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Answers to Common Questions About the Use and Safety of CT Scans

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Abstract

Articles in the scientific literature and lay press over the past several years have implied that computed tomography (CT) may cause cancer and that physicians and patients must exercise caution in its use. Although there is broad agreement on the latter point—unnecessary medical tests of any type should always be avoided—there is considerable controversy surrounding the question of whether, or to what extent, CT scans can lead to future cancers. Although the doses used in CT are higher than those used in conventional radiographic examinations, they are still 10 to 100 times lower than the dose levels that have been reported to increase the risk of cancer. Despite the fact that at the low doses associated with a CT scan the risk either is too low to be convincingly demonstrated or does not exist, the magnitude of the concern among patients and some medical professionals that CT scans increase cancer risk remains unreasonably high. In this article, common questions about CT scanning and radiation are answered to provide physicians with accurate information on which to base their medical decisions and respond to patient questions.

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Ongoing developments in computed tomographic (CT) imaging have led to an ever-increasing number of clinical applications, many of which have supplanted less accurate or more invasive diagnostic tests. For example, CT has the highest sensitivity (95%) and specificity (98%) for urinary stone detection than does any imaging technique, including radiography and ultrasound,[1-8] and CT angiography has almost replaced invasive angiography as the initial test of choice. Because of their clinical value, the number of CT scans performed annually in the United States has increased substantially; an estimated 81 million CT scans were performed in the United States in 2014.[9] Although there is a perception among some physicians and patients that the dose of ionizing radiation from medical imaging examinations, particularly CT, poses a substantial cancer risk to patients, this perception is not consistent with data from high-quality studies, nor with current consensus opinions of radiation protection organizations.[10-14] In a recent op-ed article in the *New York Times*,[15] 2 physicians expressed their opinion that CT examinations performed in the United States and elsewhere are "killing people." A growing problem in recent years is that some patients forego critically needed CT examinations because of the belief that these examinations are more harmful than beneficial[16]; this problem will likely be exacerbated by the *Times'* op-ed piece and by overinterpretation of recent epidemiological studies.[17,18] Similarly, some physicians refrain from ordering medically appropriate CT examinations because of well-intentioned, but misinformed, concerns.[16] In this article, we address common questions about the use and safety of CT to ensure that physicians are equipped with credible information on which to base their decisions when weighing the risks and benefits of ordering CT scans.

HOW IS RADIATION DOSE IN CT QUANTIFIED?

Several radiation dose metrics are currently used in CT dosimetry, each of which is used for different purposes. The volume CT dose index ($CTDI_{vol}$, reported in units of milligray) is one commonly used metric that is displayed on the CT scanner console or in patient dose reports.[19] The volume CT dose index is useful for describing the radiation output from a CT scanner and optimizing CT protocol parameters.

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However, $CTDI_{vol}$ does not represent the patient's absorbed dose.[20] Estimates of patient dose must take the patient's body habitus into account. The American Association of Physicists in Medicine developed a method to calculate size-specific dose estimates (SSDEs) using the reported $CTDI_{vol}$ values and a measure of patient size.[21] The size-specific dose estimate calculates the mean absorbed dose at the center of the scan range. For organs fully contained in the scan range, the SSDE provides reasonable approximations of organ doses. For reference the brain dose from a head CT scan is approximately 50 to 60 mGy and the colon dose from an abdomen/pelvis CT scan is approximately 15 to 20 mGy.

Because much of the data on radiation risk involves exposure to the whole body (eg, from studies of the survivors of the atomic bombings in Hiroshima and Nagasaki, Japan), a mechanism for comparing partial body irradiations, such as in CT, with whole-body irradiations is desirable. To accomplish this, a radiation protection quantity known as *effective dose* is used.[11] The effective dose does not represent the individual biological risk to any particular patient, but rather is used to compare the radiation risk from different types of radiation sources and different imaging examinations.[22] Effective doses are reported in units of millisieverts, and typical effective doses from CT scans range from less than 1 to approximately 10 mSv. For reference, in the United States the average effective dose from naturally occurring background radiation (eg, unavoidable environmental exposures, such as radon gas and cosmic rays) is approximately 3 mSv/y.

When evaluating the "dose" from a CT scan, it is essential that one understand what type of dose is being discussed and then compare that dose to risk data appropriate for that dose metric. For example, the *absorbed dose* to the brain from a head CT scan is approximately 60 mGy, but the *effective dose* from the same CT scan is only approximately 1.5 mSv.

HOW MUCH RADIATION DOES CT USE?

