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Fluoroscopy:
Radiation Protection and Safety

American Society of Radiologic Technologists

Fluoroscopy: Radiation Protection and Safety

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Advanced medical imaging modalities, particularly fluoroscopy, interventional radiology and computed tomography (CT), are associated with long exposure times and high radiation doses, making radiation protection a vital concern. In the United States, increased utilization of radiologic examinations, especially CT, has added to the effective dose to patients.

This article presents an overview of radiation protection in fluoroscopy, including radiation measurements, the biological effects of radiation, the fundamental principles of radiation protection, the ethical and legal responsibilities of medical imaging professionals, examination room design, fluoroscopy equipment safety features, and the protection of patients, personnel and special populations.

After completing this article, the reader should be able to:

- Identify and justify the need to minimize unnecessary radiation exposure of humans.
- Identify sources of ionizing radiation.
- Define radiation and units of measurement associated with radiation exposure and dose.
- Discuss the potential biological effects of ionizing radiation, including somatic, genetic, stochastic and nonstochastic effects.
- List the fundamental principles of radiation protection.
- Explain the objectives of a radiation protection program and discuss the components of an effective protection program, including documentation, occupational and nonoccupational dose limits and the ALARA principle.
- Recognize the legal and ethical responsibilities of radiation workers with respect to radiation protection.
- Discuss shielding and examination room design, including the difference between primary and secondary radiation barriers and factors affecting shielding.
- Describe fluoroscopy equipment features that limit radiation exposure.
- Describe methods to reduce patient and personnel radiation exposure, including the use of beam-limiting devices, filtration, shielding, exposure factors, positioning, immobilization and intermittent fluoroscopy.
- Explain the special considerations required for radiation protection of children, pregnant patients and pregnant radiation workers.

Starting with the discovery of x-rays in 1895 by Wilhelm Conrad Roentgen, technological advances have given birth to a variety of medical imaging modalities, including fluoroscopy, interventional radiology and computed tomography (CT). Improvements in technology and the development of minimally invasive procedures have led to extensive use of radiologic examinations, particularly fluoro-scopy-guided procedures to place needles and catheters. The advantage of these procedures is that they are cost effective and often reduce the need for surgery.

Many of these imaging modalities, however, are associated with long exposure times and high radiation doses; therefore, radiation protection is important to safeguard patients, radiology personnel and the public. It is essential that all workers involved in radiologic procedures understand the risks of ionizing radiation and the need to minimize unnecessary radiation exposure.

Sources of Radiation

Exposure to ionizing radiation comes from either natural or artificial sources. Natural sources of radiation include exposure from the earth's crust, outer space, building materials and naturally occurring radioactive materials in the body.[1] Artificial radiation sources include dental and medical exposure (including diagnostic radiology, nuclear medicine and radiation therapy), fallout from nuclear weapons, the nuclear power industry and occupational radiation exposure.[1] Radon and its decay products represent the largest contributors of natural (background) radiation exposure, and medical procedures deliver the largest amount of artificial radiation to the public.[2]

Radon gas forms from the radioactive breakdown of naturally occurring radium found in soil. Individuals are exposed to natural radiation when radon gas enters buildings through small openings in the foundation. Thus, the amount of background radiation a person receives varies depending on his or her location. Different areas of the United States have different radon levels; for example, the radon levels in Colorado differ from radon levels in Florida. According to the Centers for Disease Control and Prevention (CDC), radon is the second leading cause of lung cancer in the United States after cigarette smoking.[3]

Medical radiation comes from three sources: the treatment of benign diseases, diagnostic examinations and the treatment of malignant diseases. Data collected from the Biological Effects of Ionizing Radiation (BEIR) VII, Phase 2 study indicate that approximately 400 million diagnostic medical examinations and 150 million dental x-ray examinations are performed annually in the United States. On average, each person receives at least 2 examinations per year.[4]

Radiation Units and Measurement

Antoine Henri Becquerel discovered radioactivity in 1896; he was awarded the Nobel Prize in Physics in 1903 for his discovery, together with Marie and Pierre Curie.[5] Radioactive materials contain unstable atoms that continuously decay; the more unstable atoms are within a given substance, the greater the disintegration rate, or rate of decay. Radioactivity is expressed using the becquerel (Bq), which is the International System of Units (SI) measurement, or the curie (Ci), which is the non-SI unit. One Bq is equal to 1 disintegration per second, and 1 Ci is equal to 3.7 x 10^{10} Bq. The curie is equal to 2.2 trillion (2,200,000,000,000) disintegrations per minute (dpm) or 2.2 x 10^{12} dpm.[6,7]

Exposure

When atoms of molecules absorb x-ray energy, electrons break away from their atomic orbits, creating charged particles, or ions, thus the term "ionizing radiation."[8] Radiation exposure units include the coulomb/kilogram (C/kg) and the roentgen (R). The coulomb is a unit of electrostatic charge, and the roentgen is a unit of radiation exposure describing the ionization of atoms in air by gamma rays or x-rays up to 3 megaelectron volts (MeV). The roentgen does not measure energy absorbed or dose, but rather how many ion pairs are formed in a given volume of air when exposed to radiation.[2,9]

Absorbed Dose

Absorbed dose is defined as the energy imparted to matter by ionizing radiation per unit mass of irradiated material.[1] The measurement of absorbed dose is expressed in gray (Gy), which is the SI unit, or the older, non-SI term, radiation absorbed dose (rad). One Gy equals 100 rad and 1 rad equals 0.01 Gy. The gray describes the radiation dose absorbed by tissues following exposure to ionizing radiation. A 1-Gy dose is equal to 1 joule (J) of radiation energy absorbed per kilogram of organ or tissue weight. This unit is used to measure the dose accumulated from multiple exposures to any type of ionizing radiation. However, equal doses of different types of radiation are not equally harmful to the body. The gray or rad is not a measure of the relative biological effect on the body.[10]

Dose Equivalent

Dose equivalent is a measurement used to indicate the biological damage to living tissue from an absorbed radiation dose. It is the product of the absorbed dose and a quality factor that takes into account the effects of different types of radiation.[1] Dose equivalent is expressed in sievert (Sv), which is the SI unit, or roentgen equivalent man (rem), the conventional unit. One Sv equals 100 rem and 1 rem equals 0.01 Sv.[10]

The rem measures radiation energy absorbed by a person. For example, a chest radiograph delivers a dose of 0.1 mSv (10 mrem), roughly the same radiation dose received from making 2 or 3 coast-to-coast airline flights. The source of radiation exposure might differ, yet by obtaining measurements in a standard unit, a comparison can be made easily. Therefore, this measurement is effective in determining relative harm or risk caused by a given dose of radiation compared with other types of radiation. For this reason, the dose equivalent for occupational workers who are exposed to radiation is measured in Sv or rem.[10]

Effective Dose

Effective dose is expressed using the millisievert (mSv). Radiation sensitivity varies by cell type and according to the size of a patient's tissues and organs. (See **Box 1**.) Thus, effective dose is averaged over the entire body, allowing for differences in exposed tissues. Taking into account the full spectrum of radiation sources from natural background radiation to medical imaging procedures, the effective dose can be analyzed by risk and compared with ease.[10] The annual effective dose from naturally occurring radioactive materials and cosmic radiation is estimated to be 3 mSv (300 mrem).[2] The average effective dose for a diagnostic x-ray examination is 0.39 mSv (39 mrem) and 0.14 mSv (14 mrem) for nuclear medicine procedures.[11]

The effective dose is probably the most useful way to express and compare the dose delivered by different imaging procedures because it takes into account the distribution of dose to the radiosensitive organs in the body. The relative radiosensitivity of each organ or tissue is weighted and then the individual organ doses are added together. The estimated effective dose tells what the equivalent whole-body dose response would be, along with a risk assessment. Although lacking in precision, the effective dose communicates a complex dose pattern in terms of a single quantity and roughly describes the risk of harmful radiation effects.[12]

It is important to distinguish between the radiation risk of a whole-body exposure and that of targeted radiologic examinations. For example, the tissues of the head (eg, nerve and brain tissue) are fairly resistant to radiation, whereas the tissues of the abdomen and chest (eg, breast tissue, lung tissue or the abdominal organs) are rather radiosensitive. A CT scan of the head represents roughly twice the amount of radiation exposure as a CT scan of the abdomen. However, both examinations deliver about the same estimated effective dose.[13]

The World Health Organization suggests the use of collective effective dose to describe global trends in the medical use of radiation and to compare estimated population doses. This measure is calculated by multiplying the estimated number of radiologic procedures in a specific population by the mean effective dose for that procedure. The collective effective dose is typically measured in person-sieverts (person-SV).[14]

Box 1

Radiation Sensitivity by Cell Type[a]

Lymphocytes
Red blood
Granulocytes
Epithelial
Endothelial
Connective tissue
Bone
Nerve
Brain
Muscle

[a] *Ranked from highest to lowest sensitivity to radiation.*[9]

According to the U.S. Food and Drug Administration (FDA), CT scans, nuclear medicine studies, and interventional fluoroscopy procedures represent only 26% of the total number of U.S. radiologic examinations each year. However, these three modalities combine to deliver 89% of the total annual radiation exposure from medical imaging.[15] The concept of effective dose is estimated and becomes complicated when dealing with modalities such as CT and nuclear medicine. These modalities deliver different dose distributions within the body and cannot be directly related to the radiation risk to the patient.[12]

Potential Biological Damage From Ionizing Radiation

Radiobiology, which is the study of the effects of ionizing radiation on living things, is based on understanding x-ray beam formation and how radiation interacts with and affects matter. The practical application of this knowledge is to reduce immediate harm to exposed individuals and possible genetic damage to future generations.[16] The ultimate goal of any health care practitioner, radiologist assistant (RA) or radiologic technologist should be to minimize unnecessary radiation exposure.

