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Estimated Radiation Risks Potentially Associated with Full-Body CT Screening[1]

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PURPOSE: To estimate the radiation-related cancer mortality risks associated with single or repeated full-body computed tomographic (CT) examinations by using standard radiation risk estimation methods.

MATERIALS AND METHODS: The estimated dose to the lung or stomach from a single full-body CT examination is 14–21 mGy, which corresponds to a dose region for which there is direct evidence of increased cancer mortality in atomic bomb survivors. Total doses for repeated examinations are correspondingly higher. The authors used estimated cancer risks in a U.S. population derived from atomic bomb–associated cancer mortality data, together with calculated organ doses from a full-body CT examination, to estimate the radiation risks associated with single and multiple full-body CT examinations.

RESULTS: A single full-body CT examination in a 45-year-old adult would result in an estimated lifetime attributable cancer mortality risk of around 0.08%, with the 95% credibility limits being a factor of 3.2 in either direction. A 45-year-old adult who plans to undergo annual full-body CT examinations up to age 75 (30 examinations) would accrue an overall estimated lifetime attributable risk of cancer mortality of about 1.9%, with the 95% credibility limits being a factor of 2 in either direction.

CONCLUSION: The authors provide estimates of lifetime cancer mortality risks from both single and annual full-body CT examinations. These risk estimates are needed to assess the utility of full-body CT examinations from both an individual and a public health perspective.

There is increasing interest, particularly from independent radiology clinics, in the use of full-body computed tomographic (CT) screening for healthy adults (1–3). The technique is intended to be an early detection device for a variety of diseases, including lung cancer, coronary artery disease, and colon cancer. At present, the evidence for the utility of this technique is anecdotal, and there is considerable controversy (4,5) with regard to its effectiveness. To our knowledge, no studies have yet been reported to indicate a life-prolonging benefit of full-body screening CT (6).

While the potential benefits and risks have been debated in terms of disease detection versus false-positive findings, less attention has been paid to the potential radiation risks associated with full-body CT scanning. The radiation issue is pertinent because CT examinations result in much higher organ doses than those with conventional single-film x-rays (7).

Typical doses from a single full-body CT examination are about 16 mGy to the lung, 14 mGy to the digestive organs, and 10 mGy to the bone marrow. The effective dose, which is a weighted average of doses to all organs (8), is about 12 mSv. If, for example, 10 such examinations were undertaken in a lifetime, the effective dose would be about 120 mSv—that is, 10 times higher than that for a single examination.

To put these doses in perspective, in the most recent report (9) on cancer incidence in survivors of the atomic bomb, individuals in the dose category from 5 to 100 mSv (mean, 29 mSv) show a statistically significant increase in solid cancer risk. The lowest dose category in the exposed atomic bomb survivor population (5–50 mSv; mean, 20 mSv) is also associated with increased cancer mortality risk (10), though of marginal statistical significance ($P = .15$).

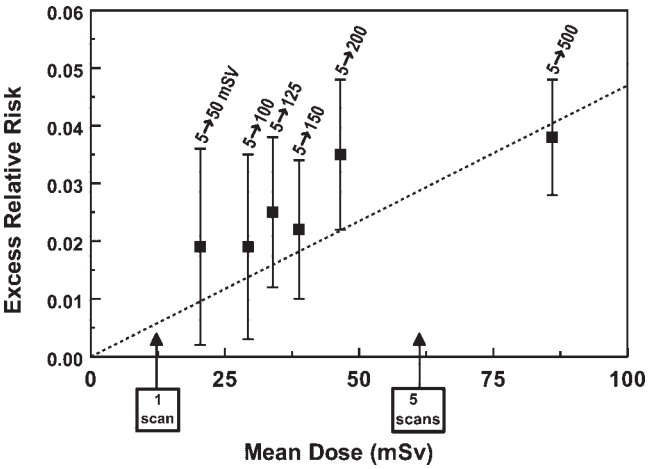

Figure 1. Graph shows estimated excess relative risk (■) (±1 standard error [error bars]) of mortality (1950–1997) from solid cancer among groups of survivors in the life-span study cohort of atomic bomb survivors who were exposed to low doses (<500 mSv) of radiation (10). Dose limits for each group are shown above each data point. Dashed line represents result of zero-intercept linear fit (10) to all life-span study data from 5 to 4,000 mSv (higher dose points not shown). Arrows refer to estimated effective doses from one and five full-body CT examinations.