A CT scan delivers an effective dose of anywhere from less than 1 to around 10 mSv, depending on the type of scan the patient receives. For example, the exposure from a head CT scan is approximately 1 to 2 mSv whereas the exposure from a body CT scan is approximately 10 mSv (Table). Some procedures require multiple scans over a region; for example, examinations using iodinated contrast material to visualize tissue vascularity may need to include scans during both the arterial and venous phases. For examinations requiring multiple scans at different contrast enhancement phases, these individual scan doses can add up to 20 to 30 mSv. However, this total is still considered a low dose of radiation, which is defined by the radiation protection and radiation biology communities as dose levels below 100 mSv.

In the United States, the annual effective dose from ubiquitous background radiation is on average 3 mSv/y; the typical range is from 1 to 10 mSv. In regions at higher elevation (which are exposed to more cosmic rays) or

TABLE. Typical Effective Dose Values Associated With Various Medical Imaging Examinations, Background Sources of Ionizing Radiation, and Regulatory Limits[a,b]

Source of radiation exposure	Examination	Effective dose (mSv)[c]
Radiography and fluoroscopy	Hand radiograph	<0.01
	Dental bitewing radiograph	<0.01
	Chest radiograph	0.02
	Mammogram	0.4
	Lumbar spine radiograph	1.5
	Barium enema	8
	Fluoroscopic coronary angiogram	7
Computed tomography	Head CT	2
	Chest CT	7
	Abdomen CT	8
	Pelvis CT	6
	Coronary artery calcification CT	3
	Coronary CT angiogram	16
Radionuclide imaging	Lung scan	2
	Bone scan	4
	Myocardial perfusion imaging	14
Naturally occurring sources of ionizing radiation (eg, cosmic rays or radon gas)		1.3-9.6 (US average=3.0)
Maximum allowable annual occupational dose to radiation workers		50 (US)

[a]CT = computed tomography.
[b]The values for effective dose presented here are typical values for examinations in adults. Variations from these values would be expected because of differences in body habitus (especially in young children and infants), details of the imaging protocols, and equipment used.
[c]Reliable estimates of risk cannot be attributed to effective doses below 100 mSv.
Data from *The Essential Physics of Medical Imaging*.[23]

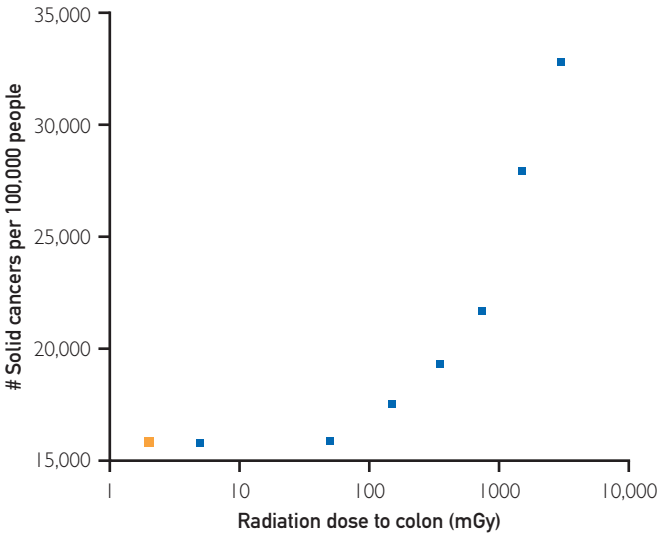

FIGURE 1. The cancer incidence and mortality of more than 86,000 survivors of the atomic bombings in Japan have been studied since 1958. The first (orange) square represents the cancer incidence in individuals from Hiroshima and Nagasaki who were not in town at the time of the bombings. An increase in cancer incidence above the cancer rate of unexposed individuals was observed only for those exposed to more than 100 mGy. Data from *Radiat Res.*[27]

over certain types of soil (that contain radon), the background radiation dose can be up to 20 mSv/y.[24] As shown in the Table, CT scans deliver doses in the same range as annual natural background radiation levels, although at a higher dose rate (ie, over a much shorter time), and targeted to specific body parts (rather than to the whole body).

HOW MUCH RADIATION IS DANGEROUS?

Acute whole-body doses of radiation in the range of hundreds to thousands of millisieverts increase the long-term risk of cancer. Increases in leukemia have been observed beginning as soon as 2 years after exposure to doses above approximately 200 mSv, although some cases did not appear for 55 years.[25] For tumors in solid organs, the latency period is in the range of 10 to 40 or more years. Reports from the ongoing epidemiological studies of the atomic bomb survivors have clearly found a small but statistically significant increase in cancer mortality for absorbed doses above approximately 150 mGy. Importantly, no statistically significant excess cancer mortality has been reported in the atomic bomb survivors who were farther away from the epicenter and who received acute whole-body doses below 100 to 150 mGy[26] (Figure 1).