No matter how small, radiation exposure is associated with some amount of risk because ionizing radiation can potentially affect normal cell function. Radiation damage is caused by the ionization of atoms. Radiation ionization occurs when subatomic particles or electromagnetic waves have enough energy to detach electrons from atoms or molecules. By removing the electron in a molecule, the molecular bond once shared by the two atoms is broken and ions are formed. When ionizing radiation is absorbed by human cells, molecules that make up the body's tissues are altered.[17]

How can radiation exposure change a human cell? Negative biological effects largely depend on whether the radiation affects a critical part of the cell such as the chromosomes. Chromosomes are considered the most important part of the cell because they contain the genetic information and instructions for cell function and replication.[17]

In many cases, ionization creates a chemically active substance that alters cellular structure. When this change is similar to naturally occurring processes, the cell remains undamaged. In other situations, ionization produces substances not normally found in the cell, leading to a breakdown of the cell and its components. Cells with limited damage might be able to repair themselves and return to normal cellular function. However, some cells are unable to perform the repair or might carry out an activity inaccurately or incompletely. The outcome is abnormal cell function, underperformance of cellular activities or damage to other cells. Damaged cells may not be able to reproduce or may proliferate at an uncontrolled rate, causing cancer. When cells are damaged extensively, reproduction function fails, resulting in cell death.[17]

A cell's sensitivity to radiation can play a role in any given outcome. Cells that are nonspecialized or divide rapidly tend to be affected at lower radiation doses than those that are more specialized or divide more slowly.[17]

The potential biological effects of radiation reflect the quantity and rate of exposure. Radiation doses can be categorized as acute or chronic. Acute doses are large doses (> 0.7 Gy or 70 rad) delivered in a short period of time to the whole or a large portion of the body. These exposures cause observable biological effects within a period of hours to weeks, and mild symptoms can be observed with doses as low as 0.3 Gy or 30 rads.[18]

Chronic radiation doses are relatively small amounts of radiation that are delivered over a long period of time. In the case of a chronic dose, the cells have time to repair damage or to replace dead or nonfunctioning cells with healthy cells. Occupational exposure is usually considered to be as a result of chronic radiation doses.[1]

Somatic and Genetic Effects

To fully understand radiation protection, health care practitioners, RAs and radiologic technologists must know how the effects of radiation apply to everyday practice. Acute radiation effects occur soon after radiation exposure, but late radiation effects remain hidden for many years. Late effects might not even appear in the exposed individual, but might be seen in future generations. Late effects can be categorized as somatic, which are those effects occurring in an exposed individual, or genetic, which are those effects observed in succeeding generations.[1]

Somatic effects are divided into two main classes — acute and delayed — based on the rate at which the dose was received. Somatic effects also can be defined as either stochastic (probabilistic) or nonstochastic (deterministic).[1]

Acute somatic effects occur when a dose of approximately 0.1 Gy (10 rad) or greater is applied to the entire body over a short period of time. An example of an acute effect is when a patient receives a dose large enough to produce temporary hair loss 3 weeks after treatment. In those cases, the hair is expected to grow back within 2 months but with altered color and texture. Acute radiation syndromes include bone marrow syndrome (1-10 Gy or 100-1,000 rad), gastrointestinal tract syndrome (10-50 Gy or 1,000-5,000 rad) and central nervous system syndrome (> 50 Gy or > 5,000 rad).[1]

Examples of delayed somatic effects include increased risk for the development of cancer and cataracts. In addition, radiation damage to the reproductive cells of an exposed individual can affect future generations. In humans, the abnormalities caused by genetic effects might or might not occur, and genetic effects represent a considerably smaller risk than the risks associated with somatic effects.[1]

Stochastic Effects

Stochastic literally means "random in nature." The probability that stochastic effects will occur increases as a function of radiation dose, and these effects generally are assumed not to have a threshold. In other words, effects occurring at any dose, no matter how small, have a probability of inducing a biological effect. Increasing the dose increases the probability that an effect will occur, but a higher dose does not increase the severity of the effect.[1]

Examples of stochastic radiation effects include induced cancers (carcinogenesis) and hereditary (genetic) effects. As a late radiation effect, carcinogenesis is an all-or-nothing phenomenon that does not have a dose threshold, meaning that any size dose can induce a cancer. Because carcinogenesis is a nonthreshold effect, it is considered a stochastic or random event.[1] Risk coefficients for stochastic effects, such as radiation-induced cancer and leukemia, are based principally on data from the Japanese atomic bomb survivors.[13]

The risk for a given dose decreases with increasing age at exposure since somatic effects can be delayed for many years or even decades. In the elderly, there is less opportunity for radiation effects to appear following x-ray examinations, and genetic effects are not significant for patients past their reproductive years.[12]

Nonstochastic Effects

Nonstochastic, or deterministic, effects are defined as an outcome for which severity increases with dose and for which a threshold usually exists, such as death after irradiation of an organ or of the total body. Tissues and organs exhibit a dose threshold — a dose below which damage will not be observed and a dose above which damage will occur. If the radiation dose is above the threshold, then the severity of the effect increases as the dose increases. Examples of nonstochastic effects as a result of radiation therapy include skin burns (erythema), hair loss (epilation) and peeling of the skin (desquamation). Fibrosis, hematopoietic damage and radiation-induced cataracts also are nonstochastic radiation effects.[1]

Under currently defined dose limits, radiation doses delivered by diagnostic imaging examinations are not sufficiently high enough to cause a nonstochastic effect.[13] However, the use of extended fluoroscopy time and irradiation to small areas of the body involved in cardiac catheterization and interventional radiology can lead to nonstochastic effects such as skin damage. Nonstochastic effects usually occur within days, weeks or months of the radiation exposure.[1,13,17]

Until recently, nonstochastic effects were highly unlikely to occur during diagnostic imaging. However, in 2009 the news media reported that CT perfusion scans performed at Cedars-Sinai Medical Center in Los Angeles caused radiation overdoses in 206 patients over an 18-month period.[18] The hospital began investigating the incidents when a patient reported losing patches of hair (a nonstochastic effect) after undergoing a CT perfusion scan. Cases like these increase awareness of radiation risk and force institutions to re-evaluate their radiation protection practices and delivery.

In general, nonstochastic effects do not occur with chronic doses; therefore, to assess exposure risks to the occupational worker, estimates are based on the risk associated with high doses. The stochastic risk model explains the relationship between the occurrence of cancer at high doses and the potential for cancer at low doses. This model assumes that because the probability of cancer increases at high doses, the same must also be true for low doses.[1]

Fundamental Principles of Radiation Protection

To avoid radiation overexposure incidents like those that occurred at Cedars-Sinai, medical imaging practitioners must have a complete understanding of all the parameters affecting patient dose. Not only should they be aware of radiation protection measures, but they also must be able to identify when parameters are not as they should be. The fundamental principles of radiation protection are time, distance and shielding. All medical imaging personnel, including RAs and radiologic technologists, should follow these principles to ensure the safety of their patients and to minimize their occupational exposure.[11] Radiation safety includes:

- Adhering to the as low as reasonably achievable, or ALARA, principle; the goal of this concept is to minimize radiation exposure while obtaining the best quality diagnostic image possible.
- Minimizing the length of time the patient or others are in the path of the x-ray beam.

- Maximizing the distance between the source of ionizing radiation and the person exposed to it.
- Maximizing shielding of the patient and others from radiation exposure.[11]

Time

Medical imaging personnel should keep the time of radiation exposure as short as possible because the amount of exposure is directly proportional to the time of exposure.[11] Simply put, increased time equals increased radiation exposure. Ways to reduce fluoroscopy time include:

- Stopping patient exposure when not viewing the monitor.
- Preplanning images.
- Avoiding redundant views.
- Being aware of the 5-minute time notifications.[11]

Distance

Medical imaging practitioners, RAs and radiologic technologists should always maintain as great a distance as possible between themselves and the source of radiation. The divergence of the x-ray beam from its source has less radiation per unit area, so increasing distance decreases radiation exposure.[11] In fluoroscopy, a person standing 1 m (3.28 ft) from the patient receives about 0.1% of the useful beam's intensity from scatter radiation.[6] The resulting scatter formation depends on patient size and the field of view used. A larger field of view increases scatter production, increasing the patient and personnel radiation risk.

X-ray and gamma radiation follow the inverse square law, which states that the intensity of radiation decreases in proportion to the inverse of the distance squared. In other words, the amount of radiation a person receives depends on the distance he or she is from the source. A person who is closer to the radiation source receives a higher dose than a person standing farther away. Exposure increases by a factor of 4 if the distance is cut in half. The opposite is also true: doubling the distance from the source reduces x-ray intensity by a factor of 4.[6] Maintaining as great a distance as possible from the source of radiation is the easiest form of radiation protection, especially during fluoroscopy.

