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Diagnostic imaging: Radiation dose and patients' concerns

ABSTRACT

Exposure to ionizing radiation during diagnostic radiologic procedures carries small but real risks, and children, young adults, and pregnant women are especially vulnerable. Exposure of patients to diagnostic energy levels of ionizing radiation should be kept to the minimum necessary to provide useful clinical information and allay patients' concerns about radiation-related risks.

KEY POINTS

Use CT with discretion: it accounts for two thirds of the cumulative patient dose from diagnostic radiologic procedures, and the cumulative dose from CT is rising as technological advances increase the number of indications for and the capabilities of CT.

Carcinogenesis and teratogenesis are the main concerns with ionizing radiation. The risk increases as the radiation dose increases. There is no minimum threshold, and the risk is cumulative: a dose of 1 mSv (0.1 rem) once a year for 10 years is equivalent to a single dose of 10 mSv (1 rem).

Whenever practical, choose an imaging test that uses less radiation or no radiation, and lengthen the periods between follow-up imaging tests.

Some patients may avoid screening mammography because of fear of radiation-induced cancer, yet this test uses a very small radiation dose (0.6 mSv, much less than the annual dose from background radiation, 3.6 mSv), and technologic improvements are lowering the dose required.

A 45-YEAR-OLD WOMAN WHO has never had a mammogram comes to see her general practitioner for a general medical examination. The physician recommends that she undergo screening mammography every year as part of a program of health maintenance, but the patient expresses concern about this. Her older sister developed breast cancer at age 50, after 5 years of regular mammographic testing, and she fears that radiation from the screening mammography tests may have contributed to the development of cancer.

How should the clinician counsel this patient?

THE GOOD AND THE BAD

The potential harm from ionizing radiation is an issue that faces every physician and patient considering diagnostic imaging.

With the exception of ultrasonography and magnetic resonance imaging (MRI), diagnostic radiologic tests involve ionizing radiation—photons with enough energy to ionize (ie, strip electrons from the nuclei of) atoms with which they interact. It can consist of x-rays, such as in plain film radiography and computed tomography (CT), or of gamma rays from radiopharmaceuticals used in nuclear medicine.

Exposure to ionizing radiation during diagnostic radiologic procedures carries small but real risks. Ionizing radiation can damage living cells by causing undesired chemical reactions that alter the structure of macromolecules within the cell. Children, young adults, and pregnant women are especially vulnerable. On the other hand, the images produced can contain critical diagnostic information that may

TABLE 1

Estimated effective radiation dose of common diagnostic imaging tests*

STUDY	EFFECTIVE DOSE IN MILLISIEVERTS†
Chest radiography, posteroanterior and lateral	0.06
Screening mammography	0.6
Gastric emptying study	1.4
Kidney-ureter-bladder radiography	1.7
CT of the head	1.8
Lumbar spine radiography	2.1
Background radiation, annual dose	**3.6**
Radionuclide bone scan	4.4
Ventilation-perfusion (V/Q) scan	6.8
CT of the pelvis	7.1
CT of the abdomen	7.6
CT of the chest	7.8
Barium enema radiography	8.7
CT angiography of coronary arteries	10
Positron emission tomography, whole body	14
Small bowel series (barium swallow x-ray study)	15
Intravenous pyelography	10.0–20.0
Whole-body screening CT	22.5
Three-phase hepatic CT scan	29.9
Dual-isotope myocardial rest and stress perfusion CT study	32.5
CT urographic study	44.1

*All values are for procedures performed at Cleveland Clinic
†10 mSv (millisieverts) = 1 rem

greatly benefit the patient. Therefore, the risks and benefits must be considered before proceeding with any diagnostic test involving ionizing radiation. Exposure to ionizing radiation should be kept as low as reasonably achievable (the "ALARA" principle) while still answering the clinical question at hand.

In this article, we review the risks and benefits of diagnostic imaging and then offer practical ways to maximize its benefits while minimizing its risks.