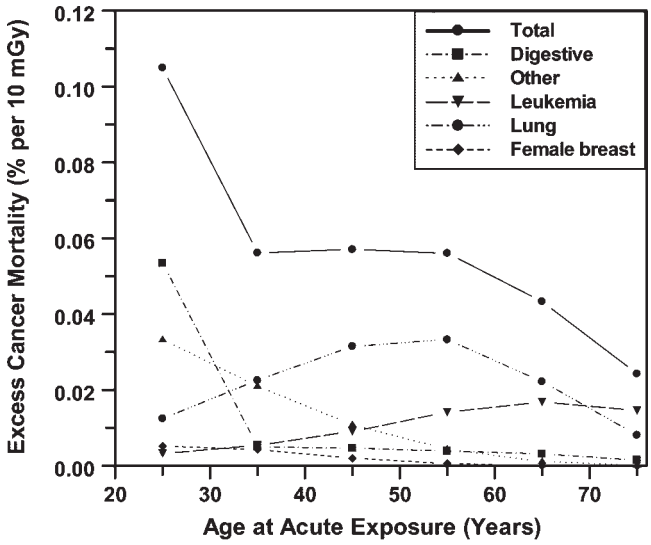

Figure 2. Graph shows estimated excess cancer mortality risk according to age at time of exposure in a stationary population, with U.S. mortality risk rates, that is exposed to a radiation dose of 10 mSv (14). Data are averages between the sexes.

Because of the increasing use of full-body CT screening (3), it is important to examine the potential risks associated with radiation exposure from full-body CT examinations. On the basis of low-dose risk estimates ultimately derived from atomic bomb data, we provide risk estimates for both single and annual full-body CT examinations. The low-dose risk estimates are based on a linear fit to the dose-response data in atomic bomb survivors (11,12).

It is important to note, as illustrated in Figure 1, that the doses of relevance here (approximately 12–350 mGy) correspond to a region in which data on increased radiation risks are directly available from atomic bomb survivors (11,12). It is also clear from Figure 1 that a linear fit to all the atomic bomb data provides estimated risks that are consistent with the data for the doses of relevance here—indeed, Figure 1 suggests that use of a linear fit for risk estimation might lead to slight underestimation of actual risks in the relevant dose range. Thus, while there will be confidence intervals around the risk estimates, it is unlikely that the risks are zero. Of course, the risk estimates for multiple (eg, annual) full-body CT examinations, for which the dose is correspondingly higher, will be considerably more robust.

The purpose of our study was to estimate the radiation-related cancer mortality risks associated with single and repeated full-body CT examinations by using standard radiation risk estimation methods.

MATERIALS AND METHODS

Overall Methods

The basic risk estimation technique is to multiply estimated sex-, age-, and organ-dependent lifetime cancer mortality risks (per unit dose) by estimated organ doses produced by full-body CT examinations. The resulting site-specific estimated cancer risks are then summed to yield the overall lifetime cancer mortality risk estimates. Further methodologic details have been described elsewhere (13).

Lifetime Mortality Risks per Unit Dose

Estimates of organ-dependent lifetime cancer mortality risks (per unit dose) have been given both by the National Academy of Sciences Biological Effects of Ionizing Radiations, or BEIR V, committee (14) and by the International Commission on Radiological Protection (8). Both estimates are based on relative risk models that are dependant on patient sex and age at exposure and inherently assume a linear extrapolation of risks from intermediate to low doses, as discussed earlier. Because of the inhomogeneous nature of the dose distribution produced by CT, we need to evaluate the age-dependent risks separately for each group of potential cancer sites; Figure 2 shows estimated age-dependent lifetime cancer mortality risks derived from the BEIR V committee report (14).

