# CT Radiation Dose and Risk: Fact vs Fiction

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Since its development in the early 1970s, computed tomography (CT) has secured a place among important diagnostic imaging procedures, helping to save countless lives and improve the outcomes of millions of patients. However, the past 8 years have been tumultuous in the history of CT. The much-publicized concerns about the radiation dose patients receive during CT scans have challenged the modality's perceived value. In many ways, the CT industry is responsible for this shift; new developments in the modality centered on speed (eg, maximizing data acquisition in the shortest time possible) even when these enhancements resulted in elevated radiation dose to the patient. In recent years, however, technological developments and best practices in CT have focused on radiation dose reduction. Imaging personnel now strive to minimize patient exposure during CT scans and vendors have developed technologies aimed at reducing dose. Although much has been accomplished to reduce the exposure patients receive during CT, questions and concerns remain.

"How dangerous is this CT scan?" or "Is this CT scan going to give me cancer?" are the type of questions CT patients are asking more and more frequently. It often is the CT technologist who is faced with answering the questions of patients who have been inundated with sensationalized headlines about the dangers of radiation and showered with statistics claiming a link between CT and cancer. Radiologic science professionals can feel as though they are caught in a tug-of-war between a health care system that relies on imaging procedures and a public concern that the radiation associated with imaging is dangerous.[1]

When patients ask about the amount of radiation they might be exposed to during a CT examination, they likely are looking for information about the risk associated with exposure rather than for a quantified dose amount. Therefore, it is important for CT technologists to be familiar with the latest empirically supported data on the risks of medical radiation exposure. Achieving widespread and consistent use of a reasonable, accurate approach to the communication of dose and risk to patients and the public should be a primary goal of those in the radiologic science profession.

## How Did This Happen?

Increased attention on the risks of medical radiation exposure can be traced back to 2009, when the National Council on Radiation Protection and Measurements issued Report 160 – Ionizing Radiation Exposure of the Population of the United States.[2] This landmark publication outlined the exponential increase in per capita radiation exposure from medical sources in the United States. It also described CT's contribution to this heightened dose, resulting from a dramatic increase in the number of CT procedures performed in the United States each year and the higher radiation dose rates associated with the advent of helical CT in the 1990s.

Report 160 and other follow-up studies concluded that, for the first time, the annual effective radiation dose from medical imaging in the United States had become greater than an average individual's dose from ubiquitous background radiation (see **Table 1**).[3]

Organizations such as the American Association of Physicists in Medicine (AAPM) responded immediately, describing how the summary findings of Report 160 should not be used to estimate the risk of biologic harm to any individual from medical radiation exposure.[4] Despite AAPM recommendations, information from Report 160 and other related research found its way into mainstream media and publicly dramatized concerns of unnecessary medical radiation exposure and the risks of cancer from imaging tests such as CT. Shortly thereafter, headlines about the dangers of medical radiation exposure appeared in prominent U.S. media outlets, including *Newsweek*, *Time*, and *The New York Times*.[5-7] Additional media reports on the topic continued over the next several years. For example, an opinion piece in *The New York Times* from January 2014, titled "We Are Giving Ourselves Cancer," surmised that "our own medical practices" might be responsible for increasing cancer rates in the United States, and that we are "silently irradiating ourselves to death."[7] The March 2015 issue of *Consumer Reports* featured an investigative report on the risks of medical radiation exposure that recommended patients question or avoid a host of medical imaging examinations, including some CT studies.[6] The report quoted the conclusions reached by other researchers that "at least 2 percent of all future cancers in the United States—approximately 29,000 cases and 15,000 deaths per year—will stem from CT scans alone."[7]

In January 2016, *The Washington Post* published an article titled, "Should you worry about the radiation from CT scans?"[8] The article recounted many of the previously described concerns, but also included information from a leading expert in medical radiation, Rebecca Smith-Bindman, MD (co-author of the *New York Times* opinion piece). Dr Smith-Bindman reported that she met with a group of 300 radiologic technologists, and was "dumbfounded by their questions," which included, "How do I pick a dose?" According to Dr Smith-Bindman, a technologist stated that in her hospital, "no one cares" about radiation doses. This rhetoric is damaging to health care personnel, patients, and members of the public. It is the responsibility of those in the radiation sciences to develop a clear and cohesive message that illustrates their commitment to dose reduction and enables thoughtful and accurate conversations about dose and risk.