Shielding

RAs and radiologic technologists are responsible for ensuring that all people who are involved in, or who are in the vicinity of, a radiographic procedure have protective apparel to shield them from ionizing radiation.[16] Any material that can be placed between an individual and a radiation source is considered shielding. The best materials for shielding have a high atomic number and are not naturally radioactive; these materials provide the greatest photoelectric absorption.[11]

Radiation Safety Programs

Diagnostic imaging procedures, with the exception of MR imaging and sonography, contribute more than 90% of the exposure to artificial radiation in the United States. Therefore, it is vital that patients, visitors, hospital staff and radiology personnel receive as little radiation exposure as possible from medical imaging examinations.[11]

Federal and state governments mandate that every radiology department have a radiation safety program to safeguard medical personnel and the public from radiation overexposure. The federal agencies that oversee such programs include the Center for Devices and Radiological Health (CDRH) of the FDA, Nuclear Regulatory Commission (NRC) and Occupational Safety and Health Administration (OSHA). The FDA and the CDRH regulate the design and manufacture of equipment. The NRC is responsible for enforcing both equipment standards and radiation safety practices. OSHA monitors the workplace, including requirements concerning occupational exposure to radiation.[11]

An underlying premise of radiation safety programs is the idea that exposure to ionizing radiation is accompanied by an overall benefit. Therefore, radiation protection policy and procedures require personnel to adhere to the ALARA principle and to the dose limits established by the National Council on Radiation Protection and Measurements (NCRP) Report No. 116, Limitation of Exposure to Ionizing Radiation.[20]

NCRP Report No. 116 states, "The specific objectives of radiation protection are: (a) to prevent the occurrence of clinically significant radiation induced deterministic (non-stochastic) effects by adhering to dose limits that are below the apparent threshold levels; and (b), to limit the risk of stochastic (probabilistic) effects, cancer and genetic effects, to a reasonable level in relation to societal needs, values, benefits gained and economic factors."[20]

A radiation safety officer supervises the radiation safety program. The officer:

- Oversees licensing and registration of the safety program.
- Ensures secure storage and proper disposable of radioactive materials.
- Reviews all radiation safety policies and procedures.
- Monitors and reviews equipment and radioactive material storage and shipment.
- Reviews the location of radiation warning signs.
- Evaluates personnel monitoring.
- Surveys all radiation areas for safety hazards.
- Performs risk assessments.
- Evaluates equipment and personnel for potential radiation exposure.
- Investigates and acts upon radiation incidents (spills and exposure).
- Supervises decontamination.
- Implements quality assurance policies and procedures for equipment and personnel.
- Reviews and submits reports evaluating radiation safety program annually.
- Conducts radiation personnel education and instruction.
- Establishes emergency radiation procedures.[20]

Emergency policies and procedures are an important aspect of the radiation safety program. These measures ensure that all radiology personnel know how to adequately identify, evaluate and react to various radiation emergencies. An emergency plan establishes the main notification processes, personnel and patient medical treatment, decontamination and incident reporting for an emergency.[20]

The main goal of emergency preparedness is to protect employees, patients and the public against potential hazards. The emergency plan must include a detailed plan of action and a list of agencies to be contacted in case of emergency. These agencies include public bodies such as the board of health, fire department and police department. Other elements of the emergency plan might include placement of exit signs, illuminated warning signs for beam on/off, evacuation plans, and the location and use of fire extinguisher and pull stations. The radiation safety officer is responsible for implementing emergency plan education and training for all employees.[20]

Radiation safety policies and procedures guarantee that all employees who administer ionizing radiation recognize their responsibilities. All radiation safety programs should properly document quality assurance (QA) policies and procedures to demonstrate compliance with federal and state regulations. Properly implemented, a radiation protection program reduces stochastic radiation risk for nonradiation workers and helps prevent nonstochastic radiation risk for the occupational worker.[11]

Documentation for Quality Improvement

Quality improvement programs rely on good record keeping; therefore, all shielding calculations, details of inspections and any corrective actions should be properly documented. All radiation safety program policies and procedures should be routinely evaluated and updated. An annual review is an important aspect of quality improvement and helps to maintain the ALARA principle. The review should include policies and procedures, dose reports, inspections, repairs, audits, personnel consultations, unmet goals from previous years and noncompliance with maintenance issues. Not only is documentation a requirement, but it also is an effective means of improving and modifying the existing safety program.[20]

Occupational and Nonoccupational Dose Limits

Researchers have studied cancer risk among physicians and other people exposed to ionizing radiation in the workplace since the 1940s. At that time, radiologists experienced increased mortality rates from leukemia compared with mortality rates of other medical specialists.[4] Radiation-induced leukemia has a latent period of just a few years compared with the decades it takes for radiation-induced solid tumors to appear.[21]

Given the demonstrated risks of radiation exposure, routine monitoring of radiation doses can reveal if a worker is approaching or exceeding the recommended dose limits. Monitoring and recording cumulative radiation doses also can verify the effectiveness of radiation control practices in the workplace. Monitoring helps confirm acceptable exposure levels and detect any changes in those levels, identifies work practices that minimize dose and provides information in the event of an accidental exposure.[20] For these reasons, routine monitoring enables radiology personnel to actively participate in radiation protection goals.

Table 1

NCRP Effective Dose Limits for Occupational Workers[1,10]

Exposure	Dose SI Units	Dose Conventional Units
Occupational Exposure		
Effective DE limits (stochastic effects)	Annual: 50 mSv Cumulative: 10 mSv x age in years	Annual: 5 rem (5,000 mrem) Cumulative: 1 rem (1,000 mrem) x age in years
Equivalent annual dose to tissues (nonstochastic effects):		
Lens of eye	150 mSv	15 rem (15,000 mrem)
Skin, hands, feet	500 mSv	50 rem (50,000 mrem)
Annual Public Exposure		
Effective dose for continuous or frequent exposure	1 mSv	0.1 rem (100 mrem)
Effective dose for infrequent exposure	5 mSv	0.5 rem (500 mrem)
Equivalent dose for tissues/organs:		
Lens of eye	15 mSv	0.05 rem (50 mrem)
Annual Exposure, Child < 18, Educational Training		
Effective dose limit	1 mSv	0.1 rem (100 mrem)
Equivalent dose limit:		
Lens of eye	15 mSv	0.05 rem (50 mrem)
Embryo/Fetus		
Total effective dose	5 mSv	0.5 rem (500 mrem)
Monthly effective dose	0.5 mSv	0.05 rem (50 mrem)
Negligible Individual Dose		
Annual per source	0.01 mSv	0.001 rem (1 mrem)

Sv = sievert; rem = roentgen man equivalent; DE = dose equivalent.

The mission of the NCRP is to support radiation protection by providing independent scientific analysis, public information, and recommendations that represent the consensus of radiation scientists.[13] The NCRP requires the following workers to be monitored for occupational radiation exposure:

- Any worker likely to receive a whole-body dose in excess of 25 mR in a given week.
- A person who potentially could receive 10% of the maximum annual dose limit.
- Any person who routinely enters a designated "high radiation area."
- Any person who operates fluoroscopic equipment.
- Operators of mobile x-ray equipment.
- People who service x-ray equipment.[9]

The NCRP is responsible for setting radiation dose limits for the occupational worker and the public. Table 1 illustrates dose limit recommendations from NCRP Report No. 116. The effective dose limits for occupationally exposed workers are given in SI and conventional units. The annual occupational effective dose limit is 50 mSv (5 rem) and the cumulative effective dose limit is 10 mSv x the worker's age (1 rem x age). The occupational equivalent annual dose for tissues and organs such as the lens of eye is 150 mSv (15 rem), and tissues such as the thyroid, skin, hands and feet may receive 500 mSv (50 rem).[9] Radiologists, RAs, radiologic technologists and other medical imaging personnel receive an average annual occupational effective dose well below the occupational limit of 50 mSv per year to the whole body.[22]

Occupational exposure, expressed as effective dose, is always much less than the actual dose recorded by monitoring devices as long as personal protective equipment, such as lead aprons and thyroid shields, are worn on a regular basis. The effective dose is a reasonable representation of the risk of carcinogenesis and hereditary effects in the first two generations of progeny due to radiation exposure.[9]

ALARA Principle

The goal of ALARA is to prevent overexposure and to reduce radiation-related risks. ALARA is the number one method to keep radiation exposure within acceptable limits for the patient, the occupational worker and the public. Eric L Gingold, PhD, explains the relationship between ALARA and dose limits in this way: "Although the ALARA principle presumes that there is no absolutely safe level, occupational dose limits are chosen to keep radiation exposures to low levels, based on two concepts. The first is to prevent radiation-induced deterministic effects by adhering to dose limits that are below the apparent threshold levels. The second is to limit the risk of stochastic effects to a reasonable level in relation to social needs, values, benefits gained, and economic factors."[22] It is the combination of ALARA and keeping dose limits below the dose threshold that make radiation protection goals attainable.

Minimizing radiation exposure is not a novel idea. However, as technology advances, concepts such as ALARA must be adapted to the changing workplace. Physicians, RAs, radiologic technologists and other health care practitioners should be involved in developing new protocols to help maintain ALARA. Radiology managers are responsible for implementing ALARA policies and procedures, establishing radiation exposure goals and guidelines, communicating those goals to all personnel, tracking and evaluating radiological performance, providing a feedback mechanism concerning performance, and implementing improvements and corrective actions. Radiation workers are responsible for knowing and minimizing their exposure, adhering to all ALARA policies and procedures, being familiar with emergency procedures, and watching for and responding to unusual radiologic situations.[11]

NCRP Report No. 107 explains the theory of ALARA in detail and offers three main recommendations for limiting dose to patients:

- The use of high kilovolt peak (kVp) and low milliamperage seconds (mAs) exposure factors reduce patient exposure.
- High-speed image receptor systems reduce patient exposure because a faster system requires a lower mAs to obtain a diagnostic image.
- Proper filtration can reduce the patient's entrance skin dose by as much as 90%.[11]

Fluoroscopic examinations can potentially deliver a considerable radiation dose to the patient; therefore, ALARA protocols should be in place when performing fluoroscopy. Dose-limiting techniques include:

- Keeping fluoroscopic milliamperage (mA) and time as low as possible when performing fluoroscopy (0.5-3 mA).
- Using a high kVp if possible (85-125 kVp). The use of a higher kVp reduces the fluoroscopic mA required to obtain adequate image brightness, thereby reducing patient dose. ■ Limiting field size as much as possible.
- Using intermittent fluoroscopy. This practice can reduce patient dose by as much as 90%.
- Using the last image-hold feature. This technique can reduce total fluoroscopic time by 50% to 80%.
- Avoiding magnification mode because this feature reduces the brightness gain of the image intensifier tube, requiring an increase in fluoroscopic mA to compensate.
- Keeping the patient-to-image intensifier distance as small as possible during mobile fluoroscopic studies with a C-arm. This practice reduces the source-to-skin distance to the patient.
- Limiting the number of spot images and reducing the spot image size. Patient dose increases as the number of spot images increases. In addition, larger spot film sizes require more radiation; therefore, patient dose is increased.[11]

These dose-limiting techniques will be discussed in greater detail later in the article.

