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Radiation Exposure in Medical Imaging

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ABSTRACT: It is a general consensus that ionizing radiation is oncogenic in nature. Much of this agreement is based upon observation of increased incidence of carcinoma in a population surviving a nuclear attack or in uranium miners exposed to radiation at the workplace. The amount of radiation used by imaging modalities is negligible as compared to the abovementioned exposures. For instance, in the United States, people are exposed to average annual background radiation levels of about 3 mSv; exposure from a chest X-ray is about 0.1 mSv, and exposure from a whole-body computerized tomography (CT) scan is about 10 mSv, and one of the reasons why physicians usually miscalculate the potential risks associated with the radiation exposure while performing procedures using radiologic imaging.[1][2] This article will attempt to explain how to quantify radiation, the biological effect of radiation, risks to health care workers as a result of radiation exposure, and certain recommendations and tips for various medical professionals.

Radiation is defined as a moving form of energy. It can be classified into two categories, i.e., ionizing and non-ionizing type. Ionizing radiations can be further classified into electromagnetic radiation (matter less) and particulate radiation. Electromagnetic radiations are energy packets (photons) traveling in the form of a wave. Basic examples of electromagnetic radiation are x-rays and gamma rays. Particulate radiation consists of a beam of particles that can be either charged or neutral. Electromagnetic radiations have high energy and can easily penetrate body tissues. Ionizing radiation is mainly used for diagnostic purposes.

KEYWORDS: radiation, exposure, medical, imaging, oncogenic, gamma

I. INTRODUCTION

The radiation you get from x-ray, CT, and nuclear imaging is ionizing radiation — high-energy wavelengths or particles that penetrate tissue to reveal the body's internal organs and structures. Ionizing radiation can damage DNA, and although your cells repair most of the damage, they sometimes do the job imperfectly, leaving small areas of "misrepair." The result is DNA mutations that may contribute to cancer years down the road.[1,2,3]

We're exposed to small doses of ionizing radiation from natural sources all the time — in particular, cosmic radiation, mainly from the sun, and radon, a radioactive gas that comes from the natural breakdown of uranium in soil, rock, water, and building materials. How much of this so-called background radiation you are exposed to depends on many factors, including altitude and home ventilation. But the average is 3 millisieverts (mSv) per year. (A millisievert is a measure of radiation exposure; see "Measuring radiation.")

Exposure to ionizing radiation from natural or background sources hasn't changed since about 1980, but Americans' total per capita radiation exposure has nearly doubled, and experts believe the main reason is increased use of medical imaging. The proportion of total radiation exposure that comes from medical sources has grown from 15% in the early 1980s to 50% today. CT alone accounts for 24% of all radiation exposure in the United States, according to a report issued in March 2009 by the National Council on Radiation Protection and Measurements.

Measuring radiation

If you mention the measurement of radiation, many people will recall the classic Geiger counter with its crescendo of clicks. But Geiger counters detect only the intensity of radioactive emissions. Measuring their impact on human tissues and health is more difficult. That's where the sievert (Sv) and millisievert (mSv) come in. These units, the ones most commonly used in comparing imaging procedures, take into account the biological effect of radiation, which varies with the type of radiation and the vulnerability of the affected body tissue. Taking these into account, millisieverts describe what's called the "equivalent dose."

We've long known that children and teens who receive high doses of radiation to treat lymphoma or other cancers are more likely to develop additional cancers later in life. But we have no clinical trials to guide our thinking about cancer

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risk from medical radiation in healthy adults. Most of what we know about the risks of ionizing radiation comes from long-term studies of people who survived the 1945 atomic bomb blasts at Hiroshima and Nagasaki. These studies show a slightly but significantly increased risk of cancer in those exposed to the blasts, including a group of 25,000 Hiroshima survivors who received less than 50 mSv of radiation — an amount you might get from three or more CT scans. (See "Imaging procedures and their approximate effective radiation doses.")

The atomic blast isn't a perfect model for exposure to medical radiation, because the bomb released its radiation all at once, while the doses from medical imaging are smaller and spread over time. Still, most experts believe that can be almost as harmful as getting an equivalent dose all at once.