A number of other groups of exposed individuals have been studied, including populations living in regions with higher background radiation levels, radiation workers, and individuals with medical exposures. For example, residents of regions with higher background radiation levels (100-260 mSv/y) have been found to have no increase in cancer risk as compared with people living in regions with lower background radiation levels.[28] The largest published study[29] in radiation workers evaluated a cohort of approximately 500,000 occupationally exposed workers, across 15 countries, who received a cumulative radiation effective dose of less than 100 mSv. A statistically significant increase in cancer mortality was originally found in this group, but subsequent analyses excluding data from Canada (which were determined to be flawed) eliminated the statistical significance of the study.[30,31] A high-quality study[32] from the United Kingdom focusing on occupational exposures did report a small but statistically significant increase in cancer risk, albeit at dose levels much higher (200-500 mSv) than the dose levels typically associated with diagnostic imaging (<1-25 mSv).

Cancer death risk estimates after exposure to x-rays are often based on the study of people exposed to a single instantaneous radiation dose (ie, the atomic bomb survivor cohort). However, the existence of a risk-moderating effect due to dose fractionation is supported by both radiobiological principles and data from animal experiments.[33] This suggests that the risk models for some cancers may be overestimated when similar exposures are received over a longer period of time, such as those that occur from multiple medical diagnostic procedures. For example, the excess relative risk for lung cancer mortality in a cohort of 64,172 Canadian patients with tuberculosis exposed to highly fractionated multiple chest fluoroscopies has been compared with estimates derived from the atomic bomb survivors.[34] In the fluoroscopic study, there was no evidence of any positive association between risk and dose, which contrasts with what was found in the atomic bomb survivors. This example suggests that cumulative absorbed doses from radiological examinations are not equivalent in biological risk to a single high-dose exposure.

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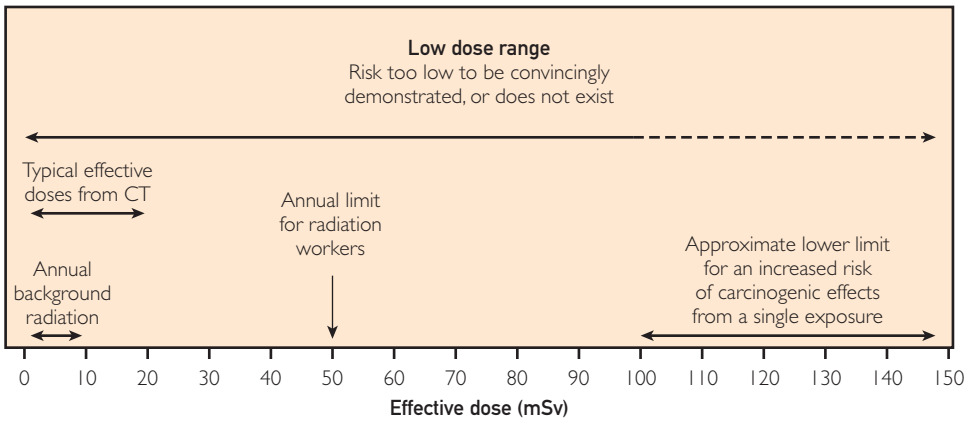

FIGURE 2. Diagram comparing the effective dose levels received annually from naturally occurring sources of radiation in the environment (1-10 mSv), effective dose levels received annually from computed tomographic exams (<1-20 mSv), the annual limit established by the Nuclear Regulatory Commission for radiation workers (50 mSv), and the approximate lower limit for an increased risk of carcinogenic effects from a single exposure (100-150 mSv). Below 100 mSv, the risk is too low to be convincingly demonstrated or does not exist. Nuclear Regulatory Commission regulations allow radiation workers to receive 50 mSv of radiation per year for each year of an estimated 40-year career. At such annual dose levels, the occupational risk for a radiation worker is considered to be similar to that of nonradiation workers.[36]

The examples discussed above do not constitute absolute proof of no risk at low dose because, as with all epidemiological studies that are observational in nature, there are confounding variables and other limitations that must be addressed. Caution should be exercised to prevent overinterpretation of any given body of evidence. What we can say is if there is a risk at low doses, it appears to be extremely low compared with the natural cancer incidence.