Table 1

**Increasing Radiation Exposure**[3]

| | 1980 | 2006 |
|---|---|---|
| Medical Radiation | 0.5 mSv | 3.0 mSv |
| Ubiquitous Background | 2.4 mSv | 2.4 mSv |

## The Profession's Response to CT Dose Concerns

A number of resources, regulations, and technologies have been developed over the past 8 years in an effort to minimize patient radiation exposure during CT studies. Several initiatives have been developed to help ordering practitioners determine whether a CT examination is justified, based on clinical indications. Developed in 1999, the American College of Radiology (ACR) has continued to expand and improve its Appropriateness Criteria for use by ordering practitioners.[9] The ACR Appropriateness Criteria website lists dozens of clinical conditions and symptoms, each with an accompanying evidence-based set of guidelines for ordering the most appropriate imaging examinations based on sensitivity, specificity, and associated ionizing radiation exposure.[10] In 2012, The American Board of Internal Medicine developed the Choosing Wisely program to help ordering practitioners choose appropriate imaging procedures and avoid those with the most potential for overuse.[11] For example, practitioners are encouraged to consider ultrasound before CT to diagnose suspected appendicitis in pediatric patients.[12]

Ordering the appropriate imaging procedure based on specific clinical indications is the first step in minimizing patient radiation exposure from CT. Once CT is justified, optimization of the procedure is the next priority. The Image Gently campaign was developed in 2007 through the coordinated efforts of several imaging-related agencies and organizations to minimize CT radiation exposure to pediatric patients by "child-sizing" protocols.[11,13] A similar campaign, called Image Wisely, was developed in 2010 to improve awareness of the need to reduce medical radiation exposure to adult patients from CT, fluoroscopy, and nuclear medicine.[14] The Image Wisely website offers a host of instructional resources about best practices in CT dose reduction.[15]

Technical improvements also have helped to minimize patient radiation exposure during CT. For example, automatic tube current modulation, commonly referred to as *AEC for CT*, has become commonplace.[16] This sophisticated system automatically adjusts tube current (milliampere) to match the size and density of the acquired anatomic region, minimizing exposure to a predetermined level. This level of automation has expanded to include control of tube potential (kilovolt) to further minimize patient dose.[17]

CT detector technology has improved dramatically over the past 2 decades.[18] The exclusive use of solid-state detector materials has resulted in extremely high efficiency levels with no signal loss, allowing for reduced radiation exposure to the patient. Perhaps the most important technology to emerge is the use of iterative reconstruction of the CT image.[19] Originally used as a mathematical reconstruction method during the early days of CT imaging, today's powerful computer processors have enabled iterative techniques to become an effective tool in efforts to reduce patient dose. Iterative reconstruction produces CT images that have minimal noise, even when technical factors have been reduced significantly. The slice wars of the late-1990s to early 2000s have given way to an ongoing dose war.[20]

Regulations have been implemented to ensure that patients undergo CT examinations in systems that are equipped with the latest dose-reducing technologies. The National Electrical Manufacturers Association published a CT dose standard through its Medical Imaging & Technology Alliance division in 2013 (commonly called MITA Smart Dose Standard [XR-29]). To comply with standard XR-29, a CT system must employ dose-saving measures, including adult and pediatric protocols, automated tube current modulation, and a CT dose check system that notifies the user of the potential for excessive patient exposure before a CT scan is initiated. Facilities whose CT systems do not meet standard XR-29 can be subject to a reduced Medicare/Medicaid reimbursement. Requiring facilities to comply with high-quality standards to receive financial reimbursement is crucial to ensuring that the commitment to dose minimization in CT becomes widespread.

## What Are the Risks?

CT technologists play a vital role in the discourse about patient radiation dose and risk of biologic harm, or detriment. Because it is the imaging professional who often has the most direct patient contact during a diagnostic examination, it is the CT technologist who is faced with answering patient questions about the radiation dose from and potential risks of an exposure. To answer the questions effectively, the technologist must be knowledgeable about the value and limitations of current medical radiation exposure and risk literature. For example, the most-publicized studies about CT risks use radiation dose data from the years before exposure-reducing initiatives were implemented. Studies that assess the risk of detriment from medical radiation exposure primarily are based on comparisons between estimated effective dose levels from CT studies and the radiation exposures experienced by survivors of the atomic detonations in Hiroshima and Nagasaki, Japan, at the end of World War II. Using decades of epidemiological data, researchers have examined the correlation between the radiation exposure experienced by a cohort of citizens who lived in the area surrounding the atomic bomb detonations and the incidence of certain types of cancer.

