		Percentage of Scanned Patients Receiving Studies*		Percentage of Radiation Delivered†	
Imaging Study	Average Effective Dose (mSv) [16,17]	1998 to 2001 (n = 2,236,998)	2002 to 2005 (n = 2,767,835)	1998 to 2001	2002 to 2005
Head CT	2	1,351,704 (60%)	1,614,948 (58%)	14%	10%
Neck CT	3	71,364 (3%)	121,571 (4%)	1%	1%
Chest CT	7	615,587 (28%)	1,007,393 (36%)	20%	24%
Spinal CT	6	173,634 (8%)	235,255 (8%)	3%	2%
Pelvic CT	6	805,409 (36%)	1,252,171 (45%)	20%	22%
Extremity CT	0.1	37,945 (2%)	83,582 (3%)	<1%	<1%
Abdominal CT	8	1,005,323 (45%)	1,401,667 (51%)	43%	40%
Bone scan	6.3	769 (<1%)	939 (<1%)	<1%	<1%
PET scan	14	1 (<1%)	36,029 (1%)	<1%	<1%

*Figures inherently do not sum to 100 because some patients received more than one CT scan.
†Figures may not sum to 100 because of rounding.

received <50 mSv, the total number of cancers increases to 1,659 and 2,185, respectively for the 2 cohorts. This reflects 0.03% and 0.04% of the study population, respectively (Table 2).

DISCUSSION

Virtually every medical technology or service can be evaluated from a cost-benefit perspective. Evidence shows that MDCT scanning offers important benefits through more accurate diagnosis and better disease management in a range of medical disorders. Our data show that with the increasing availability of high-speed CT has come a trend of increasing utilization of CT scanning, which is an expected trend when such an advance has a positive impact on diagnosis and disease management. Appropriately, this technology has come under increased scrutiny because of the well-documented carcinogenic risks of ionizing radiation and concerns regarding the risks of exposure to CT-generated radiation [2,20,21].

In the era of MDCT, it has been hypothesized that 1.5% to 2.0% of all cancers may be caused by CT-induced radiation [2]. One recent study stated that CT scans performed in 2007 will eventually contribute to 29,000 cancers, or approximately 2% of the 1.4 million cancers that are diagnosed annually in the United States [22]. Our study estimates the number of excess cancers due to ionizing radiation in elderly adults who harbor most diseases that typically rely on CT scanning for diagnosis and disease management and therefore receive the highest exposure to CT imaging. Combining both low-risk and high-risk patient groups (50-100 and >100 mSv), as well as those who received <50 mSv, we estimate that only 1,659 cases of cancer (0.03%) will develop in the 1998 to 2001 cohort and 2,185 (0.04%) in the 2002 to 2005 cohort.

It is worth pointing out that for many of the patients in our cohorts who received high radiation doses, the imaging they received may have been in response to the pres-

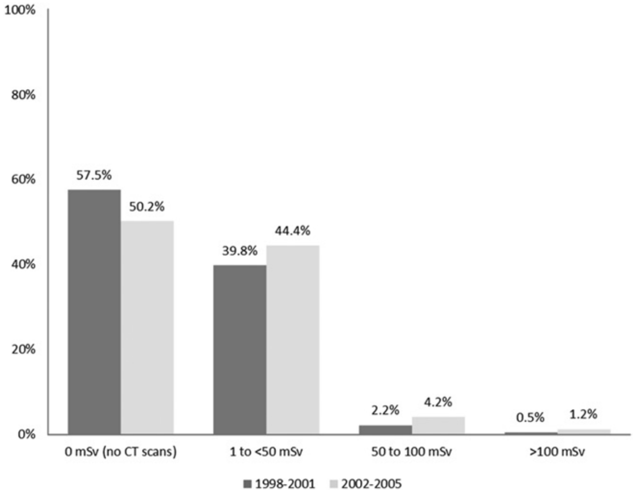

Fig 1. Distribution of effective doses of radiation, stratified by cohort (1998-2001, n = 5,267,230; 2002-2005, n = 5,555,345).