In summary, across different studies that focus on different types of exposures, in different populations, and that use different methods of estimating dose and different cancer outcomes, there is no convincing epidemiological evidence of increased cancer incidence or mortality at low doses (<100 mSv). A reasonable interpretation of this fact is that the extrapolated data that these studies rely on are not effective in detecting a small increase in long-term effects of low-dose exposures when measured in the presence of the high background of lifetime cancer incidence (43% for men and 38% for women) and mortality (23% for men and 19% for women) from all causes,[35] or that, in fact, the risks are nonexistent. A number of US and international radiation protection organizations, including the United Nations Scientific Committee on the Effects of Atomic Radiation, the International Commission on Radiation Protection, the National Council on Radiation Protection & Measurements, the Health Physics Society, the American Association of Physicists in Medicine, and the Académie Nationale de Médecine (French National Academy of Medicine), have repeatedly cautioned that reliable estimates of cancer risk cannot be attributed to doses below 100 mSv (Figure 2). In its 2012 report to the United Nations General Assembly,[13] the United Nations Scientific Committee on the Effects of Atomic Radiation specifically noted that an increase in the incidence of health effects in populations cannot be attributed to exposure to radiation doses at levels that are typical of global background radiation levels, that is, 1 to 10 mSv/y, which is the same as in most medical imaging examinations (see Table).

IS THERE ANY DIRECT EVIDENCE THAT CT SCANS CAUSE CANCER?

At the low radiation doses from typical medical imaging examinations, the magnitude of any long-term increase in cancer risk is controversial because, as discussed above, the risks (if they exist) are lower than our ability to discern

them with confidence from current epidemiological studies. Even if we could control for all confounding variables, it would require an epidemiological study of more than 5 million people to be able to demonstrate an increased cancer risk from exposures to radiation doses below 10 mSv—the typical doses delivered by body CT scans.[37] Several ongoing studies, however, are evaluating the incidence of cancer in people who underwent CT scans during childhood. Two recent publications[38,39] indicate that CT scans might cause an increase in cancer risk; however, the findings must be interpreted with caution because of some serious methodological limitations[17,18,40,41] and several highly improbable results. A third[42] and a fourth[43] article, which addressed many of these shortcomings by taking into account predisposing factors and performing careful dosimetric analyses, found no increase in cancer risk because of childhood CT examinations. Here, we will briefly discuss the controversies surrounding the 2 articles with positive findings[38,39] to demonstrate that the matter is far from settled.

Pearce et al[39] conducted an observational retrospective cohort study examining the incidence of leukemias and brain cancers in patients who underwent CT scans between 1985 and 2002, when they were younger than 22 years. This study did not include individual dose assessments or take into account specific information on the type of machine used or the procedure performed, but rather estimated doses using data from national surveys of typical CT acquisition parameters. This study found that the estimated doses delivered to the red bone marrow and brain by CT were associated with the subsequent incidence of leukemia and brain tumors. On the basis of their assessment, Pearce et al estimated that in the 10 years following head CT scans of 10,000 children performed in their first decade of life, 1 excess case of brain tumor and 1 excess case of leukemia might be attributable to CT imaging. They conclude that radiation doses from CT scans should be kept as low as possible and that alternative imaging strategies not involving radiation should be considered when such alternatives offer similar diagnostic benefits.

Similarly, Mathews et al[38] compared cancer incidence in children aged 0 to 19 years exposed to CT scans between 1985 and 2005 with incidence in the corresponding unexposed population. The overall incidence of cancer was found to be 24% higher in the exposed group than in the unexposed group; risk increased with dose and with younger age at exposure. The rates of both solid and nonsolid tumors increased.

A number of concerns must be taken into account when evaluating these studies. First, the radiation doses assigned to individuals were highly uncertain. No doses were measured or estimated for any individual patient. Furthermore, doses from any other imaging examinations using x-rays or radiopharmaceuticals were not accounted for, even though missing exposure data would result in inflated estimates of risk. Finally, the doses applied were adult dose levels, taken from the national survey data and typical scanner settings, assuming that, in most cases, the dose was not decreased for children. However, such decreases in dose have been the standard of care for more than a decade.[44,45] Thus, even if the patient doses used in these studies were accurate, they would be 2 to 5 times higher than those used in current CT scanning, making the results less relevant to today's practice.

Another important limitation of these studies was the lack of any clinical information about the reason for the CT referral. It is plausible that in some cases, the patient's symptoms leading to CT examination were from an existing preclinical cancer or other predisposing risk factor. This is particularly true for cases in which children underwent multiple CT scans, which indicates the potential presence of recurrent symptoms or ongoing disease. Thus, confounding by indication may have played an important role in these studies, thereby weakening a causal interpretation of the results. This "reversed causality" phenomenon is an established weakness in epidemiological studies of radiation in medical cohorts.[17,46-48]

Another set of significant concerns is related to the discordance of these studies with previous reports. Radiation is perhaps the single most studied carcinogen in the world, with studies dating back to the early 20th century. Thus, any single study adds to a vast body of literature and must be interpreted in the context of previous results, particularly results that have been replicated in multiple studies. Articles by both Pearce et al and Mathews et al include a large number of observations that are not consistent with the existing literature on radiation effects.