Higher radiation–dose imaging

Most of the increased exposure in the United States is due to CT scanning and nuclear imaging, which require larger radiation doses than traditional x-rays. A chest x-ray, for example, delivers 0.1 mSv, while a chest CT delivers 7 mSv (see the table) — 70 times as much. And that's not counting the very common follow-up CT scans.

In a 2009 study from Brigham and Women's Hospital in Boston, researchers estimated the potential risk of cancer from CT scans in 31,462 patients over 22 years. For the group as a whole, the increase in risk was slight — 0.7% above the overall lifetime risk of cancer in the United States, which is 42%. But for patients who had multiple CT scans, the increase in risk was higher, ranging from 2.7% to 12%. (In this group, 33% had received more than five CT scans; 5%, more than 22 scans; and 1%, more than 38.)[4,5,6]

What to do

Unless you were exposed to high doses of radiation during cancer treatment in youth, any increase in your risk for cancer due to medical radiation appears to be slight. But we don't really know for sure, since the effects of radiation damage typically take many years to appear, and the increase in high-dose imaging has occurred only since 1980.

So until we know more, you will want to keep your exposure to medical radiation as low as possible. You can do that in several ways, including these:

Discuss any high-dose diagnostic imaging with your clinician. If you need a CT or nuclear scan to treat or diagnose a medical condition, the benefits usually outweigh the risks. Still, if your clinician has ordered a CT, it's reasonable to ask what difference the result will make in how your condition is managed; for example, will it save you an invasive procedure?

Keep track of your x-ray history. It won't be completely accurate because different machines deliver different amounts of radiation, and because the dose you absorb depends on your size, your weight, and the part of the body targeted by the x-ray. But you and your clinician will get a ballpark estimate of your exposure.

Consider a lower-dose radiation test. If your clinician recommends a CT or nuclear medicine scan, ask if another technique would work, such as a lower-dose x-ray or a test that uses no radiation, such as ultrasound (which uses high-frequency sound waves) or MRI (which relies on magnetic energy). Neither ultrasound nor MRI appears to harm DNA or increase cancer risk.

Consider less-frequent testing. If you're getting regular CT scans for a chronic condition, ask your clinician if it's possible to increase the time between scans. And if you feel the CT scans aren't helping, discuss whether you might take a different approach, such as lower-dose imaging or observation without imaging.

Don't seek out scans. Don't ask for a CT scan just because you want to feel assured that you've had a "thorough checkup." CT scans rarely produce important findings in people without relevant symptoms.[7,8,9] And there's a chance the scan will find something incidental, spurring additional CT scans or x-rays that add to your radiation exposure.

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II. DISCUSSION

Advances in medical imaging have had a considerable impact on medical practice over the past few decades. Regrettably, many such procedures expose patients to ionizing radiation, which may result in injury. Survey data show that physicians generally underestimate the magnitude of radiation doses and their associated effects, and thus underestimate the risk to patients undergoing medical imaging procedures.[1–4] This view may be due to both the general lack of epidemiologic data specific to medical procedures and the nature with which radiation-induced injuries progress. In this issue of the journal, Eisenberg and colleagues help close the knowledge gap regarding the risk of cancer associated with exposure to low-dose ionizing radiation from medical imaging and therapeutic procedures in a contemporary cardiac population.[5]

As with all aspects of medical care, physicians must weigh the potential benefits against the potential harms when recommending a procedure using ionizing radiation. The benefits of such procedures tend to be evident. The risks, on the other hand, are not so apparent. The reason for this may be threefold.

First, in most cases it is difficult to predict who will be harmed, because many negative effects of exposure to ionizing radiation, such as cancer, are stochastic in nature (i.e., randomly occurring). However, although the severity of such effects does not vary by magnitude of exposure, the probability does increase with dose.[10,11,12]

Second, the appearance or diagnosis of radiation-induced cancers can occur many years after exposure. Thus, it is difficult to attribute the cancer to a specific exposure.