Effect of Dose Fractionation

In estimating the risks for annual full-body CT examinations, we have simply summed the age-dependent risks of individual examinations. This method is appropriate given the low doses of radiation under consideration. Specifically, at high doses, theory (15), animal data (16), and epidemiologic data (17) suggest that fractionation decreases the overall risk at a given dose, but at the low doses of relevance here, both theory (15) and animal data (16) suggest that the risks are independent of fractionation.

Organ Dose Estimation

Clearly, organ doses depend on the techniques used for full-body CT screening. For our study, we used a representative full-body CT scanning protocol from Fishman and Horton (18) from Johns Hopkins Hospital. This protocol involves the use of multi–detector row CT with a Volume Zoom scanner (Siemens, Munich, Germany) from the C3 vertebra through the symphysis pubis, an assumed length of 0.76 m. The protocol specifies 110–150 effective mAs at 120 kV, with a rotation time of 0.5 seconds. The collimation (beam width) is 10 mm, and the pitch, based on the total beam width, is 1.75. On the basis of the pitch, the true milliampere-second range is 190–260 mAs; we used a value of 230 mAs for all calculations.

On the basis of these CT parameters, organ doses can be estimated reliably by using a variety of techniques. We used the Imag-

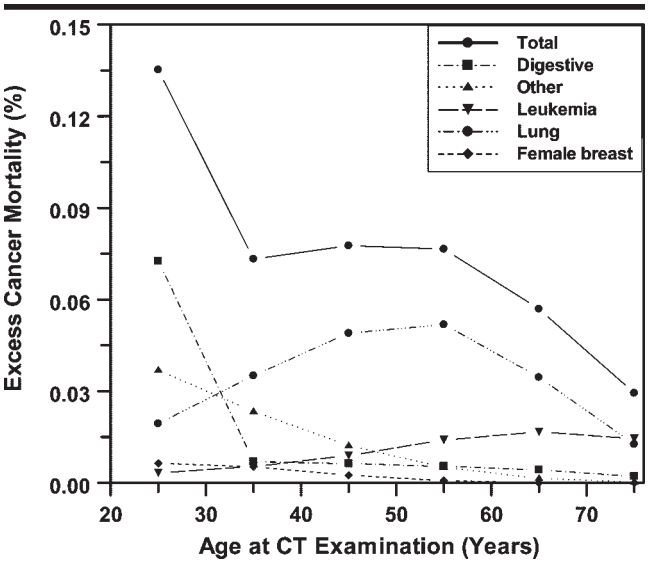

Figure 3. Graph shows excess cancer mortality risks estimated to be associated with radiation from a single full-body CT examination at a given age. Estimated 95% credibility limits are approximately a factor of 3.2 in either direction.

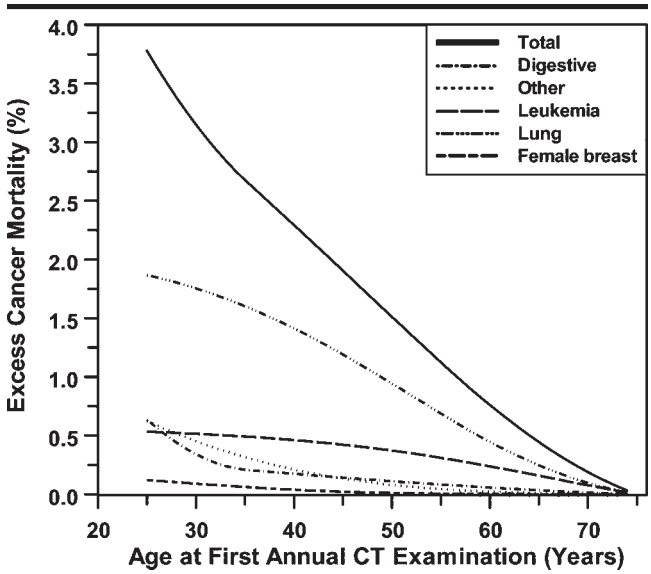

Figure 4. Graph shows excess cancer mortality risks estimated to be associated with radiation from annual full-body CT examinations. Annual examinations are assumed to commence at the specified age and continue until age 75.