Communicating About Radiation Risk

Stochastic effects, particularly carcinogenic and genetic effects, are the primary risks from the low radiation doses received in a medical or an occupational setting.[1] A low dose is defined as an ionizing radiation level that is well below the point at which there is a clear and measureable connection between the radiation exposure and a biological effect.[22] Although it is clear that acute high-dose exposures can cause late effects, more importantly, late effects also can be due to a single low dose or chronic low doses of radiation over a long period of time, such as those received by patients or by occupationally exposed workers.[1]

Real or imagined, radiation risk has an enormous influence on the radiology field. Researchers have established that the low-level radiation used in medical imaging procedures has the potential to adversely affect human tissues; however, it is difficult to quantify these low-level radiation effects. Thus, the subject of radiation risk is filled with uncertainty and conflicting perceptions. Radiation exposure limits have been established and re-established based on the best available scientific judgment at the time, but the risk the public will accept for a given benefit, in part, determines what limits are permissible.[23]

The media often influences public perception by highlighting radiation risk. Headlines such as, "Low-level Radiation Causes More Deaths than Assumed," "Higher Cancer Risk Found in Radiation" and "Radiation Is Dangerous," can have a negative effect on radiology. The fact that subtle differences in how risks are presented can influence an audience suggests there is considerable potential to manipulate perception.[23]

Radiologists, RAs and radiologic technologists are responsible for educating patients, their families and the public about the possible radiation risks associated with medical imaging procedures. The information should balance the risks of radiation with the benefits of its use. In addition to recognizing the harmful effects of radiation exposure, medical imaging professionals should emphasize the continuous effort to reduce radiation exposure.[20] Advances in technology have not only decreased radiation exposure, but they also have improved image quality and, therefore, the quality of care.

Good communication can affect public perception positively. One approach is to contrast various activities and their natural levels of risk because every activity involves some amount of risk. It is important to note that comparisons should be presented with caution. Comparisons that convey the magnitude of a particular risk estimate, occur in the same decision context (eg, the risk associated with flying vs driving to a given destination) and those that have a similar outcome are more useful explanations.[23]

Individuals engage in voluntary activities such as hang gliding, smoking or traveling by car that carry substantial risk; that same level of risk might be unacceptable to a company or its workers. Occupational risk often is compared to voluntary risk to determine "acceptability"; however, individuals might not necessarily judge those risks on the same basis.[23] To put occupational risk into perspective, radiation exposure often is compared with voluntary activities or occupations that are considered safe.

Another approach is to estimate the total number of days that are lost during an individual's life (loss of life expectancy, or LLE) because of certain behaviors such as smoking and being obese or occupations such as being a construction worker or radiation worker.[17] For example, smoking a pack of cigarettes a day is associated with an estimated 2,370 days of life expectancy lost. Being overweight by 20% is equal to an estimated 985 days of life expectancy lost. A construction worker has an estimated 302 days of life expectancy lost. A radiation worker receiving 340 mrem per year for 30 years has an estimated 49 days of life expectancy lost, and the life expectancy lost for a radiation worker who receives 100 mrem per year for 70 years is an estimated 34 days.

It is important to recognize that these figures are estimates. Radiology is considered to be a safe occupation that relies heavily on safe practices and effective radiation protection programs.[17] It also is important to note that lifetime radiation risk varies considerably with the individual's age at the time of exposure because the risk during childhood is about twice that of adulthood.[23]

If a patient wants to know the amount of radiation that he or she received from a chest radiograph or CT scan of the chest, it's not helpful to say "about X mSv" because that response does not answer the question in a way the average person can understand. For example, the patient dose from a typical chest CT examination is 7 mSv; however, another way of describing the patient dose is that it is about 350 times more than a conventional PA chest radiograph (0.1 mSv).[24] **Table 2** is a summary of typical effective doses for adult patients delivered by selected diagnostic examinations and the approximate time period a person would receive an equivalent effective dose from natural background radiation. Generally speaking, most CT examinations expose a patient to more than a year of background radiation (approximately 3 mSv), particulary repeated examinations with and without contrast.[25] A CT scan with a dose of 10 mSv has an average cancer induction risk of about 1 in 1,000, with half of those cancers being fatal (most are expressed decades after the scan).[21]

Stewart Bushong, ScD, of the Baylor College of Medicine in Houston, Texas, describes negligible individual dose (NID) or negligible individual risk level (NIRL) as a useful concept for radiation management. The concept essentially asks, "Can we identify a radiation dose level below which we do not have to be concerned?" NCRP Report No. 116 recommends a negligible individual annual dose of 0.01 mSv (1 mrem).

Bushong, however, argues that identifying any amount as a negligible dose violates the ALARA concept because ALARA assumes a linear nonthreshold dose-response relationship. This dose-response relationship indicates that even the smallest dose has the potential to cause a radiation response.[6,13]

With that in mind, how does the radiologist, RA or radiologic technologist respond to patient inquires about the possible danger of radiologic procedures? Bushong's suggested response is, "The probability that this examination will cause you injury is near zero. It is less than 0.001%."[6]

Table 2

Effective Radiation Doses for Adult Patients vs Approximate Time Period To Receive an Equivalent Effective Dose From Natural Background Radiation[25]

Diagnostic Examination	Approximate Effective Adult Dose (mSv)[a]	Approximate Time To Receive Equivalent Effective Dose from Natural Background Radiation[b]
Bone densitometry	0.001	3 hours
Screening mammography	0.4	7 weeks
Radiography – chest	0.1	10 days
Radiography – spine	1.5	6 months
CT – head	2	8 months
Intravenous pyelogram	3	1 year
CT – spine	6	2 years
CT – chest	7	2 years
Radiography – upper GI tract	6	2 years
Radiography – lower GI tract	8	3 years
CT – abdomen, pelvis	10	3 years
CT angiography	12	4 years

mSV = millisievert

[a] *Approximate value for an average-sized adult. The actual effective dose can vary based on an individual's size and imaging protocols.*

[b] *Based on an average effective dose from natural background radiation of 3 mSv per year. The actual effective dose can vary based on geographic location.*

Legal and Ethical Responsibilities for Radiation Protection

Ethics are designed to deal with the many challenges and dilemmas within a professional field, including issues involving radiation protection and safety.[1] Ethics essentially defines a set of moral principles that governs a person's course of action. Most professions have a set of ethical principles (code of ethics) that directs professional behavior. For RAs and radiologic technologists, the American Registry of Radiologic Technologists (ARRT) has developed standards that outline a technologist's duties and responsibilities with respect to peers, patients and coworkers.[16]

Regarding radiation protection and safety, the Code of Ethics adopted by the ARRT states that "the radiologic technologist uses equipment and accessories, employs techniques and procedures, performs services in accordance with an accepted standard of practice, and demonstrates expertise in minimizing radiation exposure to the patient, self, and other members of the healthcare team." Additionally, with respect to patients' rights, the code maintains that "the radiologic technologist respects confidences entrusted in the course of professional practice, respects the patient's right to privacy, and reveals confidential information only as required by law or to protect the welfare of the individual or the community."[26]

These ethical positions are founded on basic philosophies that shape how professionals approach their practice. All health care practitioners, regardless of their specific area of expertise or discipline, should be familiar with their ethical and legal responsibilities. This knowledge helps to avoid legal difficulties and ensures that patients receive the highest quality care.

Standards of Care

RAs and radiologic technologists, as well as other medical professionals, are obligated to practice under certain parameters known as practice standards. These standards of care are established through a specific scope of practice and educational requirements outlined by professional and certification organizations.[27] For example, the scope of practice for radiographers developed by American Society of Radiologic Technologists includes "applying principles of ALARA to minimize exposure to patient, self, and others."[28] Additionally, the radiography practice standards state that the practitioner "participates in radiation protection, patient safety, risk management, and quality management activities."[28]

Legally, a standard of care is defined as the degree of care and skill used by a reasonable professional practicing in the same or similar circumstances as other professionals in the field. In a courtroom, expert medical testimony generally is required to establish that the standard of care was below accepted practice and that this breach of care was the cause of injury or death.[27]

Although each professional field dictates standard practice, it is the patient who ultimately determines the type of care he or she will receive after consulting with the physician or other medical personnel. When patients consent to treatment, they understand the benefits, risks and alternatives of the proposed procedure, including the risks associated with radiation exposure. Only after the patient has this information can a truly informed decision concerning medical care be made.[27]

Medical Negligence

Health care professionals come into contact with the legal system as parties to or as witnesses in medical negligence or malpractice litigation. The injured parties in these cases seek compensation from the individual or organization that has allegedly harmed them.[27] The injury suffered by the patient or plaintiff can represent actual physical injury, emotional distress or economic loss because of lost wages or employment opportunities. In addition, plaintiffs can make legal claims of assault, battery, false imprisonment or defamation due to improper or inadequate health care practices. In these cases, the legal system is asked to protect those who cannot protect themselves or to help injured parties collect compensation for their injuries.[27]

Medical negligence involves three requirements: the injured party must prove that the health care professional owed a duty to a patient, that the duty was breached and that, because of this breach, the patient was injured. The first requirement involves the health care provider's behavior toward other people and what duties are owed to others. When a patient is brought to the radiology department, the RA, radiologic technologist and any other personnel assigned to that patient are responsible for the patient's well-being. Clearly, adhering to recognized radiation protection and safety practices is part of delivering quality patient care. A failure to follow the norms of practice could constitute negligence.[27]

With respect to the second requirement, the medical imaging professional is obligated to perform a duty (once established) in a manner that will bring about a successful outcome. If the professional fails or violates the duty, he or she may be responsible for any injury to an individual resulting from that failure. The third and final condition of negligence involves damage to the individual because of the breach of duty. For negligence to apply, the breach of duty must cause some damage to the person or property. If no damage occurs, then under the legal definition, there is no negligence.[27] For example, if a patient received an excessive amount of radiation during a fluoroscopy procedure resulting in a severe skin burn or damage then that patient might have a case involving medical negligence.