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For example, the relationship between increased risk and age at exposure observed in the study by Pearce et al was exactly the opposite of what has been observed in the atomic bomb survivor cohort and numerous other studies. Similarly, in the study by Mathews et al, no significant increase in leukemia was seen for those exposed before the age of 10. This is inconsistent with other studies of radiogenic childhood leukemia, which reported the highest leukemia risk for those exposed at the earliest ages.

Two recent studies that considered the conditions that prompted the CT scan, family history and other predisposing factors (~70,000 children in France[42] and ~45,000 children in Germany[43]), found no significant excess cancer risk from CT scans. In Journy et al,[42] 32% of the observed cancers were among children with predisposing factors. Predisposing factors were also associated with specific patterns of CT use. Adjustment for predisposing factors reduced the excess risk estimates such that no significant excess risk was observed in relation to CT exposures. This study suggests that the indication for examinations should be considered to avoid overestimation of the cancer risks associated with CT scans.

Considering the limitations of epidemiological research, these studies do not prove that there is zero risk, just as studies with positive findings do not prove that there is risk; the effect, if present, is too small to be convincingly demonstrated with the epidemiological data available to date.

ARE ESTIMATES OF HOW MANY PEOPLE EXPOSED TO CT WILL DIE OF RADIATION-INDUCED CANCER ACCURATE?

A 2009 article[49] estimated that CT scans conducted in 2007 (~70 million) could cause a projected 29,000 excess cancer cases (0.04% increase) and 14,500 excess deaths (0.02% increase) over the lifetime of those exposed. It is essential to note that this study, and others like it, was a hypothetical exercise. Using data from the National Academies of Sciences BEIR VII report,[33] the authors took *small and highly uncertain estimates* of the risks from ionizing radiation (ie, a fraction of a percent increase in lifetime cancer risk from a typical body CT examination) and multiplied these values by a large number of performed CT scans. No single patient was studied, no doses for any patient were measured or calculated from known CT exposure parameters, and no excess cancer cases were reported. The inference that there will be any excess cancer deaths using this speculative mathematical exercise has been criticized by a number of scientific organizations,[10,12-14,41,50] including the American Association of Physicists in Medicine, the Health Physics Society, the National Council on Radiation Protection & Measurements, the International Commission on Radiation Protection, the International Organization for Medical Physics, and the United Nations Scientific Committee on the Effects of Atomic Radiation.

CHILDREN ARE MUCH MORE SENSITIVE TO RADIATION THAN ARE ADULTS: IS IT APPROPRIATE TO USE EXAMINATIONS LIKE CT IN CHILDREN?

It is true that some tissues are more sensitive to radiation in children than in adults. For example, children are more radiosensitive than adults with regard to the development of thyroid, skin, breast, hematopoietic, and brain cancers. However, in other tumor types, children are either no more sensitive (eg, bladder cancer) or actually less sensitive (eg, lung cancer) than adults.[17] In the remaining half of the 23 tumor sites evaluated (eg, Hodgkin lymphoma, esophagus, prostate, rectum, and uterus cancer), there is either no evidence of a link between radiation and cancer or the evidence is too weak to draw any conclusions, particularly with regard to risk as a function of age.

Nevertheless, even for tissues that may not be more sensitive in children, lower doses are frequently warranted in children because of their smaller size and because they have a longer life expectancy than do adults, which may enable tumors with long latency to develop. For a body CT scan of a baby, the amount of radiation used should be approximately 20% of that used for an adult. Appropriately adjusting the radiation dose for children has been a major area of focused attention and improvement over the past 10 years. The "Image Gently"[51] campaign and other efforts have been effective at bringing this issue to the attention of the imaging community, referring physicians, and patients.

WHAT IS BEING DONE TO LOWER RADIATION EXPOSURES AND WHY?

Although radiation doses from individual CT examinations are low and the level of risk (if

any exists) is low, prudence suggests a conservative approach: namely, we assume that there may be a small increase in cancer risk even from these low doses. Therefore, there have been efforts across the globe to keep doses of ionizing radiation from all types of medical examinations, including CT, as low as diagnostically acceptable.[52] This as low as diagnostically acceptable approach to medical imaging is the current standard of care and should reassure patients and physicians that the lowest possible dose consistent with the medical objective is being used.