Table 2. Excess cancers due to ionizing radiation from CT predicted in the first (1998-2001) and second (2002-2005) cohorts

	1998 to 2001 (n = 5,267,230)	2002 to 2005 (n = 5,555,345)
Excess cancers predicted		
<50 mSv	1,431	1,685
50-100 mSv	156	317
>100 mSv	72	183
Total	1,659	2,185
Excess cancers as a percentage of study population	0.03%	0.04%

ence of serious medical conditions, such that the receipt of imaging could have produced important benefits for these patients. For such a population, the surveillance and diagnostic benefits of a CT examination may outweigh the risk of radiation from the examinations. Radiation risk should not necessarily be assumed to represent the most important consideration when managing patients harboring serious diseases. Although nothing warrants the unnecessary use of CT, it may well be that some patients are more likely to experience significant morbidity or mortality from conditions that CT examinations aim to diagnose rather than from CT radiation-induced cancer. One of the key issues in this population is life expectancy. The carcinogenic risk of CT-related radiation in older populations is at least partly diluted when one considers the typical 15-year latency period for developing radiation-induced cancer [16].

We used the excess cancer incidence values from the Biological Effects of Ionizing Radiation VII report, which decrease with age. In addition, the Biological Effects of Ionizing Radiation VII risk models consider those who survived the Japanese atomic bomb explosions, which were acute, not protracted, exposures [19]. Thus, our calculations still likely overestimate the true number of cancers seen above the specified radiation thresholds.

CT scans of the head were the most common type of CT study and the most common scan for a patient to receive (eg, removing weighting of multiple examination types). In the 2 cohorts, 60% and 58% of scanned patients underwent head CT. However, CT scans of the abdomen delivered the greatest proportion of radiation, accounting for approximately 40% of the total radiation in each cohort. This is because of the greater effective dose delivered by an abdominal CT compared with other examinations. The pelvic and chest CT scans represented the second and third largest sources of CT radiation in the study population. When analyzing these common examination types, it is interesting to note that brain MRI can diagnose many of the same pathologies as head CT scans, and to a lesser extent, both abdominal ultrasound and abdominal MRI can do the same for abdominal CT scans.

In comparing the 2 cohorts, the number of patients receiving radiation doses >100 mSv more than doubled, while the number of patients receiving >50 mSv nearly doubled (Figure 1). Although it is difficult to predict the future growth rate of CT imaging, the increases we have witnessed thus far sufficiently underscore the need for the judicious use of CT scanning and implementation of newer techniques, such as active dose modulation. Such techniques can reduce radiation from a single CT examination by as much as 60% [23]. Although the percentage of patients receiving a single CT scan grew from 42% to 50% across the cohorts, the total number of patients receiving a CT scan grew by almost 24% from the first 4-year period to the second.

This growth is likely multifactorial. Some of this growth was likely related to the increased use of MDCT beginning in the early 2000s. CT angiography grew from <1% (n = 7,792) of all CT scans in the earlier cohort to >5% (n = 157,589) of all CT examinations in the second cohort. Although the procedure contributes high radiation doses, it has significant advantages compared with invasive diagnostic catheter angiography, including less risk for serious side effects or complications and lower costs from necessary personnel or inpatient care.

One of the limitations of our study is that it is derived from claims data. This makes it impossible to draw conclusions about factors such as indications for the studies and underlying diagnoses. A further limitation is its inability to accurately extrapolate radiation risk to young adults or children, given their higher sensitivity to radiation and consequent increased carcinogenic risk. Furthermore, as widely asserted by others, the implications of radiation exposure from imaging are based on the limited understanding of the effects of ionizing radiation on the human body. Our theories are derived largely from cancer incidences among atomic bomb survivors [17]. Although those radiation estimates are generally accepted and are used to determine formal population and occupational exposure limits, they were derived from estimated exposures. Although low and protracted doses of radiation (ie, <50 mSv) have not been shown to confer statistically significant carcinogenic risk in the past [17], a recent study suggested that there may be small increases in excess relative risk even with cumulative doses <50 mSv [24]. The study showed this to be true only for lung cancer but did not adjust for smokers in the population. As of this publication, protracted exposure to radiation in low cumulative doses (ie, <50 mSv) is not considered to be carcinogenic. In fact, several studies have failed to prove such a linkage [24-26]. The historical impediment to determining the true protracted radiation risk of low doses has been the inability to assemble sufficiently large populations [17].

CONCLUSIONS

We find that with advances in high-speed CT technology, the risk for secondary cancers is still very low in the elderly, but radiation doses have been increasing along with the increasing reliance on CT scans for diagnosis and management. Our study reveals a pattern of increasing radiation exposure from CT over the period examined. Given the increasing importance of CT to diagnosis and therapy, this trend needs careful monitoring. Although modern CT imaging is inarguably a vital part of medical care, its utilization must include a conscious acknowledgment of radiation exposure and an awareness of the pursuant carcinogenic risk. As medical care continues its dependence on advanced technologies such as

MDCT, we emphasize the importance of continuing technological research that encourages the exploration of lower radiation dose methodologies.

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