Estimated Organ Doses for a Typical Full-Body CT Examination

Organ	Radiation Dose (mGy)
Thyroid	24.7
Bone surface	15.7
Esophagus	16.2
Lung	15.5
Stomach	14.4
Liver	14.0
Bladder	13.9
Breast (female)	12.3
Gonads (female)	12.2
Colon	11.6
Red bone marrow	9.9
Skin	7.5
Gonads (male)	2.6

Note.—Doses were estimated for a full-body CT examination with a Volume Zoom scanner (Siemens) operated at 120 kV and 230 true mAs with a pitch of 1.75. The examination was from the C3 vertebra through the symphysis pubis. Dose estimation was performed with the ImPACT CT patient dosimetry calculator (19). Note if a lower amperage setting is used, the doses would be proportionately lower. The total effective dose (weighted average of organ doses) is 13.5 mSv for females and 11.6 mSv for males.

ing Performance Assessment of CT, or ImPACT, patient dosimetry calculator, which involves the use of techniques described by Jones and Shrimpton (19), together with an extensive database of almost all modern CT machines. Dosimetric calculations were also performed for Mx8000 (Philips, Andover, Mass) and LightSpeed Plus (GE Medical systems, Waukesha, Wis) scanners by using the same settings (120 kV, 230 mAs, 1.75 pitch, and 10-mm collimation).

Uncertainties in Risk Estimates

By using the methods described in reference 20, we estimated 95% credibility intervals (the range of risks that has a 95% probability of containing the true value) associated with these risk estimates. This was done by combining estimates of the various individual sources of uncertainty, such as the effect of fractionation and the risk transfer from Japanese to U.S. populations, which contribute to overall credibility limits.

RESULTS

The estimated organ doses for the previously described CT techniques used with the Volume Zoom scanner (Siemens) are given in the Table. These estimated organ doses were then used to calculate mortality risks. Even with the same settings, different scanners will produce somewhat different organ doses. For example, we calculated the total effective doses for the Mx8000 (Philips) and the LightSpeed Plus (GE Medical Systems) to be 3% and 37% higher, respectively, than that for the Volume Zoom scanner (Siemens). In particular, the calculated dose to the lung is 15.5 mGy for the Siemens scanner, 16.1 mGy for the Philips scanner, and 21.2 mGy for the GE Medical Systems scanner.

Figure 3 shows the estimated lifetime cancer mortality risk attributable to a single full-body CT examination at a given age. Thus, for example, a single full-body CT examination in a 45-year-old patient would result in an estimated lifetime attributable cancer mortality risk of around 0.08% (8×10^{-4}). From Figure 3, it is clear that radiation-induced lung cancer is the dominant cause of cancer mortality in this context.

By using the methods described previously (20), we estimate that the 95% credibility limits for the radiation risk estimates from a single full-body CT examination are a factor of 3.2 in either direction.

Figure 4 shows the corresponding risks for annual full-body CT scans, from a given age up to (but not including) 75 years. For example, a 45-year-old adult who plans to undergo annual full-body CT examinations up to age 75 (30 examinations) would accrue an overall estimated lifetime attributable risk of cancer mortality of about 1.9%. Because the doses are correspondingly higher for multiple examinations, the 95% credibility limits for the radiation risk estimates are narrower and are estimated to be a factor of 2 in either direction for 30 examinations.