In recent years, patients have become informed (and sometimes unfortunately misinformed) about the potential risks of medical imaging examinations or procedures recommended as part of their medical care. Although it should go without saying, it is important to recognize and emphasize the fact that the immediate medical benefit of appropriate imaging examinations far outweighs the low, future, and theoretical risk of the radiation received.[53-55]

The Joint Commission[56,57] now requires radiology departments to track dose levels used and to compare their data with those from other medical centers. This is facilitated through use of a commercial dose tracking software package or via participation in the Dose Index Registry of the American College of Radiology.[58] These data are useful in demonstrating that doses are indeed on the decline as well as in prompting radiology departments to examine their CT practices if their dose levels fall above national normative data. The observed reduction in dose for CT imaging is partly due to a requirement for all new CT scanners to include several types of dose reduction technology.[59] These technical features help reduce dose without compromising the diagnostic value of the examination. Combined with advances in image processing, the replacement of older CT scanners with new models has resulted in dose decreases of 30% to 70%, depending on the type of examination performed.[45]

The decision to order a CT scan should be based on appropriate clinical criteria, and each CT scan should be carefully optimized to provide the required diagnostic information while delivering the lowest possible radiation dose to the patient.[50] The American Association of Physicists in Medicine has developed numerous activities focused on radiation dose optimization in CT imaging, including educational summits, symposia, and teaching materials; standardized scanning protocols; and scientific reports and testing protocols to allow an accurate quantification of scanner radiation output and patient absorbed doses. Other professional medical societies focused on medical imaging, such as the Radiological Society of North America, the American College of Radiology, and the Society of Nuclear Medicine and Molecular Imaging, have supported a large number of ongoing educational and quality improvement initiatives, including educational websites, appropriate use criteria and guidelines, accreditation and training programs, and advocacy at the national level for legislation to mandate important imaging safety and quality improvement activities. The Society of Pediatric Radiology has led an international alliance to educate imaging providers, referring physicians, patients, and parents on how to "Image Gently."[51] A similar alliance focused on adult imaging, "Image Wisely,"[60] provides a similar wealth of resources.

In addition to requiring that radiologic technologists undergo annual training for radiation dose reduction techniques for smaller patients and different types of CT examinations, the Joint Commission mandates that CT protocols (ie, technical instructions for CT data acquisition and image reconstruction) at each institution are reviewed by a radiologist, medical physicist, and supervising CT technologist at regular intervals.[58]

WHY DO THE DOSES PROVIDED IN RADIATION REPORTS VARY SO MUCH?

A number of institutions are beginning to provide information on radiation dose in their radiology reports. In California, this is now required by state law. However, the doses reported for the same examination can vary considerably. This variability is not necessarily a failure of the radiology department to provide consistent quality or dose. Rather, as noted above, the dose needed to produce an image adequate for answering a specific diagnostic question or performing a specific therapy will vary with the indication, patient size, and equipment used. For example, the amount of radiation produced by a CT scanner must be higher for a larger patient relative to a smaller patient in order for the interpreting radiologist to accurately interpret the image, just as a

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larger patient might need a larger dose of medication, relative to a smaller patient, to achieve a specific therapeutic response. In addition, higher radiation doses may be required to image small structures (eg, the inner ear) or detect subtle soft tissue abnormalities (eg, liver metastases). Performing CT imaging at a too low a radiation dose may result in diagnostically unacceptable images that prevent the CT scan from realizing its intended diagnostic use. Thus, the appropriateness of a dose cannot be determined without knowing the size of the patient, the clinical indication and diagnostic task (including likely alternatives to the differential diagnosis), and the CT system hardware and software. Although the aforementioned variables can explain most variations in reported doses, there remains a need for vigilance among imaging specialists to ensure that scan protocols provide appropriate and consistent levels of image quality and dose across machine types and institutions.

Knowing the amount of x-ray attenuation in the scan region, which is correlated with, but not the same as, patient weight or body mass index (calculated as the weight in kilograms divided by the height in meters squared),[20] is important because the dose received by the patient is determined both by the amount of radiation produced by the scanner (the number that is reported on most scanners and dose reports) and by the patient attenuation. Doubling or tripling the amount of radiation produced by the scanner when imaging an obese patient does not necessarily result in an increase in that patient's dose because of the absorption of energy in the adipose tissue surrounding sensitive tissues and organs.[20] A dose parameter referred to as the SSDE is a more appropriate indication of the dose received by an individual patient and is just beginning to be adopted by the radiology community. In a study of 545 adults ranging in "size" from 42 to 84 cm (anterior/posterior thickness plus lateral thickness), the amount of radiation produced by the scanner was (appropriately) increased as patient size increased to obtain similar levels of diagnostic quality.[61] However, after taking the patient attenuation in the scan region into account, the SSDE indicated no correlation with patient size.[61] Thus, variations in the scanner radiation output metrics contained in many radiology reports, such as $CTDI_{vol}$ and dose-length product, can be a sign that appropriate steps have been taken to modify the scanner output according to patient size, and these variations should therefore not necessarily be a source of concern.

AT WHAT POINT DOES THE CUMULATIVE DOSE FROM REPEATED EXAMINATIONS BECOME DANGEROUS? SHOULD PREVIOUS EXAMINATIONS BE CONSIDERED WHEN ORDERING NEW EXAMINATIONS?