Medical negligence is based on a relationship between the provider and the patient that establishes a duty owed. Generally, when a patient sees a physician for a particular condition or examination and the physician agrees to perform the necessary services, a duty is created. The physician must deliver those services with the appropriate skill and care. The duty involves using the degree of care and skill that would be expected of a similar, reasonably competent practitioner, acting in the same manner and under similar circumstances. A physician's failure to provide those services within a required standard of care can lead to a charge of medical negligence. The same is true for other medical professionals such as RAs and radiologic technologists.[27]

Medical Malpractice

Miscommunication is often the cause of medical malpractice. Patients many times are scared, confused and do not understand medical procedures. They rely on medical professionals to answer their questions, meet their needs and deliver the best care possible. Practitioners can reduce a patient's fears and suspicions and avoid potential conflicts if they take the time to listen and talk with their patients.[27]

Malpractice suits involving radiology can incorporate any of the following elements:

- Failure to correctly interpret.
- Negligence in the performance of radiologic procedures.
- Factors contributing to negligence, such as patient motion resulting in poor-quality radiographs.
- Failure to obtain informed consent.
- Unavailability of previous radiographs for comparison.
- Improper communication leading to delayed diagnosis and care.
- Admission of fault.[29,30]

It is tempting not to report a medical error. One study found that only half of house staff physicians who admitted making serious clinical errors told medical colleagues about their mistakes, and only 25% disclosed the errors to patients or their families. However, apologizing for mistakes might improve the physician-patient relationship and ease the radiologist's conscience, although it is not known whether an apology will prevent a malpractice lawsuit.[29,30]

Risk management can minimize medical errors, reduce the likelihood of medical malpractice lawsuits and contribute to a successful defense if a suit is filed.[31,32] To avoid malpractice, all professionals should be aware of any changes to practice standards that affect the delivery of care.[27] The public and the courts are constantly demanding that radiologists and other physicians expand the nature and the amount of information that must be disclosed to patients.[33] Such demands might include communicating about radiation risk and measures taken to minimize radiation exposure.

Legal Documentation

All health care team members are responsible for documenting the care they have provided. Documentation can improve quality of care, promote effective communication, prevent significant errors in information and identify legal responsibilities. Effective documentation should be factual, accurate, complete, current and organized.[34]

The medical record is a legal document that serves several functions: It provides information for communication, education, assessment, research, financial billing, auditing and legal accountability. A patient's medical record is highly confidential and private and must not be shared with anyone other than the actual patient and the members of the medical staff assigned to that patient.[34]

There is a difference between care given and care documented. Patient care that is actually provided might have been excellent; however, in a court of law, "care not documented is care not done."[34] The radiology department is not exempt from such legal concerns. To ensure quality of care and maintain legal standards of care, the following items should be documented for fluoroscopy procedures:

- Radiation dose.
- Fluoroscopy time.
- Contrast media and IV medication administration.
- Immobilization techniques.
- Safety measures.
- Catheter insertion and removal.[34]

All personnel should participate in documentation to enhance communication, reduce risks and improve patient care.

Shielding and X-ray Room Design

The primary reason for x-ray room shielding is to protect the medical imaging staff, patients, visitors and people working near the x-ray room. X-ray room shielding design depends on the type of x-ray equipment, usage or workload, positioning, whether multiple tubes and receptors are used, primary beam access vs scatter only, the operator location and the surrounding areas.

General radiography, fluoroscopy, dental, mammography and CT equipment all pose different requirements for shielding and room design because radiation characteristics vary for each modality. Several of these characteristics have unique effects, such as where the x-ray beam is directed, the type of procedure and the kVp of the x-rays.

CT, fluoroscopy and mammography units use an x-ray beam that is always stopped by the image receptor, thus reducing shielding requirements. For radiography, the type of tube suspension also plays a role depending on location (eg, ceiling mounted, floor mounted or C-arm). Multiple tubes raise the total radiation dose, changing the volume of shielding.[35]

Materials

Many types of materials are used for shielding radiation. Although lead is most commonly used, brick, gypsum/barite plasterboard, concrete block, lead glass and acrylic are other shielding materials. Overall construction and integrity of the shielding occasionally is challenging because of problem areas in the wall joints, window frames and doors.[35]

Proper filtration is necessary to remove low-energy photons from the x-ray beam. A patient's skin dose can increase by as much as 90% if the photons are not removed.[11] Half-value layer (HVL) and tenth-value layer (TVL) are terms that describe the efficiency of an absorbing material such as lead.[13]

Half-value layer is defined as the amount of filtering material that reduces radiation intensity to one-half its original value. The best method to determine whether adequate filtration exists is to measure the HVL. The HVL should not vary from the value established at acceptance or its value at the beginning of a quality control program. Factors that affect the HVL include the kVp used, the total beam filtration and the type of x-ray generator.[11] The HVL for diagnostic x-rays is 3 to 5 mm of aluminum or 4 to 8 cm of soft tissue.[36]

The TVL is the thickness of absorber material that reduces the radiation intensity to one-tenth its original value. Depending on the magnitude of the TVL, the absorbed dose index and the dose equivalent index values can be different. One TVL is equal to 3.3 HVL.[6,13]

Primary and Secondary Barriers

Room shielding protects against three sources of radiation: primary (the x-ray beam), scattered (from the patient) and leakage (from the x-ray tube). Radiation from the primary x-ray beam passes unscattered or undeflected from either the x-ray tube or a radioactive source.[37] In other words, primary radiation is the radiation directly emitted from the x-ray machine through the collimator. Scatter radiation is the radiation produced by the scattering of the primary x-ray beam in the patient, and leakage radiation is the radiation that escapes through the x-ray tube. The tube housing usually contains about 2 to 3 mm of lead and is considered to be a source of leakage radiation. The amount of leakage radiation is based on the maximum rated tube current. Most radiographic x-ray tubes have a tube current of about 3 to 5 mA at 150 kVp.[35]

A primary x-ray barrier is located where the primary radiation x-ray beam strikes.[38] For example, the ceiling and the floor of an x-ray room can be considered primary barriers if the x-ray beam strikes them directly. Primary barriers are usually constructed of lead or similar material and are designed to block the ionizing radiation exiting the x-ray tube.[16]

Secondary barriers prevent scatter and leakage rather than block direct radiation.[16] Thus, the primary x-ray beam should never be directed toward a secondary barrier. An example of a secondary barrier is the radiographer's control area or protective cubicle. Lead aprons, gloves and certain walls and ceilings of the x-ray room also are considered secondary barriers.[38]

Secondary barriers only need to have a lead equivalent high enough to protect against scatter radiation emitted from the patient, the table or other objects. A medical physicist usually monitors the efficiency and adequacy of primary and secondary radiation barriers by measuring the amount of radiation passing through the barriers or cracks in the barriers.[38]

Controlled and Uncontrolled Areas

A radiation area is defined as "any area accessible to personnel in which there exists radiation at such levels that a major portion of the body (whole body, head and trunk, active blood-forming organs, gonads, or eye lenses) could receive in any one hour a dose equivalent in excess of 5 mrem, or in 5 consecutive days a dose equivalent in excess of 100 mrem."[37] Any area that is regulated through protective measures and safety provisions is considered a controlled area. Routine radiation exposures are monitored in these areas or contamination is restricted during normal working hours. The idea is to anticipate the extent of potential exposures and require some form of personal radiation protection measures and administrative control. Restricted access to controlled areas should be properly labeled with warning signs, lights or audible alarms. Illuminated signs can indicate when the x-ray unit has power, when treatment is programmed or when the beam is actually turned on.[35]

An uncontrolled area is a space that does not require radiation protection measures or administrative control. For example, rooms adjacent to the radiation area can be uncontrolled areas. These areas have recommended shielding and barrier requirements.[37] The room design is usually based on a limit of 5 mSv per year for an occupationally exposed person (25% of dose limit) and 1 mSv (100 mrem) for the public.[35]

Use Factor and Workload

The use (U) factor refers to the fraction of time in a day the radiation is directed toward a barrier.[35] Usage is referred to as workload or how much the x-ray room is used within a given time period. More shielding is required when using high kVp and high mAs. Each week the total mAs is used to gauge the total x-ray dose delivered, demonstrating the U factor.

Workload (W) is a measure of the radiation output expressed in milliampere-minutes (mA-min) per week. Usually the workload of a particular unit is estimated using the kVp range, mAs range, patients per day, usage (eg, 7 days per week) and the average number of images captured. For example, a typical radiography room has equipment with a range of 50 to 120 kVp; the exposure for each image is 5 to 100 mAs; 80 patients are imaged per day, 7 days a week; and 1 to 6 images are acquired for each patient. Assuming an average of 50 mAs per image and 3 images per patient, the workload would equal 50 mAs x 3 images x 80 patients x 7 days a week. According to these calculations, the workload equals 84,000 mAs per week or 1,400 mA-min per week (84,000 mAs divided by 60 seconds) for a typical radiography room. This amount compares with a typical CT workload of about 28,000 mA-min per week, depending on the unit.[35] Spiral CT units or multidetector units can have higher workloads.

Occupancy

Occupancy factor (T) is the fraction of time a particular area is occupied by staff, patients or the public. NCRP Report No. 147 sets the occupancy factor, which is usually a conservative value. Areas fully occupied by an individual, such as administrative or clerical offices, have an occupancy factor of 1, whereas corridors and employee lounges have an occupancy factor of one-fifth.[35]

Distance

The location and orientation of the x-ray unit affects shielding design and layout with respect to the distance and the direction of the x-ray beam. Distance is important because the inverse square law affects the radiation dose to radiology personnel. The number of x-ray tubes and their different directions also complicate the shielding calculations.

Occupancy of adjacent rooms, including those above and below the examination room, affects the shielding design. Adjoining rooms that are not frequently used require less shielding than occupied rooms. Since the consequences of undershielding are more serious than those for overshielding, shielding calculations should use a worst case scenario as opposed to a typical case.[35]

Fluoroscopy Equipment

The medical imaging staff must have a thorough understanding of different parts of the fluoroscopy unit and ways proper equipment use can limit radiation dose to the patient and personnel.