Finally, much of what we know regarding cancer risk from ionizing radiation comes from large observational studies involving workers in the nuclear industry and atomic bomb survivors. Exposure in these groups is by and large much higher than those typically seen in clinical populations. Risks to individuals exposed to radiation at doses used in most medical imaging procedures must be extrapolated from epidemiologic data for “high-dose” populations (e.g., atomic bomb survivors) using a linear “no threshold” model.[6,7] However, there are no epidemiologic data to support the validity of this model for low-dose exposures (< 10 millisieverts [mSv]) and thus no direct data regarding the risk to individuals undergoing typical medical imaging procedures.[7] It is likely for these reasons that health care providers have difficulty quantifying the risks associated with many imaging procedures, because they have little or no epidemiologic data suitable to their patients or direct clinical experience with known radiation-induced injuries.

Common medical imaging tests, such as radiography and mammography, expose patients to radiation doses of less than 1 mSv. Assuming a linear no-threshold model, this level of exposure may not constitute a significant risk to individual patients. However, the frequency with which such tests are performed may pose a population risk. More sophisticated imaging modalities, such as computed tomography (CT), cardiac perfusion (nuclear stress) tests, and fluoroscopy-guided diagnostic and therapeutic procedures, often involve radiation doses in the range of 5–15 mSv. These procedures fall in the low end of exposure for which we have epidemiologic evidence of increased cancer risk (i.e., acute dose of > 10 mSv).[7] Again, this level of exposure may not pose much risk to the individual, but the risk may be important at the population level. The real trouble arises when an individual undergoes multiple tests or procedures.

As Eisenberg and colleagues show, a substantial number of patients underwent multiple procedures in a short period.[5] A large observational study involving about one million adults (age 18–65) in the United States reiterates this point.[8] Both studies show that multiple procedures in an individual can result in a cumulative exposure that approaches or exceeds the level for which there is reasonably good epidemiologic evidence of an increased risk of cancer (i.e., cumulative dose > 50 mSv).[7] It is through multiple exposures that rather insignificant risks on an individual level can become significant for a particular patient.

The study by Eisenberg and colleagues shows a positive dose–response relation for radiation exposure and cancer risk at cumulative doses for which there is little previous epidemiologic evidence of increased cancer risk (i.e., cumulative dose < 50 mSv).[5] Despite the demonstrated risk, only a few of the cancers diagnosed in their study were likely a direct result of exposure to radiation from the medical imaging. For example, if we consider a lifetime risk of cancer of about 2.5% for every 1000-mSv dose among individuals between the ages of 40 and 60, we would expect one new cancer for every 2000 patients receiving a 20-mSv dose that is directly attributable to the radiation exposure from the medical procedure.[9] Many of the patients in the study by Eisenberg and colleagues received a dose in this range. However, such

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estimates are theoretical, based on extrapolations of risk at higher doses (assuming a linear projection of risk). Although the risk of cancer at this exposure level seems to be relatively small, the fact that a large number of individuals are undergoing multiple procedures does pose a potential risk at the population level.

The current wisdom for minimizing the risk to the patient is to adopt the ALARA (as low as reasonably achievable) principle.[10] This principle can be realized in a number of ways. The first is through technological innovations, which may provide means of producing suitable images with reduced levels of radiation exposure. For example, innovations in cardiac CT technology over the past five years have resulted in a decrease in the minimum achievable dose from 10–16 mSv to as low as 1–3 mSv. Another way is for physicians to optimize their technique or protocols.

As with other health risks, the best strategy may be prevention. This could mean referring the patient for a procedure that involves lower or no radiation exposure or, in some circumstances, avoiding the procedure altogether. Prevention may become of prime importance in situations where a patient has undergone or is expected to undergo a series of tests or procedures with moderate to high levels of exposure to radiation. [13,14,15]The standard by which one chooses to avoid a procedure or suggest an alternative may depend on whether the procedure is indicated for the purpose of improving prognosis or for diagnosis only. For example, in the case of primary angioplasty in acute myocardial infarction, the immediate and substantial improvement in prognosis may sufficiently outweigh the comparatively small risk of cancer in the long term. Communication between the referring physician and the radiologist or specialist should be encouraged in an effort to find the optimal diagnostic or therapeutic strategy for the patient.

