Radiation Safety

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Radiation safety is rapidly becoming a major concern of every patient. Poor understanding of ionizing radiation and its effects frequently heightens anxiety. The average United States resident receives about 125 mrem of radiation per year from natural background radiation and another 120 mrem from man-made sources. The 240 million x-ray procedures performed annually contribute 90 percent of the man-made portion. It is assumed that the risks of medical radiation are outweighed by the benefits gained from the information obtained. If present in sufficiently high dosage, radiation can have harmful effects, such as induction of leukemia and thyroid malignancy. No deleterious effects have been shown to have been caused by diagnostic radiation. It is reassuring that the risks of medical radiation appear to be quite small compared with other common hazards most people face daily. Careful attention to the use of radiographic safety and protective technique will ensure the lowest possible radiation dose. The physician's discretion in ordering only appropriate and indicated x-ray films will ensure the patients are exposed to the lowest possible amount of radiation.

With the introduction of atomic weapons, nuclear power plants, x-ray machines, and radioisotopes, *radiation* has become a household word. It is frequently reported on in the media, and patients are concerned about it when x-ray examinations are ordered for diagnosis or treatment. Few people, however, really understand what radiation is and how it works.

Background

There are two types of radiation: ionizing and nonionizing. Ionizing radiation comes from atomic weapons, nuclear reactors, x-ray machines, and radioactive material. The term is derived from the phenomenon that radiation produces when it interacts with matter, that is, it causes atoms to lose or gain electrons, creating ions. If these ionized atoms happen to be in the human body, they may affect biological function. Nonionizing radiation, such as microwaves, sound waves, and light, can also create biological effects. The mechanisms of nonionizing radiation effects are much different and will not be discussed in this paper.

Present since the origin of the universe, radiation in either form is ubiquitous. Even with the advent of nuclear technology, man-made radiation accounts for only one half of radiation exposure. The average background dose from natural sources for individuals living in the United States is about 125 mrem each year.* Cosmic radiation from the sun and stars constantly bombards the earth, which is protected by its atmosphere. As one increases distance from the earth, exposure to cosmic radiation becomes greater. A transcontinental airline flight will expose a passenger to 20 to 40 mrem over surface level background, an amount roughly equivalent to that necessary to create one chest roentgenogram. Mineral and gas-

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*A mrem, or one thousandth of a roentgen equivalent in man, is a unit of radioactive dosage that will be defined later.

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eous sources within the earth cause still more radiation exposure. Granite, for example, is one of the more highly radioactive substances. During the government hearings concerning the Three Mile Island accident, a witness displayed a Geiger counter in the hearing chamber which indicated a reading greater than the amount of radiation released during the 1979 incident. The radiation was due to the natural radiation from the granite columns lining the hearing chambers. Radiation from within the body contributes to the natural background because of the amount of radioactivity in food caused by phosphate fertilizers. Small quantities of potassium 40 in human muscle tissue also contribute to background exposure.

Ninety percent of man-made radiation is derived from medical and dental x-ray examinations and from the use of radioactive materials to diagnose and treat disease. Current estimates are that an average of 90 mrem are delivered annually to each individual in the United States. It should be emphasized that this is an average figure. Some seriously ill patients receive much more than 90 mrem, whereas healthy people may not receive any at all. This average figure is derived from the 240 million x-ray procedures performed annually in the United States.[1] It is assumed that risks from exposure to medical radiation are far outweighed by the benefits gained from the information provided.[2]

The risk involved in undergoing radiographic procedures is very difficult to ascertain. Sources compare the risk of dying from cancer induced by the radiation involved in a chest roentgenogram equivalent to the risk of smoking two cigarettes, driving 78 miles in a car, or crossing the street 84 times. For the radiation involved in a lumbar spine series, the risk is roughly equivalent to smoking 46 cigarettes, driving 1,700 miles in a car, or crossing the street 2,000 times.[3,4]

The remaining 10 percent of man-made radiation comes from residual fallout from atomic weapons testing, nuclear-powered electric generating plants, other industrial uses of radioactivity, and emissions from certain consumer products such as color television sets, watch dials, and smoke detectors. These sources combine to expose the population to an additional 10 mrem per year per person. Table 1 shows the average radiation doses from natural and man-made sources.[5]

Table 1. Average Radiation Dosage

Source	Amount (mrem/yr)
Natural	
Cosmic radiation (sun and stars)	50
Internal radiation (from body tissue	25
Terrestial radiation (earth)	50
Man-Made	
X-rays (medical)	90
Occupational	20
Fallout	2-15
Environmental	5
Miscellaneous (television, watches)	2
Total	244-257

From Jucius RA[5]

Workers in nuclear industries and medical radiation workers are exposed to radiation levels above those received by the general public. All possible measures are taken to keep this exposure at a minimum. In light of present knowledge, the radiation received by these workers is at safe levels. In the early part of this century, however, some radiologists developed leukemia from radiation exposure,[6] and dentists lost fingers from repeatedly holding dental film plates in the patients' mouths during exposure. This was, of course, before the hazards of radiation were known.