DISCUSSION

The practice of full-body CT screening of healthy adults is increasing rapidly. The technique is intended as an early detection device for a variety of diseases, including lung cancer, coronary artery disease, and colon cancer (1–6). One aspect in assessment of the technique is the potential risk from radiation exposure associated with a full-body CT examination. In the present

study, we estimated the radiation-related cancer mortality risks associated with single or repeated full-body CT examinations.

The risk estimates provided here are ultimately based on data from atomic bomb survivors. The doses from a single full-body CT examination are only slightly lower than the mean doses in groups of atomic bomb survivors in which statistically significant increases in cancer risks are seen (9,10,12). Doses for multiple full-body CT examinations are correspondingly higher. Thus, the risk estimates provided here are not the result of extrapolation of risks from atomic bomb data at much higher radiation doses. Indeed, as discussed in the Introduction, estimation of the risks by using a linear model based on atomic bomb survivor data may result in slight underestimation of the risks in the dose range of interest.

Relevant organ doses from a representative full-body CT examination range from 10 to 16 mGy and result in a mean effective dose (ie, a weighted average over all relevant organs) of about 12 mSv. To put this in perspective, a typical screening mammogram produces about 2.6 mGy to the breast (21), with a corresponding effective dose of about 0.13 mSv—a factor of almost 100 times less. Another comparison would be with the annual natural background exposure, for which a typical effective dose is around 3 mSv (22).

Radiation-induced lung cancer is estimated to be the dominant cause of cancer mortality from full-body CT examinations. This is not unexpected because while radiation-related cancer risks generally decrease markedly with increasing age at exposure, radiation-induced lung cancer does not apparently show this decrease in risk until approximately age 55 (14,23,24).

The estimated lifetime cancer mortality risks from a single full-body CT examination are about 8×10^{-4} (about one in 1250) for a 45-year-old adult and about 6×10^{-4} (about one in 1700) for a 65-year-old adult. To put these values in perspective, the odds of an individual dying in a traffic accident in the U.S. during the year 1999 were about one in 5900 (25). Of course, there is uncertainty in the radiation risk estimate: We estimate that the 95% credibility limits for the radiation risk estimate are about a factor of 3.2 in either direction—thus, the lifetime risk from a full-body CT examination in a 45-year-old adult could be as low as 2.5×10^{-4} or as high as 2.5×10^{-3}.

The risk estimates for multiple CT examinations are correspondingly higher. For example, a 45-year-old adult who plans to undergo 30 annual full-body CT examinations would potentially accrue an estimated lifetime cancer mortality risk of 1.9% (almost one in 50). Note that the risk associated with 30 annual full-body CT examinations is somewhat less than 30 times the risk of a single examination at age 45, despite the assumption of risk additivity, since the single-examination risks decrease with increasing age at exposure.

Correspondingly, a 60-year-old who plans to undergo 15 annual full-body CT examinations would potentially accrue an estimated lifetime cancer mortality risk of one in 220. Again, for comparison, the lifetime odds that an individual born in the United States in 1999 will die in a traffic accident are estimated to be one in 77 (25).

As a result of the higher doses involved for multiple examinations, the credibility limits on the risk estimate are narrower, typically by about a factor of 2 in either direction for 30 examinations. The risks from multiple full-body CT examinations can, of course, be reduced by undergoing fewer examinations and/or starting at a later age.

It is important to note that the doses and risk estimates used here are based on a particular full-body CT protocol (18). Even with the same CT settings, different scanners will produce different doses and therefore different risks—we estimate by up to 35%. Full-body CT protocols are by no means standardized at this time, and higher milliampere-second settings will result in correspondingly higher doses and therefore higher risks.

Because of the comparatively low doses associated with full-body CT examinations, the risk estimates provided here have non-negligible uncertainties associated with them. However, despite these uncertainties—factors of 2 to 3—these risk estimates are sufficiently robust to be useful in the assessment of the utility of full-body CT examinations, from both an individual and a public health perspective.

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