Beam-limiting Devices

Beam-limiting devices, such as collimators, restrict the size of the x-ray field, thereby controlling the amount of radiation exposure to the patient. For example, increasing the field size from 10 x 12 to 14 x 17 increases scatter radiation, which in turn increases the patient radiation dose. These devices also affect image contrast.

The following components of the beam-limiting system should be assessed: light field-radiation, field congruence, image receptor-radiation field alignment, accuracy of the x-y scales and illuminator bulb brightness. The beam-limiting system should be evaluated at acceptance and then every 6 months or whenever maintenance is performed on the system.[11] Quality control tests for beam-limiting devices include:

- Collimator test tool.
- Eight-penny (nine-penny) test.
- Image receptor-radiation field alignment test.
- Illuminator bulb brightness.
- Beam alignment using a beam alignment tool.
- X-ray beam-Bucky tray alignment or central ray congruency using the beam alignment test tool.
- Washer or coin method.
- Source-to-image distance indicator.[11]

Collimators

A collimator is a device of a high-absorption material used in diagnostic and therapeutic units to confine an x-ray beam to a given area.[39] In nuclear medicine, a collimator restricts the detection of emitted radiation to a given area of interest.[1] Each x-ray unit has a specific maximum useful area (field size). Most fluoroscopy systems allow the operator to reduce the field size by using lead shutters or collimators. When irradiating larger field sizes, scatter radiation emitted from the patient increases and a portion of the increased scatter enters the image intensifier, degrading the image. The image intensifier captures or stops the x-rays and converts the x-ray energy into light.[39]

Collimators block out "bright areas," such as lung or other low density regions, to provide better resolution of the surrounding tissues. Limiting the beam size also produces many benefits that lower radiation dose. Since less tissue is irradiated, the patient's total dose is reduced. Consequently, the dose to imaging staff also is decreased because there is less scatter radiation. In addition, the noise added to the image from scatter radiation is decreased. Overall, improved image quality is a major advantage that comes with the collimator use.[39]

Magnification Modes

An important concept that affects radiation dose and image quality during fluoroscopy is the proper use of magnification modes. Electronically manipulating a smaller radiation image intensifier input area over the same output area results in magnification. In some cases, the use of magnification reduces radiation input, subsequently lowering image brightness. Automatic brightness control systems compensate for the decrease by increasing radiation production, which negatively affects the radiation dose received by the patient and staff. The additional radiation dose raises the patient entrance skin dose and can become quite high, especially when small fields of view are chosen.[39]

When the whole x-ray beam is used to produce a bright image, normal magnification mode generates little magnification. Most fluoroscopy examinations rely on normal magnification mode because there is sufficient radiation output to obtain the diagnostic images needed to guide procedures or to observe dynamic operations. During fluoroscopy employing the magnification 1 mode, a smaller x-ray beam is projected to the same image intensifier output. The resulting object size is larger; however, the image is dimmer because of the decrease in beam input. The FDA, which regulates the construction of all fluoro-scopy systems, limits the maximum entrance skin exposure to 10 R per minute. The use of higher radiation rates (ie, boost mode) is appropriate for situations requiring high video image resolution.[39]

Beam-on Time

During fluoroscopy, radiation exposure is directly proportional to the beam-on time (ie, the length of time the unit is energized). Increasing the period of time the x-ray unit is on increases radiation exposure. Fluoroscopy units do not contain a fail-safe switch or automatic timer to terminate the exposure like regular x-ray units do.[39]

Cineangiography (cine) in the filmless environment isolates several separate diagnostic quality images per minute. The data collected for each image are equivalent to a normal flat-plane x-ray image. A cine unit requires more output than a fluoroscopy unit, usually 10 to 20 times higher than fluoroscopy, hence the need for careful use.[39]

Boost mode (ie, a higher current mode) improves image quality by significantly increasing the number of x-rays produced, but at the cost of increased radiation dose to the patient and staff. In general, an audible alarm indicates the high-level mode. The boost mode has a limited exposure rate of up to 20 R per minute compared with the maximum of 10 R per minute for normal automatic brightness control modes and a maximum of 5 R per minute for manual mode.[39]

Visual and Audio Monitors

Visual recording devices such as digital cameras, cine and spot films use a closed-circuit video system that produces a "live" image on a TV monitor. Imaging applications that use spot films or cineangiography, such as angiography and cardiac catheterization, have a higher radiation output than conventional radiography. One way an operator can decrease radiation exposure time is by using the last image hold. This method allows practitioners to observe the last image or video recording at their convenience, avoiding unnecessary patient and staff radiation dose.[40]

Image quality can vary according to the adjustments made to the image monitoring system. Monitor settings are normally modified annually and during service. Brightness and contrast controls altered by the operator can diminish image sharpness, contrast and distortion. Low light is essential for the human eye to differentiate image details detected on the TV monitor. Too much light can affect the ability of the eye to see details; therefore, dim lighting is used during fluoroscopy to enhance image visualization and reduce exposure time and dose.[40]

During fluoroscopy, the audio timer sounds at 5-minute intervals and must be physically reset so that the operator is aware of significant radiation exposure. The facility's radiation safety committee stipulates fluoroscopy time and requires that the total elapsed fluoroscopy time be recorded for every procedure that exceeds 10 minutes.[39]

Exposure Control Devices

A complete understanding of exposure control devices is the best way for imaging staff to significantly reduce patient and staff radiation exposure. Three basic controls regulate the quantity and quality of the x-rays produced: the kVp, mA and time (start and stop of the exposure). Of the three, the amount of time the x-ray beam is on is most critical to limiting the radiation dose.

Tube current (mA) controls the quantity of x-rays produced per unit of time; therefore, if the mA is doubled, then dose to the patient and staff is doubled. As previously stated, most radiographic x-ray tubes have a tube current of about 3 to 5 mA at 150 kVp.[35] An exposure rate of 2 R per minute reflects the patient entrance skin exposure during fluoroscopy. There is an exponential decrease in radiation exposure with increasing tissue depth because of attenuation and the inverse square law. In general, only 1% of the original x-ray beam reaches the image intensifier for image creation.[39]

Current fluoroscopy units use either a manual or an automatic mode to produce images from the image intensifier. When the manual mode is selected, the radiation exposure rate is independent of patient size, body part imaged and tissue type. However, these factors adversely affect image quality and brightness when the operator pans across different tissues with different thicknesses. Therefore, most fluoroscopic procedures are performed using the automatic mode rather than the manual mode.[39]

The automatic mode controls the x-ray intensity measured at the image intensifier so that image quality is consistent during dynamic imaging. This mode constantly monitors the image intensifier output and exposure factors and then adjusts the brightness automatically. The number of x-rays reaching the image intensifier is influenced by both the patient and the operator.[39]

Radiation reception at the image intensifier determines the image brightness. If the image is too bright, the automatic brightness control compensates by decreasing the mA (ie, generating fewer x-rays) or decreasing the kVp (ie, producing less-penetrating x-rays). On the other hand, when the image is not bright enough, the automatic brightness control compensates by increasing the mA and increasing the kVp.[39]

The patient's size affects an x-ray unit's radiation output. Obese patients require more output, adding to radiation exposure and the risk of skin injury.[39]

Interlocks

One safety measure for x-ray equipment is the x-ray tube interlock. The interlock is a device that prevents personnel from accidentally entering the primary beam or automatically shuts off the primary beam. Each x-ray tube housing has an interlock that shuts off the tube if it is removed from the radiation source housing or if the housing is disassembled.[37]

On-off Switches and Emergency Controls

A fail-safe design consists of indicator or safety components that keep personnel safe from radiation exposure even if the equipment fails. For example, if the light indicating "X-ray On" fails, the production of x-rays is stopped. Fail-safe features prevent the primary beam from being turned on if a safety or warning device fails. In the case of an x-ray equipment emergency, there are several red emergency cut-off buttons in various locations of the radiation area. These cut-off switches turn off the power to the x-ray generator.[20]

Quality Assurance

Quality assurance programs should include written policies and procedures that are available to all staff members. These policies should address holding patients during examinations, use of gonadal shielding and pregnant patient care, as well as operator and personnel monitoring. Daily testing using a simple test tool evaluates the x-ray system to optimize system performance.[11]

System performance is an extremely important aspect of quality control (QC). Performance testing guarantees that equipment functions correctly and that system maintenance and repairs are tracked. The complex design and the intricacy of fluoroscopy equipment requires routine maintenance, which is performed at least every 6 months or as indicated by state law. To ensure the lowest possible patient dose, strict QC guidelines and protocols should be in place to minimize variation in equipment performance.[11]

Federal guidelines for fluoroscopic equipment can be found in Title 21 of the Code of Federal Regulations Part 1020 (21 CFR 1020), subchapter J. The guidelines were developed with input from the American College of Radiology (ACR), the American Association of Physicists in Medicine (AAPM) and various other groups.[11] X-ray equipment problems must be documented and corrected within a 60-day window. The physician who registers the x-ray equipment is responsible for radiation safety and implementing a QA program.