People who have undergone many imaging examinations worry about a cumulative effect and possible long-term consequences of malrepaired DNA damage. Although all CT examinations must be clinically justified and the radiation exposure limited to what is clinically necessary, it is important to keep in mind that DNA damage and repair occurs naturally in the human body. DNA damage due to the many oxidative processes associated with cellular respiration and errors that occur during cellular replication have required the body to develop robust, albeit sometimes imperfect, mechanisms for repairing such damage.

Some patients undergo multiple scans over a relatively short time frame because of a complex medical history or a significant life-threatening trauma or illness. In these cases, the examinations are used to make the initial diagnosis, plan treatment, evaluate initial response to therapy, follow the patient to detect potential complications, and monitor the patient for recurrent illness over time. Even though these patients undergo multiple CT scans and therefore receive higher radiation doses, the benefit-to-risk ratio in these patients remains high: the low theoretical increase in risk is more than offset by the increased benefit of the clinical information, particularly in the context of a serious disease or injury.

It is generally agreed that the decision regarding an imaging examination must be made on the basis of the current clinical question at hand and the availability of other medical information. If adequate diagnostic information is available from an appropriate and recent examination, then perhaps a repeat examination is not necessary. However, if the needed information is not available or cannot be determined from previous examinations, then the clinician should order the appropriate and medically

necessary examinations, regardless of imaging history.[54,55,62-64]

SHOULD I ORDER EXAMINATIONS THAT USE LOWER DOSES OF RADIATION (SUCH AS CHEST RADIOGRAPHS) OR NONIONIZING RADIATION (SUCH AS ULTRASOUND AND MAGNETIC RESONANCE IMAGING) RATHER THAN CT SCANS?

Every type of imaging test has advantages and disadvantages: cost, speed, anatomic coverage, availability, comfort, image quality, and diagnostic accuracy all need to be considered.

Referring physicians can be proactive in reducing radiation doses by talking to a radiologist or other imaging specialist to ensure that the safest and most appropriate examination is performed. As much specific information as possible should be provided at the time of the order, including the specific indication for imaging as well as the anatomy to be imaged. For example, rather than ordering a "chest CT scan", noting that the indication is "rule out pulmonary emboli" would allow the radiologist to request a tailored chest CT scan, that is, a pulmonary CT angiogram, the most appropriate examination for ruling out pulmonary emboli. Although a CT examination exposes patients to doses of radiation hundreds of times higher than does a conventional x-ray examination, conventional radiographic examinations cannot be used to diagnose pulmonary embolism or stage a lung cancer. Although the use of such basic imaging modalities would result in substantially lower radiation exposure to the patient, it would be an unwarranted exposure because it would not provide the necessary medical benefit.

Referring physicians can also minimize exposure by conferring with a radiologist to determine whether another recently performed imaging examination could answer the current question, an alternative examination that uses less ionizing radiation (eg, a conventional radiograph) or no ionizing radiation (eg, an ultrasound or magnetic resonance imaging [MRI] exam) might be appropriate, or a more limited or targeted examination might suffice.

There are some examinations that are considered to be equally acceptable because they have the same ability to make the right diagnosis. For instance, for a patient with Crohn disease, MRI and CT enterography have similar accuracy for the detection of intestinal inflammation and penetrating complications. Some physicians and patients will opt for MRI because it does not use ionizing radiation. However, MR enterography may not be available at every institution or may have limited access, is typically more expensive, generally takes longer to perform, and may require sedation if the patient cannot hold still or is extremely anxious. Any of these factors may prompt the physician and patient to choose CT, particularly if the patient is symptomatic and a delay in obtaining the correct diagnosis may have serious consequences. In addition, some patients cannot undergo MRI because of the presence of a contraindicated medical device or other metallic object in their body, and other patients are claustrophobic and do not want MRI.

The American College of Radiology[65] has developed evidence-based "appropriateness criteria" for physicians to use as a decision aid. For a wide range of clinical scenarios, imaging modalities are ranked on a scale of 1 (least appropriate) to 9 (most appropriate). When all considerations have been weighed, including availability, local expertise, patient comfort, and cost, it would be reasonable to choose a low- or no-radiation procedure only if it is ranked at least as appropriate as the higher-radiation procedure for the specific diagnostic task. In cases in which CT is ranked higher, an expert panel familiar with the performance of the imaging alternatives has weighed the available evidence and determined that CT is more likely than other modalities to provide information that would best assist the referring clinician and patient.

WHAT IMPORTANT POINTS SHOULD I CONSIDER DISCUSSING WITH PATIENTS CONCERNED ABOUT RADIATION EXPOSURE?