Recent published studies often use this research to compare dose approximations for CT procedures and draw conclusions about the risk of similar carcinogenic effects from exposure to medical radiation. For example, Berrington de Gonzalez et al proposed direct links between CT radiation exposure and the incidence of cancer using risk estimates derived from post–World War II data.[10] In 2009, the same group of researchers published the controversial estimation that CT could be responsible for up to "29,000 future cancers." This became a commonly quoted statistic during the early stages of the CT dose controversy and still is cited today. However, radiologic science professionals have begun to challenge the validity of such comparisons in consideration of the significant differences between the single high dose of ionizing radiation exposure encountered from an atomic bomb detonation and the smaller, protracted dose from a single or series of medical imaging procedures.[21] This fundamental difference in the type of radiation and mechanism of exposure has been cited as a significant weakness of the existing published studies about medical radiation dose and risk.[22,23]

Other researchers, such as Pearce et al, used retrospective cohort studies to propose links between CT radiation dose and carcinogenesis.[24] In their 2012 article in *The Lancet*, Pearce et al reviewed medical record data and concluded that, "Use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer."[25]

Some scientists, including McCullough et al, have since argued that such retrospective cohort studies have significant limitations, including unspecified radiation doses and a lack of clinical information about the indication for the CT studies included in the research.[24] A reverse causality phenomenon might result when the clinical indication for a CT of the brain (ie, headache, dizziness, change in mental status) is not controlled for in this type of research. In this situation, the possibility exists that an early, undiagnosed brain cancer has led to a head CT examination, whereas the researchers propose that the CT of the head led to the development of a brain tumor.[24]

An additional critique of the current literature is related to the use of effective dose as an indicator of risk in these comparative studies.[25-27] One issue involves the limitations and the potential for misuse of effective dose as a risk estimator. The effective dose unit attempts to provide a measure of the potential stochastic detriment or risk of biologic harm (eg, carcinogenesis or hereditary effect) from a given dose of radiation exposure. The effective dose can be estimated by summing the weighted equivalent doses to the varied organs and tissues exposed during a CT examination. Established (and routinely revised) tissue factors are used to weight the equivalent dose estimations to each organ or tissue type to calculate an estimated whole-body risk from the partial body exposure that occurs during a CT study. The effective dose from a CT study is derived by converting the dose length product of a partial body acquisition (absorbed dose) into a whole-body dose estimation (effective dose). Conversion to a whole-body exposure is necessary so that comparisons of risk can be made to the epidemiological data available from studies of post–World War II atomic bomb survivors (see **Figure**). Brenner and others describe the limitations of effective dose as a risk estimator as[28]:

- Potential inconsistencies due to committee-determined tissue weighting factors set by the International Commission on Radiological Protection. For example, the tissue-weighting factor for the gonads was adjusted from 0.25 to 0.08 in 2007. These revisions are based on the latest epidemiological information but are subject to varying interpretation by a committee of scientists that fluctuates over time.
- The inability of effective dose estimations to account for the various radiosensitivity factors inherent in the individuals, including age at exposure, gender, and genetic predisposition—all factors thought to be related to risk of biologic detriment.
- Confusion and the casual interchanging of effective dose in the literature with other dose metrics, including absorbed and equivalent dose.

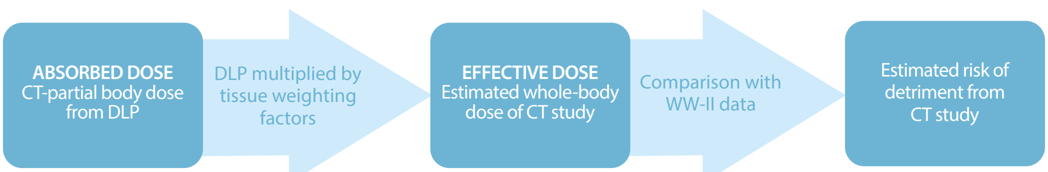


**Figure.** *Method of risk estimation involves calculation of whole-body effective dose for comparisons with World War II epidemiological data. Abbreviations: CT, computed tomography; DLP, dose length product; WW–II, World War II. Figure courtesy of the author.*

- Inappropriate use of effective dose to estimate the risk to individuals. Effective dose estimations have significant value in efforts to optimize technical factors for dose reduction during CT. However, the uncertainty (+/− 40%[25]) in effective dose estimations renders them ineffective for estimating detriment risk to an individual.

To be informed consumers of current literature about radiation dose and risk, technologists must understand the appropriate use and inherent limitations of effective dose estimations.