Quality assurance programs establish the components of performance testing, including:

- Tests to be performed and how often they are performed.
- Acceptable limits for each test.
- A brief description of the procedures to be used for each test.
- A list of the equipment to be used for testing.
- Sample forms to be used for each test.[11]

Equipment records for each x-ray tube should contain the initial test results, the current year, records of repairs and other pertinent data. These records are useful to identify changes over time and to improve system performance. If significant equipment malfunctions are discovered, then testing can be performed more frequently.[11]

The three main parts of a typical fluoroscopic unit are the x-ray tube and generator, the image intensifier and the video monitoring system. Generally, the x-ray tube and generator perform according to the same standards as those for radiographic units and are evaluated in a similar way. Factors such as filtration (HVL), focal spot size, x-ray tube heat sensors, overload protection, kVp, accuracy, reproducibility, linearity, output waveforms, automatic exposure control (AEC) for spot film devices, and grid uniformity and alignment should be tested at least every 6 months. Fluoroscopic systems also require visual inspection, environmental inspection and performance testing.[11]

The QC test for television monitor resolution evaluates the resolution capability of the fluoroscopic imaging system. This test is performed annually using a copper mesh test pattern tool. For a 23-cm (9-in) image intensifier tube coupled to a standard TV display system, the minimum mesh holes per inch visualized should be 20 to 24 in the center of the display and 20 at the edge of the display.[36]

A visual inspection of the equipment should be performed every 6 months to guarantee optimal system performance. Components requiring visual inspection include:

- Fluoroscopic tower and table locks.
- Protective curtain and aprons.
- Bucky slot cover.
- Exposure switch.
- Compression device.
- Table angulation and motion.
- Fluoroscopic cumulative timer.
- Collimator shutters.[36]

Environmental inspections are essentially the same for fluoroscopic units as for radiographic units and should be performed at least every 6 months. Generally, the visual and environmental inspections are performed simultaneously, evaluating the condition of high tension cables and wires, as well as the mechanical condition of the image intensifier tower and table.[11]

Exposure rate charts help maintain the consistency of image quality. For example, charts containing the fluoroscopy exposure rates for selected x-ray examinations should be posted for each fluoroscopic unit. The QC test for maximum fluoroscopic exposure rate is conducted semiannually to ensure that the system provides an exposure rate that will image patients of all sizes with optimal image quality. The entrance skin exposure rate should not exceed 2.6 mC per kg per minute (10 R/min) or 100 mGy per minute (10 R/min).[36]

Patient and Personnel Protection

Methods to reduce patient and personnel radiation exposure include intermittent fluoroscopy, collimation, technical factors, filtration, protective shielding and immobilization. Using intermittent fluoroscopy (short, quick bursts of radiation) can significantly reduce radiation exposure to the patient and staff.[40]

Beam-limiting Devices

The use of aperture diaphragms, cones and cylinders, and collimators can quickly and easily restrict the radiation beam and thereby reduce patient exposure.[13] These devices limit the beam to the area of interest, or field of view.[36] A smaller x-ray field results in a smaller volume of tissue irradiated, and a smaller volume of irradiated tissue means less x-ray scatter reaches the detector, improving subject contrast and image quality.[41] For these reasons, beam restriction dramatically reduces the patient's effective dose.

Collimators are the most commonly used beam-limiting devices. Regardless of whether automatic collimation is used, medical imaging personnel always should ensure that the size of the x-ray field is the same as or less than the size of the image receptor.[41] The overall radiation dose received by the patient and staff during fluoroscopy is reduced greatly when collimating to the area of interest. Normally, collimation reduces the image brightness, requiring a corresponding increase in the patient's entrance skin exposure dose.

Another beam-limiting device is the grid. The use of a grid limits the amount of scatter radiation reaching the image receptor, improving radiographic contrast. Grid and grid ratio selection controls the balance of image quality and patient protection.[41]

Filtration

Low-energy photons created during x-ray production are unable to penetrate the patient. They are considered unnecessary radiation exposure to the patient and radiology personnel. Placing some type of filtration in the path of the x-ray beam limits unnecessary exposure to this low-energy radiation. Filtration decreases patient dose by reducing the number of photons in the beam, resulting in better x-ray quality.[41] Filtration is considered either inherent or added.

Inherent filtration is permanently in the path of the x-ray beam.[41] Radiology personnel cannot change inherent filtration; however, over time vaporization of the filament deposits tungsten on the inside of the glass envelope, increasing the inherent filtration.[36] Inherent filtration is generally 0.5 mm aluminum equivalent.[41]

Added filtration is filtration attached to the port of the x-ray tube.[41] The amount of added filtration can be controlled because the type and thickness of the added filter depends on the kVp.[36] Aluminum is primarily used for this purpose because it absorbs the low-energy photons while allowing the useful, higher-energy photons to exit.[41]

The total filtration in the x-ray beam is the sum of the added filtration and the inherent filtration.[41] Minimum total filtration for x-ray tubes operating above 70 kVp is 2.5 mm of aluminum or its equivalent.[10] The glass envelope, the oil and the collimator mirror of the x-ray tube are considered inherent filtration, and compensating filters, such as wedge and trough filters, are considered added filtration.[41]

Shielding

Adequate shielding reduces radiation exposure to the patient and radiology personnel. Fluoroscopy shielding usually contains lead, such as lead-lined side table drapes, hanging shields, ceiling-mounted lead acrylic face shields and portable radiation shields. All these devices can significantly reduce occupational radiation exposure. Other protective barriers include walls, floors, ceilings, entrance doors and windows.

Personal shielding devices include lead aprons, thyroid shields, lead glasses, lead-lined gloves, clear lead shields, lead windows, gonadal shields, blankets, sheets, curtains, storage racks, table drapes and stand-up barriers. Radiosensitive tissues and organs should be shielded when they are located within or near the exposed area. These structures include the thyroid, breast, reproductive organs and lens of the eye.[40]

Contact shields are placed directly on the patient, and shadow shields are suspended over the patient. With shadow shields, the field light is used to determine the shielded area. Specific shielding is warranted, however, only if it does not obstruct demonstration of the desired anatomy.[40]

Personnel often use a wraparound lead apron rather than a simple lead apron for added protection during fluoroscopy. If it were not for lead aprons, most personnel would exceed their dose limits. Lead aprons do not prevent all x-rays from reaching the wearer, but they reduce radiation exposure 80%. Two advantages of using the wraparound lead apron are increased shielding and improved weight distribution of the apron. The apron's effectiveness is reduced when more penetrating radiation is used (eg, when the automatic brightness control boosts kVp for thick patients).[40] Although a 1-mm lead equivalent apron provides maximum exposure reduction, these aprons are very heavy and a 0.5-mm lead equivalent apron often is the compromise between protection and weight.[13]

Optically clear lead glasses reduce the operator's eye exposure by 85% to 90% and are recommended for personnel who have very high fluoroscopy workloads, such as busy radiology and cardiac-interventional practitioners. These glasses offer splash protection and should be wraparound in design.[40]

Fluoroscopy units have interlock devices so that radiation only can be produced when the entire primary beam is intercepted by the image intensifier and its associated shielding. Most fluoroscopic units provide additional shielding from scatter radiation in the form of Bucky slot covers and lead drapes.[23]

Exposure Factors

Radiology practitioners, RAs and radiologic technologists must be familiar with the principles of radiographic exposure, including the appropriate selection of technical factors to produce a quality diagnostic image.[23] Beam quality (kVp) is the maximum energy of the resulting x-ray spectrum, while the tube voltage (kV) controls the maximum energy of electrons produced by the x-ray tube. Kilovoltage peak is the maximum potential difference applied between the anode and cathode by a pulsating voltage generator. Patient dose can be reduced by using higher kVp techniques; however, doing so reduces the contrast between different tissues.[37] Image quality optimization is accomplished by manipulating the kVp and mA control settings.

Positioning

Both patient positioning and the position of the x-ray tube influence radiation exposure of patients and personnel. For example, inaccurate patient centering produces an image that is underexposed or overexposed, requiring the exam to be repeated and therefore an additional radiation dose to the patient.[41] This is especially true in CT scanning, because proper patient centering affects the estimate of the patient dose.

The RA or radiologic technologist also can position the patient to reduce exposure. An example is to place the patient so that radiosensitive areas receive the exit radiation dose rather than the entrance dose. Another method is to rotate the patient so the gonads are away from the primary beam.[13]

Radiology personnel must understand the proper beam part-image receptor alignment with respect to the radiation source, imaging modality and area to be examined.[16] At no point during the imaging process should any portion of the operator's body be in the primary beam. Scatter radiation spreads out in all directions and is the cause of the majority of radiation dose received by the operator. Scatter radiation is not uniform because it can either be absorbed by the patient or pass through the patient, reducing its intensity.[39]

Because scatter radiation follows the inverse square law, the intensity of the scatter radiation decreases with increasing distance from the source. Thus, scatter radiation is highest near its source, the x-ray beam entry site on the patient. Radiation doses are notably lower on the image intensifier side than the x-ray tube side.[39]

Depending on the operator's location in relation to the patient, radiation levels increase with decreasing distance from the x-ray source. An operator standing

0.91 m (3 ft) from the x-ray beam entrance area receives 0.1% of the patient's entrance skin exposure. During fluoroscopy, the tableside operator receives the highest occupational radiation dose, with the highest levels directed at the waist. When the x-ray tube is beneath the patient during fluoroscopy, radiation levels are the highest below the table.[39]

If the x-ray tube is angled obliquely toward the operator, the operator's head and eyes receive a higher radiation dose; the operator receives less radiation to the head and eyes when the x-ray tube is angled obliquely away from his or her body. For this reason, the operator should work on the image intensifier side of the table (ie, with the image intensifier toward the operator).[39,40]

Continuously using the same x-ray beam entry point can cause a very high skin dose to a small area. Changing the x-ray beam entry reduces skin dose, but longer beam paths must be used with caution because this will increase patient and personnel radiation doses. Sharply angled oblique images are typically associated with increased radiation exposure because the x-rays must pass through more tissue before reaching the image intensifier. Placing the tube in oblique positions (ie, bringing the x-ray tube closer to the operator) increases patient scatter and radiation doses to both the patient and personnel. Operator exposure can be reduced by using alternative projections whenever possible. For example, dose rates can be reduced by a factor of 5 when the operator stands on the image intensifier side of the table during a lateral projection.[42]

Immobilization

Immobilization techniques reduce patient movement and repeat rates, which can ultimately lower radiation exposure. Immobilization can be as simple as requesting the patient to "hold your breath." Holding individuals is an immobilization technique, but radiology personnel should not restrain patients because it involves unnecessary occupational exposure. If immobilization techniques such as bolsters or sandbags are inadequate, then a relative (preferably a man) or a nonradiology coworker should be requested to assist. Devices such as the Pigg-O-Stat (Modern Way Immobilizers Inc) and wrapping techniques are commonly used to immobilize pediatric patients. Secure immobilization is important but not at the cost of injury or respiratory difficulty.[42]

Fluoroscopic Techniques

As with any area of radiology, balancing image quality and patient dose always is an issue. In keeping with the ALARA principle, the fluoroscopy operator must be concerned with radiation exposure, especially fluoroscopy time. Fluoroscopy time is the most important factor influencing radiation dose to the patient and staff. Favorable clinical outcomes hinge on the careful use of fluoroscopy time and good judgment to balance image quality and patient dose.[11]

Fluoroscopy is widely used for gastrointestinal (GI) examinations, vascular and cardiac studies, and interventional procedures. Until recently, fluoroscopy was the principal source of medical radiation for the U.S. population; CT now represents the largest single source of medical exposure and its use is increasing rapidly.[43] These studies have long exposure times, and upper GI fluoroscopy in particular is the most commonly conducted fluoroscopic procedure in the United States contributing to the patient's effective dose. In that light, efforts must be taken to ensure the benefits of fluoroscopy exceed the risks to the patient and staff.