Computed tomographic examinations should be performed when they are medically justified and may result in patient benefit by detecting or staging a disease or by excluding suspected disease. The potential benefit of each CT examination will vary on a case-by-case basis, and even then, the benefit of a particular CT scan cannot always be predicted (eg, many large abdominal aortic aneurysms or treatable cancers have been detected incidentally). When a patient expresses concern about the potential risk from a CT scan, it is an opportunity for the provider to reflect with the patient on both the potential benefits and

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potential risks of the examination. According to our experience, a pragmatic approach that puts both benefit and risk into perspective, that teaches about similar low levels of risk, and that discusses alternatives to CT imaging (and their potential benefits and risks) is often effective.

Providers and patients are used to thinking about the potential benefits and adverse effects of medications. Medications are given to achieve an expected benefit only when the potential adverse effects are considered to be acceptable, or if unacceptable, highly unlikely. In CT imaging, because the potential risks for a given patient are low (and may be nonexistent), the principal consideration for the appropriateness of a CT examination is the expected benefit that the diagnostic information from CT scans will provide. For common clinical scenarios, the potential benefit of CT imaging will be the detection or staging of disease or injury to facilitate medical or surgical treatment. This general rationale, as well as the specifics of an individual scenario, should be shared with patients. The Quality Safety Appropriateness Criteria of the American College of Radiology[65] provide a relative scale of imaging appropriateness for many common clinical indications. Using this resource to confirm the appropriateness of a CT examination for a given indication is often reassuring to patients. However, point-of-care clinical decision support systems are needed to increase the utilization of such appropriateness criteria. It has been shown that when such tools are made available at the point of care, the utilization patterns of imaging services change, with an overall slowing of the growth of outpatient imaging examinations.[66]

With respect to the risks of radiation, it is helpful to explain that the risks of radiation have been examined in a large number of studies and that scientific and governmental organizations examining this evidence have concluded that the risks of CT imaging are thought to be low to nonexistent. Furthermore, sharing the fact that the amount of radiation produced by a CT scanner is similar to or slightly higher than the annual natural background radiation level in the United States is often reassuring, because patients may not be aware that we all are exposed to similar levels of radiation each year from "natural" sources.

Comparing the magnitude of the low potential risk of cancer from CT imaging (eg, 1 in 2000 [0.05%]) with that from other activities can help patients put the magnitude of risk into perspective relative to other risks from everyday living. Although not meant as a direct comparison (as the nature of both the benefit and the risk differs), but rather for the purpose of understanding the magnitude of the risk from CT, the estimated risk of dying from a motor vehicle accident in the United States is approximately 1 in 109 (0.9%).[67] This is 18 times higher than the potential risk of dying from cancer from an abdominal CT scan. A more direct comparison can be made with the population risk of dying from cancer in the United States, which is currently between 1 in 4 (25%) and 1 in 5 (20%). Understanding these relative magnitudes can assist patients in weighing the risks and benefits of CT imaging for themselves. For patients with known diseases (eg, known malignant tumor or cirrhosis), the relative risk of CT scans in comparison to the risks associated with their known disease is extremely low.[53]

There are imaging alternatives to CT for many clinical indications. Although the performance of ultrasound and MRI, as alternatives to CT imaging, varies by diagnostic task, CT has some unique features that often make it the examination of choice. Ultrasound and MRI are generally targeted to smaller body regions, so in trauma cases or clinical scenarios in which occult malignancy is suspected (in which large portions of the body need to be imaged), there are few realistic alternatives to CT imaging. A similar argument for CT imaging can be made in the staging of many thoracoabdominal cancers that metastasize to locations in the chest, abdomen, and pelvis. When imaging of pulmonary parenchyma is required, especially for the detection of pulmonary nodules, CT is often the modality of choice; the speed with which CT can be performed is an important factor. Computed tomographic imaging may also provide needed information at lower risks than do other imaging alternatives (eg, CT angiography vs catheter angiography), with invasive procedures reserved for patients who can be treated endovascularly.

CONCLUSION

The use of CT has revolutionized the practice of medicine and been a dominant factor in reducing mortality and potential morbidity associated with

more invasive procedures. Recent improvements in technology have lowered doses while maintaining image quality. Although, as with any procedure, only medically necessary CT scans should be ordered, a convincing case for a causal link between CT scans and increased cancer rates has not been made and no patient should forego a needed examination because of concerns about radiation exposure. To further assist physicians in discussing CT imaging and radiation safety with their patients, answers to a number of frequently asked questions are provided in the Supplemental Appendix (available online at http://www.mayoclinicproceedings.org).

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SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at: http://www.mayoclinicproceedings.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **CT** = computed tomography; **$CTDI_{vol}$** = volume computed tomography dose index; **MRI** = magnetic resonance imaging; **SSDE** = size-specific dose estimate

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