## What Can Be Done?

Improved communication with patients about radiation dose and risk can help counteract negative messages in mainstream media and problematic findings from researchers. In addition, a consistent response across facilities and technologists about the expected radiation dose from a CT procedure and the risk of harm to patients could improve the public's perceptions of the profession and of technologists' vital role on the health care team. When patients hear conflicting messages, or technologists use different approaches to explain the dose/risk relationship—perhaps by using unrelated comparisons to the risk of automobile travel or exposure to the harmful rays of the sun—the message is diluted and could be perceived as less accurate.

To reduce the spread of misinformation, imaging professionals should implement evidence-based methods to relay dose and risk information to patients.[29,30] One viable method is to use simple and clear descriptors to rate the estimated risk of a given imaging procedure (see **Table 2**).[28,31] For example, when asked what the risk of a head CT might be, the technologist would state that it is very low. Consistent use of these descriptor terms by all imaging personnel could improve communication with patients and the public. Another evidence-based method is known as *background equivalent radiation time*, or BERT (see **Table 3**).[32] The estimated effective dose from a given procedure is reframed as a comparable dose of natural radiation one receives simply by living on the planet for a period of time. BERT is a valuable approach to communicating dose and risk information because it reminds patients that medical imaging is not the sole, or even primary, source of exposure to ionizing radiation. Practitioners could combine both approaches to develop their own method of communicating risk information to patients (see **Table 4**). Consistent and appropriate responses to questions concerning dose and risk from CT technologists and from all radiologic science professionals could help to restore and then to maintain trust in technologists' commitment to maintaining the safety of patients.

## Conclusion

CT remains a safe and crucial medical imaging modality with superior sensitivity and specificity.[34] The profession's efforts in the areas of best practices, regulations, and technological improvements have decreased patient radiation dose from CT.[31] Considerable empirical evidence supports that the low radiation dose levels achieved in CT have little associated risk of significant biologic detriment.[32] Because some risk still exists, technologists must continue to make every effort to optimize their technical approach to limit exposure while maintaining the diagnostic efficacy of CT procedures. At the same time, technologists also must

Table 2

**Relative Risk Descriptors That Would Simplify Communication With Patients About Radiation Dose and Risk[28,31]**

| Effective Dose (mSv) | Level of Risk | Descriptor | Examination |
|---|---|---|---|
| < 0.1 | < 1 in 1 million | Negligible | Radiography of chest, extremities, or teeth |
| 0.1-1.0 | 1 in 100 000 | Minimal, or extremely low | Radiography of abdomen, spine, or pelvis |
| 1.0-10 | 1 in 10 000 | Very low | BE, CT brain, chest, or abdomen, nuclear medicine bone scan |
| 10-100 | 1 in 1000 | Low | Multiphase CT |
| > 100 | > 1 in 100 | Moderate | Interventional; multiple/repeat CT |

*Abbreviations: BE, barium enema; CT, computed tomography; mSv, millisievert.*

Table 3

**BERT Comparisons Used to Clarify and Normalize Radiation Exposure to CT Patients**[32]

| Radiographic Examination | Effective Dose (mSv) | BERT |
|---|---|---|
| Bone densitometry | 0.001 | 3 h |
| Extremity radiography | 0.001 | 3 h |
| Chest x-ray (PA and LAT) | 0.1 | 10 d |
| Mammography | 0.4 | 7 w |
| Spine radiography | 1.5 | 6 mo |
| CT head (noncontrast) | 2 | 8 mo |
| Upper GI series | 6 | 2 y |
| Cardiac CTA | 12 | 4 y |
| CT abd/pel – pre and post | 20 | 7 y |

*Abbreviations: adb/pel, abdomen/pelvis; BERT, background equivalent radiation time; CTA, computed tomography angiography; GI, gastrointestinal; LAT, lateral; PA, posteroanterior.*

Table 4

**Communicating Radiation Risk to Patients**[33]

| Do | Do Not |
|---|---|
| Tell the truth, using the simplest language possible | Use overly complicated jargon |
| Avoid absolutes | Talk theory without a clear, non-technical explanation |
| Stay calm and positive | Discuss worst-case scenarios |
| Clarify to make sure patient understood | Link risk and benefit; address each separately |
| Cite only trustworthy data | Compare unrelated risks (eg, airplane or automobile travel) |

consider the risks of reducing dose to the point that image quality falters or diagnoses are delayed or missed. Balter et al summarized this important consideration by stating, "There is no radiogenic risk if the patient does not survive long enough to manifest the cancer."[35]

CT technologists must serve as advocates for the profession and for the work they do to improve patient outcomes and save lives. The challenge for all radiologic science professionals is to become the experts in radiation health that the profession needs and the patients deserve.

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