Radiation is measured in roentgens, rads, and roentgen equivalents man. Definitions are as follows:

Roentgen (R): Unit of exposure dose of x or gamma radiation that produces a specific amount of ionization in a specified mass of air.

Rad: Unit of absorbed dose (radiation absorbed dose). The energy is absorbed by the material, such as tissue. With x- or gamma rays, 1 roentgen of exposure would produce about 1 rad of absorbed dose in soft tissue.

Roentgen equivalent man (rem): Unit of biological dose weighted for relative biological effectiveness of different types of radiation. Most exposures dealt with are in fractions of a rem. One millirem (mrem) equals 1/1000 of a rem.

There is reason to be concerned with dose because of the potential harm radiation can inflict. Radiation causes two broad categories of injury:

(1) damage to the individual and (2) undesirable effects in future generations.

Damage to the Individual

Damage to the individual includes the following categories: (1) general effects on the body, such as production of leukemia[7] and anemia, (2) injuries to superficial tissues, (3) induction of malignant tumors, and (4) other deleterious effects such as cataract formation.

Because of these varied effects, it is difficult to estimate the likelihood of a given amount of radiation causing a given effect. It is even difficult to derive a measurement of dose from a given x-ray procedure because the radiation is not uniformly distributed throughout the body, and the dose is often localized and shielded by beam restriction and gonadal shields.

A recent study utilizing simulation phantoms has accurately established the dose from computed tomographic (CT) scanning. The midplane dose varied from 0.5 to 3.6 rads depending on which brand of CT machine was used.[8] These figures were 30 percent lower than those obtained in 1977.

General Effects

Of the effects mentioned above, the production of leukemia is probably the most dangerous. Leukemia is frequently fatal, whereas the other effects, such as superficial tissue injury and cataract formation, do not directly endanger life. Since bone marrow is the organ responsible for the production of leukemic cells, the radiation dose to this organ is important in the development of leukemia. Table 2 lists the bone marrow dosage of various common x-ray procedures.[9]

According to UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation),[10] the relative risk of leukemia induction is on the order of 15 to 25 cases per million persons per rad, with a mean interval between exposure and leukemia death of 10 years. For a given person, this risk is 1 in 50,000. UNSCEAR is quick to point out that this estimate was derived from observing individuals who received an excess of 100 rem. They allowed that the damage rate might be substantially lower for dose rates below 100 rem. The living cell has a tremendous capacity to repair damage inflicted by low-level radiation. A recent study from the Mayo Clinic suggests that no statistically significant increase of developing leukemia was present after radiation doses of 0 to 300 rads to the bone marrow.[11] These doses were administered in small increments over long periods of time, as in routine medical care. One hundred thirty-eight patients with leukemia, representing all of the known cases of leukemia in residents of Olmsted County, Minnesota, between 1955 and 1974, were evaluated for their radiation exposure. It was found that exposure to low-level medical radiation did not increase the risk of leukemia in those persons studied.

Table 2. Mean Active Bone Marrow Doses to United States Population, 1970

Type of Examination	Millirads per Examination
High Bone Marrow Dose Group	
Barium enema	875
Pelvimetry	595
Upper gastrointestinal series	535
Lumbosacral spine	450
Small bowel series	422
Intravenous pyelogram	420
Lumbar spine	347
Thoracic spine	247
Medium Bone Marrow Dose Group	
Gallbladder	168
Abdomen	147
Ribs	143
Pelvis	93
Skull	78
Hip	72
Low Bone Marrow Dose Group	
Cervical spine	52
Femur	21
Chest	10
Dental	9.4

Note: Specific departments of radiology and other radiographic installations utilizing all safety measures mentioned would have substantially lower doses
From the Public Health Service, Food and Drug Administration[9]

Damage to Superficial Tissue

The superficial skin erythema as might be seen in certain types of radiation therapy is not a factor in diagnostic radiology. The notorious increase of thyroid malignancy in patients who received radiation treatments for enlarged thymus gland, tonsillitis, and acne has been widely publicized. These treatments have long since ceased, but occasional cases of thyroid carcinoma are still found in patients who have received this type of radiation therapy. Individuals known to have undergone such treatment should be evaluated periodically.