It is not uncommon for a patient to be referred for a variety of medical imaging tests and procedures by different physicians. It can be difficult, therefore, for an individual physician to keep track of the patient's cumulative exposure (assuming information about the radiation dose is available for each procedure — it is often not).

The implementation of a strategy to track radiation doses may help physicians and patients stay aware of the cumulative exposure. Health care and nuclear industries currently use such strategies to monitor exposure among employees. However, as Rehani and Frush point out, there are currently no examples of good nationwide programs to do so for patients.[11] Programs to track radiation doses, such as the International Atomic Energy Agency's Smart Card/SmartRadTrack Project (http://rpop.iaea.org/RPOP/RPoP/Content/News/smart-card-project.htm), are now becoming a reality. It is imperative that Canadian health care providers adopt a similar strategy.

III. RESULTS

We are constantly exposed to radiation from a number of sources, including radioactive materials in our environment, radon gas in our homes, and cosmic rays from outer space. This is called background radiation and it varies across the country.

The average American is exposed to about 3 mSv (millisieverts) of radiation from natural sources over the course of a year. (A millisievert is a measure of radiation exposure.) But background radiation exposure varies throughout the United States, and the world.

The largest source of background radiation (typically about 2 mSv per year) is radon, a natural gas found in our homes. Radon levels vary greatly from one part of the country to another.

Location also plays a role because the earth's atmosphere blocks some cosmic rays. This means being at a higher altitude increases a person's exposure. So, people living in the higher parts of New Mexico and Colorado are exposed to more radiation per year (about 1.5 mSv more) than people living closer to sea level. And a 10-hour airline flight increases cosmic ray exposure by about 0.03 mSv.[16,17,18]

The amount of radiation exposure from an imaging test depends on the imaging test used and what part of the body is being tested. For instance:

- A single chest x-ray exposes the patient to about 0.1 mSv. This is about the same amount of radiation people are exposed to naturally over the course of about 10 days.
- A mammogram exposes a woman to 0.4 mSv, or about the amount a person would expect to get from natural background exposure over 7 weeks.

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Some other imaging tests have higher exposures, for example:

- A lower GI series using x-rays of the large intestine exposes a person to about 8 mSv, or about the amount expected over about 3 years.
- A CT scan of the abdomen (belly) and pelvis exposes a person to about 10 mSv.
- A PET/CT exposes you to about 25 mSv of radiation. This is equal to about 8 years of average background radiation exposure.

Keep in mind that these are estimates for an average-sized adult. Studies have found that the amount of radiation you get can vary a great deal.

If you have concerns about the radiation you may get from a CT scan, PET scan, or any other imaging test that uses radiation, talk to your health care provider. Ask whether the test is needed and if it's the best one to use in your case. You may also want to know what you and your health care provider can expect to learn from it.

The best advice at this time is to get only the imaging tests that are needed and try to limit your exposure to all forms of radiation. If you do need to have a test that will expose you to some radiation, ask if there are ways to shield the parts of your body that aren't being imaged. For example, a lead apron can be used to protect parts of your chest or abdomen from getting radiation, and a lead collar (known as a thyroid shield or thyroid collar) can be used to protect your thyroid gland.

You may also want to keep a medical imaging record to track your own history of imaging tests and share it with your health care providers. This may help prevent repeat tests from being ordered. English and Spanish examples of imaging records for adults can be found online at www.imagewisely.org.

Remember that MRI and ultrasound exams do not expose you to radiation.
Children are more sensitive to radiation than adults. Because of this, health care providers are careful to reduce radiation exposure to pediatric patients for imaging tests that use radiation. Still, parents can and should ask questions before any imaging tests are done.

Here are some questions to ask:

- Why does my child need an imaging test?
- What type of imaging test do you think my child needs?
- Does it use radiation?
- Are there other options that don't use radiation?
- Can the amount of radiation used be adjusted for my child's size?

Again, the benefits of the test should outweigh the risks of radiation exposure.
You may also want to keep a medical imaging record to track your child's history of imaging tests and share it with their health care providers. An English version for children can be found online at www.imagegently.org.[19,20,21]
Radiation exposure depends on the type of test done, the area of the body exposed, the person's body size, age, and sex, and other factors.