QUANTIFYING THE RADIATION DOSE

Quantifying the radiation dose is not a simple matter. The energy and quantity of the photons, the size of the patient, and the vulnerability of irradiated tissues must be factored into any estimate. Medical physicists often must undertake extensive calculations to accurately estimate the dose of radiation received by a specific patient in a specific study.

The concept of *effective dose*, measured in millisieverts (mSv) or "roentgen equivalents man" (rem; 10 mSv = 1 rem) allows many of these factors to be compared and controlled for.

But remember that everyone is constantly exposed to naturally occurring ionizing radiation, commonly called background radiation. Some comes from radioactive elements present in the earth since its formation (primordial radionuclides), such as uranium and the natural products of its decay, radium and the gas radon. Other background radiation is in the form of cosmic rays, high-energy particles that constantly bombard the atmosphere and create radioisotopes of carbon and nitrogen. The average annual effective dose from background radiation is estimated at 3.6 mSv (0.36 rem).

Some diagnostic procedures involve an effective dose of radiation that is a tiny fraction of that from background radiation, whereas many impart several times that amount (**TABLE 1**).

RADIATION RISKS OF IMAGING

Deterministic vs stochastic effects

The damaging effects of ionizing radiation are catagorized as deterministic or stochastic.

Deterministic effects occur only when the dose has reached a threshold, beyond which the effects increase in severity as the dose increases. Fluoroscopy is the imaging procedure for which deterministic effects are a main concern: it can damage the skin, leading to inflammation, epilation, and necrosis.

More worrisome are the stochastic effects carcinogenesis and teratogenesis, which increase in likelihood but not in severity as the radiation dose increases. Stochastic effects have no minimum threshold, and the risk is cumulative. For example, a dose of 1 mSv (0.1 rem) once a year for 10 years is equivalent to a single dose of 10 mSv (1 rem).

The risk of stochastic effects is often discussed in terms of the "linear no-threshold" model, which states that risk varies linearly with dose and assumes that no minimum or threshold dose is needed to increase risk.

The BEIR VII estimates cancer risk

A widely accepted estimate of the risk of radiation-induced carcinogenesis in diagnostic imaging comes from the National Research Council Committee on the Biological Effects of Ionizing Radiation (BEIR VII) of the National Academy of Sciences. The BEIR VII states that an effective dose of 10 mSv (1 rem) to a working-age adult results in a 1 in 1,000 lifetime risk of developing radiation-induced cancer. Or, if 10,000 adults receive this dose, around 10 of them will develop radiation-induced cancer during their lifetime. The relative risk is small, however, since 4,200 people out of 10,000 are expected to develop cancer for other reasons.

Pregnancy

Ionizing radiation can be both carcinogenic and teratogenic to the fetus. The National Council on Radiation Protection and the American College of Obstetricians and Gynecologists maintain that a cumulative effective dose to the fetus of less than 50 mSv (5 rem) is not associated with any increased risks—and none of the studies listed in TABLE 1 exceeds this.

Nevertheless, the use of diagnostic imaging in pregnant patients requires careful consideration. The fetus is most sensitive to the teratogenic effects of ionizing radiation during organogenesis, ie, from the second to the eighth week of development. But exposure at even up to 20 weeks of development increases the risk of microcephaly, mental retardation, and growth retardation, and radiation exposure at all gestational ages increases the risk of childhood leukemia.

THE LIMITATIONS OF RISK ASSESSMENT

The BEIR VII risk estimate and the concept of effective dose have significant limitations. Most importantly, they do not consider age, a very important factor for several reasons. First, solid tumors have an asymptomatic latent phase, usually 10 to 40 years. Second, rapidly dividing and undifferentiated cells are more sensitive to radiation than are fully differentiated cells, and therefore younger patients are much more vulnerable to the carcinogenic effects of radiation than are older patients, as more of their cells are still dividing, and they are likely to live long enough for a developing tumor to become symptomatic. Conversely, older patients are less vulnerable because more of their cells are differentiated, and they are more likely to die of unrelated causes during the latent period of tumor development.