Controversy over screening and diagnostic mammography has arisen within the past five years. It was noted that subjects receiving very high radiation doses (eg, victims of nuclear weapons,[12] tuberculosis patients receiving frequent chest fluoroscopies,[13] mastitis[14] and ankylosing spondylitis patients treated by radiation therapy) subsequently developed breast malignancies at a rate that was greater than that in the general population. It was inferred that if a very high dose causes a given breast malignancy rate, then a very low dose would cause a proportionately lower increased incidence of cancer induction. This lower rate of cancer, however, would still be higher than the population at large.[15,16] This logic has been refuted by other studies stating that the predicted increase from low-level radiation has never been demonstrated.[17] In addition, they argue that there seems to be a special threshold dose, below which there is no evidence of malignancy induction. This matter remains unsolved, but technological advances have dramatically lowered the breast dose in mammography while enhancing resolution and lesion detection. The current midgland dose with state-of-the-art equipment is 200 to 300 mrem. This dose is approximately 10 percent of the former level received. Even if a slight risk is present, the Breast Cancer Detection Demonstration Project[17] has shown that the benefits of mammography in detecting early nonpalpable malignancies far outweigh any theoretical risk. In screening 270,000 women with mammography, the Breast Cancer Detection Demonstration Project detected 711 cancers by mammography alone (45 percent of all cancer detected). Compared with older women, in younger women there was a higher percentage of cancer detected by mammography alone. It had been suggested that mammography was relatively less useful in the detection of cancer in younger women. In fact, it was found to be even more effective in detecting cancer in younger women than in older women. Assuming that there is no threshold for cancer induction and that some cancers may be caused by mammography, the Breast Cancer Detection Demonstration Project showed the contribution of mammography to be a factor in increasing the survival of 213 patients significantly. The benefit-risk factor has been calculated to be 22 to 1.[17]

Effects on Future Generations

Diminished fertility has been demonstrated in individuals whose gonads have been irradiated. It is theoretically possible that future generations may be affected because of chromosomal damage. Genetic effects are very difficult to establish, but to date no hereditary defects have been documented. Table 3 lists the gonadal doses delivered by various procedures.[9]

The unborn fetus is quite sensitive to radiation, especially during the first 12 weeks of gestation, the period of organogenesis. Scientists generally believe that neither major malformations nor spontaneous abortion is likely to result from exposure to diagnostic levels of radiation. Evidence does suggest, however, that the risk of development of childhood malignancy may be enhanced by as few as three to four exposures to the maternal abdomen.[10,18-20] One would hope that diagnostic ultrasound could answer most of the questions formerly answered by prenatal x-ray examinations.[17]

Conclusions

It is apparent that determining the exact risk from undergoing a given x-ray examination is impossible. The risks of low level radiation are quite low, and the results of the Mayo Clinic study are encouraging. Except for the risk to the developing fetus from exposure to the maternal abdomen, there has been no direct evidence of human harm from diagnostic doses of radiation.[11] Experts believe risks do exist, but they appear to be small compared with other common hazards that most persons face every day. These risks are also small compared with the risks assumed by not having necessary x-ray studies.

In most x-ray departments, many measures are taken to make certain that exposure is as low as reasonable while still allowing enough radiation to cast a high-quality image. Strict beam limitation (collimation) is employed to ensure that only the body part in question is exposed. Newly purchased x-ray equipment is required to have an

Table 3. Median Gonad Doses: United States, 1970

	Millirads per Examination
High Gonad Dose Group	
Male	
Hip	418
Pelvis	317
Female	
Lumbar spine	608
Barium enema	574
Pyelograms, intravenous	448
Pelvis	158
Abdomen, kidneys, ureters, bladder, flat plate	144
Hip	109
Medium Gonad Dose Group	
Male	
Barium enema	22
Pyelograms, intravenous	20
Lumbar spine	10
Abdomen, kidneys, ureters, bladder, flat plate	9
Female	
Upper gastrointestinal series	91
Cholecystography	27
Thoracic spine	6
Low Gonad Dose Group	
Male	
Skull	*
Chest	*
Cervical or thoracic spine	*
Upper gastrointestinal series	*
Cholecystography	*
Upper extremities	*
Lower extremities	*
Female	
Chest, photofluorographic	1
Chest, radiographic	*
Skull	*
Cervical spine	*
Upper extremities	*
Lower extremities	*

Note: Figures are for medical radiography only and do not include fluoroscopic, dental, or therapeutic exposures. Specific departments of radiology and other radiographic installations employing all safety measures mentioned would be expected to have considerably lower doses than listed above
*Less than 0.5 millirads per examination
From the Public Health Service, Food and Drug Administration[9]

automatic collimation system to prevent the beam size from being larger than the film being used. Gonadal shielding is used whenever feasible. High-speed film and intensifying screens have dramatically reduced radiation exposure while maintaining or improving image quality. X-ray machine operators and technologists should be well trained and competent, thus reducing the need for repeat films. Most important, selectivity and discretion in ordering only appropriate and indicated x-rays will assure that patients are exposed to no more radiation than necessary.

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