Radiation experts believe that if imaging tests do increase the risk of cancer, the increase in risk is likely to be very small. Still, it's hard to know just how much radiation exposure from imaging tests might increase a person's cancer risk. Most studies on radiation and cancer risk have looked at people exposed to very high doses of radiation, such as uranium miners and atomic bomb survivors. The risk from low-level radiation exposure is not easy to calculate from these studies. We do know that children are more sensitive to radiation and should be protected from it as much as possible.

Because radiation exposure from all sources can add up over a lifetime, and radiation can, indeed, increase cancer risk, imaging tests that use radiation should only be done for a good reason. In many cases, other imaging tests such as ultrasound or MRI may be used. But if there's a reason to believe that an x-ray, CT scan, or nuclear medicine scan (such as a PET scan) is the best way to look for cancer or other diseases, the person will most likely be helped more than the small dose of radiation can hurt.

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IV. CONCLUSION

X-rays are a form of energy – like light and radio waves. X-rays are also called radiation. Unlike light waves, x-rays have enough energy to pass through your body. As the radiation moves through your body, it passes through bones, tissues, and organs differently. This allows a radiologist to create images of them. The radiologist is a specially trained doctor who can examine these images on a computer display. X-rays allow the radiologist to see the structures in your body [22,23]in very fine detail.

X-ray exams provide valuable information about your health and help your doctor make an accurate diagnosis. Your doctor may use x-rays to help place tubes or other devices in your body or to treat disease.

When radiation passes through the body, some of it is absorbed. The x-rays that are not absorbed are used to create the image. The amount the patient absorbs contributes to the patient's radiation dose. Radiation that passes through the body does not contribute to this dose. The scientific unit of measurement for whole body radiation dose, called "effective dose," is the millisievert (mSv). Other radiation dose measurement units include rad, rem, roentgen, sievert, and gray.

Doctors use "effective dose" when they talk about the risk of radiation to the entire body. Risk refers to possible side effects, such as the chance of developing a cancer later in life. Effective dose considers how sensitive different tissues are to radiation. If you have an x-ray exam that includes tissues or organs that are more sensitive to radiation, your effective dose will be higher. Effective dose allows your doctor to evaluate your risk and compare it to common, everyday sources of exposure, such as natural background radiation.

We are exposed to natural sources of radiation all the time. According to recent estimates, the average person in the U.S. receives an effective dose of about 3 mSv per year from natural radiation, which includes cosmic radiation from outer space. These natural "background doses" vary according to where you live.

People living at high altitudes such as Colorado or New Mexico receive about 1.5 mSv more per year than those living near sea level. A coast-to-coast round-trip airline flight is about 0.03 mSv due to exposure to cosmic rays. The largest source of background radiation comes from radon gas in our homes (about 2 mSv per year). Like other sources of background radiation, the amount of radon exposure varies widely depending on where you live.

To put it simply, the amount of radiation from one adult chest x-ray (0.1 mSv) is about the same as 10 days of natural background radiation that we are all exposed to as part of our daily living.

Here are some approximate comparisons of background radiation and effective radiation dose in adults for several radiology procedures described on this website. These values can vary greatly, depending on the size of the patient and the type of imaging technology being used. Manufacturers of imaging technology continue to make improvements towards reducing radiation exposure while maintaining image quality.

ABDOMINAL REGION	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Computed Tomography (CT)–Abdomen and Pelvis	7.7 mSv	2.6 years
	Computed Tomography (CT)–Abdomen and Pelvis, repeated with and without contrast material	15.4 mSv	5.1 years
	Computed Tomography (CT)–Colonography	6 mSv	2 years
	Intravenous Urography	3 mSv	1 year