No one yet has directly studied the effects of diagnostic radiation on humans. Theories about the damaging effects of diagnostic radiation are based on studies of populations such as atomic bomb survivors, patients with ankylosing spondylitis and mastitis treated with radiation in the early 20th century, and radium watch-dial painters. Doses were calculated retrospectively, and most people in these cohorts received effective doses that were much larger than the doses from today's diagnostic radiologic procedures.

Despite uncertainty about the true risks of exposure to levels of radiation used in diagnostic imaging, the linear no-threshold model is nearly universally accepted. This concept and overwhelming evidence that larger radiation doses are carcinogenic have led radiologists to follow the principle of using the lowest possible radiation dose necessary to provide the diagnostic information that answers the clinical question.

A cumulative effective dose to the fetus of < 50 mSv is considered safe

WAYS TO MINIMIZE PATIENT EXPOSURE

When ordering a diagnostic radiologic procedure, consider the following principles:

Use CT with discretion. CT accounts for two thirds of the cumulative patient dose from diagnostic radiologic procedures. The cumulative dose from CT is rising as technological advances increase the number of indications for and the capabilities of CT. For example, the newer machines with multiple detectors are faster than the older machines, allowing imaging in multiple phases after contrast administration. CT urography consists of three consecutive CT examinations of the abdomen and pelvis, and it exposes the patient to the highest radiation dose of any commonly used diagnostic imaging studies (TABLE 1).

Minimize imaging of pregnant women. For example, consider renal ultrasonography rather than CT of the abdomen and pelvis to assess for urinary obstruction resulting from suspected renal or ureteral calculi. If CT is absolutely necessary, then a single, low-dose CT scan of the abdomen and pelvis is preferred. If urography is indicated, conventional excretory urography is likely to entail a lower radiation dose than CT urography.

If a pregnant woman requires imaging, specific procedures will minimize fetal exposure, including lead shielding of the abdomen and pelvis and low-dose techniques.

Consider nuclear medicine studies that use radiopharmaceuticals with a lower radiation dose. For example, most of the effective dose of a dual-isotope cardiac stress test comes from the thallium. A two-stage study with technetium uses one third of the dose.

Minimize imaging of the young. Risks from radiation exposure are higher in children and young adults, as these patients are likely to survive the latent period of cancer development.

Avoid studies that do not influence patient care, such as plain radiography for suspected rib and coccyx fractures, and lumbar spine radiography in a patient without radiculopathy, which uses an exceptionally high effective dose for a plain radiographic study (TABLE 1).

Consider alternatives to ionizing radiation. Ultrasonography and MRI as yet have no practically demonstrated adverse effects. Also, direct visualization by endoscopy or laryngoscopy can often answer a clinical question without any radiation.

Consider whether follow-up diagnostic radiologic studies are truly necessary and what the appropriate follow-up interval should be. Doubling the follow-up interval for regular examinations halves the cumulative effective dose.

When in doubt, consult with a medical physicist or radiologist.

WHAT TO TELL THIS PATIENT

One in every eight women will develop breast cancer, and one in every 30 will die of it. Clinical trials have shown that screening mammography is associated with a 20% to 40% reduction in the rate of death from breast cancer. Women such as our hypothetical patient, with a first-degree relative who had breast cancer, have a risk of dying from breast cancer two to four times that of women without this risk factor. She therefore stands to benefit even more.

Also worth mentioning to such patients is that mammography is one of the most tightly regulated diagnostic tests, and the radiation doses used are very small (TABLE 1) and are getting smaller with technical advances.

In short, the expected benefit of screening mammography in patients such as this far exceeds the risks.

This patient's concerns should remind us that exposure to ionizing radiation is associated with small but real risks, that children, young adults, and pregnant women are especially vulnerable, and that exposure in diagnostic imaging should be kept as low as possible while still answering the clinical question.

Medical physicists in hospital departments of radiology can provide specific information about radiation doses of common diagnostic procedures.

SUGGESTED READING

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