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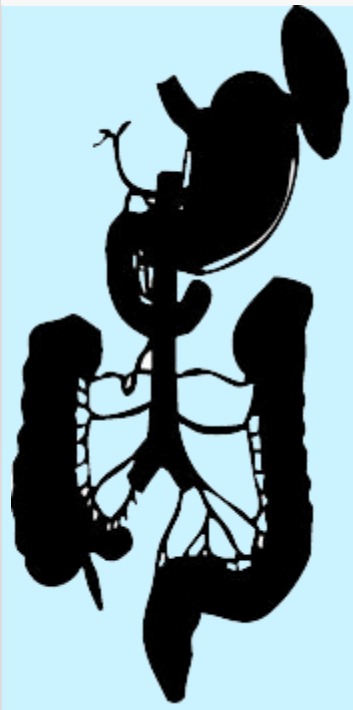	(IVU)		
	Barium Enema (Lower GI X-ray)	6 mSv	2 years
	Upper GI Study with Barium	6 mSv	2 years

BONE 	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Lumbar Spine	1.4 mSv	6 months
	Extremity (hand, foot, etc.) X-ray	Less than 0.001 mSv	Less than 3 hours

CENTRAL NERVOUS SYSTEM	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Computed Tomography (CT)–Brain	1.6 mSv	7 months
	Computed Tomography (CT)–Brain, repeated with and without contrast material	3.2 mSv	13 months
	Computed Tomography (CT)–Head and Neck	1.2 mSv	5 Months
	Computed Tomography	8.8 mSv	3 years

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	(CT)–Spine		

CHEST 	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Computed Tomography (CT)–Chest	6.1 mSv	2 years
	Computed Tomography (CT)–Lung Cancer Screening	1.5 mSv	6 months
	Chest X-ray	0.1 mSv	10 days

DENTAL 	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Dental X-ray	0.005 mSv	1 day
	Panoramic X-ray	0.025 mSv	3 days
	Cone Beam CT	0.18 mSv	22 days

HEART 	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Coronary Computed Tomography Angiography (CTA)	8.7 mSv	3 years
	Cardiac CT for Calcium Scoring	1.7 mSv	6 months

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	Non-Cardiac Computed Tomography Angiography (CTA)	5.1 mSv	Less than 2 years
MEN'S IMAGING 	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Bone Densitometry (DEXA)	0.001 mSv	3 hours
NUCLEAR MEDICINE 	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Positron Emission Tomography–Computed Tomography (PET/CT) Whole body protocol	22.7 mSv	7.6 years
WOMEN'S IMAGING 	Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
	Bone Densitometry (DEXA)	0.001 mSv	3 hours
	Screening Digital Mammography	0.21 mSv	26 days
	Screening Digital Breast Tomosynthesis (3D Mammogram)	0.27 mSv	33 days

Note for pediatric patients: Pediatric patients vary in size. Doses given to pediatric patients will vary significantly from those given to adults. For more information on radiation safety in pediatric imaging, visit http://www.imagegently.org/Roles-What-can-I-do/Parent (opens in a new tab).

Please note that this chart attempts to simplify a very complex topic. If you have questions about radiation risks, ask your medical physicist and/or radiologist about these risks and the benefits of your medical imaging procedure.
*The effective doses are typical values for an average-sized adult. The actual dose can vary substantially, depending on a person's size, the reason for imaging, and differences in imaging practices.

The International Commission on Radiological Protection (ICRP) Report 103 states: "The use of effective dose for assessing the exposure of patients has severe limitations that must be considered when quantifying medical exposure," and "The assessment and interpretation of effective dose from medical exposure of patients is very problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure which is the case especially with x-

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ray diagnostics." In other words, effective dose is not always the same for everyone. It can vary based on a person's height and weight, how the procedure is performed, and the body area being exposed to radiation.

Benefit versus risk

The risk associated with medical imaging procedures refers to possible long-term or short-term side effects. Most imaging procedures have a relatively low risk. Hospitals and imaging centers apply the principles of ALARA (As Low As Reasonably Achievable). This means they make every effort to decrease radiation risk. It is important to remember that a person is at risk if the doctor cannot accurately diagnose an illness or injury. Therefore, it could be said that the benefit from medical imaging, which is an accurate diagnosis, is greater than the small risk that comes with using it. Talk to your doctor or radiologist about any concerns you may have about the risks of a given procedure.[24]

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