The Joint Commission requires a medical physicist to establish patient doses for commonly performed examinations by each radiographic unit. The dose delivered during fluoroscopy should be limited to 0.1 Gy (10 rad) per minute under normal circumstances.[23]

Fixed and mobile fluoroscopy units have similar features and radiation protection measures. Radiation protection guidelines offer several ways to reduce fluoroscopy radiation dose. For example, when evaluating fluoroscopy images, the operator always should be looking at the monitor when the fluoroscopy unit is functioning. The use of the last image-hold function and preplanning the images can reduce time and dose. This is accomplished by placing the fluoroscopy tower over the area of interest and then turning the fluoroscopy unit on. Prolonged observation does not improve the image brightness or resolution.[40]

The use of road mapping during interventional procedures, such as angioplasty and stent placement, avoids redundant views. Automatic contrast injectors significantly lower occupational dose because the staff can leave the examination room during contrast injections and x-ray exposures, thereby increasing the distance from the x-ray source and shielding from room walls.[40]

Source-to-tabletop distances are important during fixed and mobile fluoroscopic procedures, especially during interventional radiology and cardiac catheterization procedures because acute localized radiation effects can cause skin damage. These effects are not seen immediately but develop shortly after the procedure and sometimes they are thought to be caused by a source other than radiation. Epilation, a nonstochastic effect, has a dose threshold of 3 Gy (300 rad) and appears 3 weeks after irradiation. It takes 1 hour of fluoroscopy at 5 R per minute to produce epilation.[44]

Placing the image intensifier closer to the patient reduces radiation dose because doing so decreases the image intensifier-to-patient air gap and the divergence of the x-ray beam. The closer the x-ray tube is to the patient, the higher the radiation dose, given the inverse square law. Placing the patient as close to the image intensifier as possible is the preferred method for reducing the air gap because the tube port produces higher skin doses. The use of a separator or spacer cone is another way to reduce distance from the x-ray source and the associated high skin dose rates. The spacer cone is attached to the tube housing and is designed to keep the patient at a reasonable distance from the x-ray source.[44]

Unnecessary Examinations

One of the largest sources of unnecessary radiation dose to the patient is radiologic procedures that are performed but that are not required. Although many believe that more radiologic studies are performed than are necessary, the issue is difficult to assess.[45] Thus, the appropriateness of radiologic procedures currently is being questioned. Radiology organizations such as the ACR are developing national clinical guidelines to help physicians compare the effectiveness and cost of different radiologic procedures.[45]

In addition to physicians ordering multiple examinations to confirm a diagnosis, several factors have contributed to the increase of radiologic examinations, including the aging population and the impact of AIDS, drug abuse and crime.[45] Recent health care reform legislation has highlighted the need to reduce the number of unnecessary medical imaging examinations. Radiologic examinations should be performed when there is a specific medical indication. Pre-employment physicals, hospital admission testing (eg, examinations that duplicate procedures preformed at other facilities), annual health check-ups and self-referred CT screening might be considered unnecessary examinations, especially when there is an alternative test that does not involve ionizing radiation. Unnecessary examinations can be reduced by carefully analyzing the risk vs benefits of the procedure and educating ordering physicians, patients and family members about the risk-benefit ratio.[13]

Special Considerations

Excessive exposure to ionizing radiation or radiation amounts above the accepted level delivered in a brief time period can result in either illness or potential genetic damage to future generations. Certain factors potentially increase the adverse effects of ionizing radiation. These factors include the patient's age at exposure, sensitivity of the exposed cells and the portion of the body exposed. Those who are most vulnerable to radiation effects are the very young and pregnant women.[16] Pediatric and pregnant patients require special attention when using ionizing radiation for diagnosis. Special circumstances require practitioners to consider alternative examinations such as endoscopy, magnetic resonance (MR) imaging or sonography.

Pediatric Patients

Pediatric patients generally pose a unique challenge in the medical field. In the United States, the rising number of radiologic examinations, particularly CT scans, has increased concerns over the effective dose to pediatric patients.[46] In 2012, approximately 5 to 9 million CT scans were performed on children in the United States.[47]

The Law of Bergonié and Tribondeau states that the resistance or sensitivity to radiation depends on the metabolic state of a cell, tissue or an organ. Tissues most susceptible to radiation are those that are young and rapidly dividing. Radiosensitive cells have high metabolic rates, and at times they are nonspecialized and well nourished. Thus, mature cells have a better chance of surviving ionizing radiation. In essence, it takes more radiation to destroy or impair mature cells than to destroy or impair immature cells such as the cells found in children. Because an embryo or fetus has a large number of immature and nonspecialized cells, unborn children are more radiosensitive than adults.[8,42] Therefore, additional radiation protection measures are extremely important for pediatric patients and pregnant women.

In keeping with the ALARA principle, techniques that decrease the radiation dose to children and pregnant women include collimation, shielding, limited studies and immobilization. The use of these techniques also improves image quality.

Other radiation protection measures are used for specific modalities. In fluoroscopy, high kVp and low mA technical factors are preferred techniques to lower patient and radiology staff dose. A dose-limiting technique such as the 15% rule states that increasing the kVp by 15% decreases the mAs by 50%. At higher kilovoltages, the beam has more penetrating power and tends to pass through the body, rather than being absorbed by it.[6,42] Unfortunately, when kVp is increased, the contrast scale lengthens and might not be suitable for all types of imaging, especially in newborn chest examinations, bone radiography and iodinated contrast studies.[42]

Chronic and recurring conditions can increase the number of examinations pediatric patients undergo during their lifetimes. Typically, a dose received from a single procedure is low. However, pediatric patients who need repeated exams over time to evaluate pulmonary, cardiac, urinary or orthopedic conditions can receive relatively high cumulative doses.[4] When imaging pediatric patients, it is imperative to use protective measures such as collimation to the anatomical area of interest and proper shielding methods.

Certain radiosensitive areas are of particular concern in the pediatric patient, including the thyroid, breast, reproductive organs, lens of the eye and active bone marrow tissues. It might be difficult to provide adequate pediatric gonadal shielding. The patient's size and gonadal proximity to the area of interest might not lower the radiation dose by much because of internal scatter.[42] Shielding of gonadal tissue more than 2 cm from the edge of the field of view is less important than the dose caused solely by internal scatter.[42,48]

Precautions should be taken to decrease the effective dose to all patients and especially to children. For instance, most facilities have set limits on the number of images or CT scans using exam-specific protocols. For example, CT protocols for children and sometimes patients of reproductive age only allow for scans in the contrast phase, omitting the noncontrast phase and delayed scans. Examinaton protocols are especially important because the radiologist and ordering physicians are able to limit studies by determining which projections should be included in routine examinations and whether imaging the contralateral extremities in children is useful.[42]

Good communication can lead to decreased exam time and increased patient and parent cooperation. The success of immobilization often depends on good communication between the RA or radiologic technologist and the patient and parents.[42]

Pregnant Patients

The potential risks and benefits of a specific procedure have a bearing on the radiation protection measures taken for the pregnant patient. NCRP Report No. 116 gives allowable fetal doses for pregnant patients. Only pregnant patients undergoing radiologic examinations that could produce doses greater than 2 mGy (200 mrad) to the fetus are considered to be at any risk from radiation exposure. This value was chosen because it is 40% less than the fetal dose recommended for pregnant workers by NCRP Report No. 116.[49]

Shielding pregnant patients is almost never necessary for two reasons. First, shielding is contraindicated if it obscures the area of interest. In addition, repeat examinations performed because of improper shielding double the patient and fetal dose. Second, external shielding does not attenuate internal scatter radiation, and if the uterus is not in the x-ray field, the only radiation reaching the fetus is internal scatter radiation. However, providing an external lead shield might make the patient feel better and will demonstrate concern for radiation safety.[49]

Radiation protection of the pregnant patient becomes complicated because the benefits of the procedure always must outweigh the risks. Therefore, the risks of radiation exposure must be illustrated clearly. Three comparisons are useful in describing the possible risks to the fetus: background radiation, loss of life expectancy and the chances of developing cancer. For example, the background radiation level of a city at 5,000 feet elevation is approximately 4 mGy (400 mrad) per year or roughly 80 µGy (8 mrad) per week. This amount reflects the amount of radon, cosmic, terrestrial and internal sources of natural radiation. The fetus does not receive the radon dose. With this information, an examination resulting in a fetal dose of 4 mGy would be similar to the dose received by a person living for 12 months in Denver, Colorado.[49]

Table 3

Fetal Risk From Selected Radiology Examinations[49]

Examination	Fetal Dose	Time Period To Receive Equivalent Dose From Natural Sources	Additional Cancer Deaths[a]	Fetal Life Expectancy Lost
Abdomen/pelvis, KUB	2 mGy	6 months	2	14 hours
Intravenous pyelogram	6 mGy	1.5 years	6	43 hours
Barium enema	9 mGy	2.25 years	10	64 hours

[a] *Additional cancer deaths among the children of 10,000 women undergoing the examination.*

The concept of loss of life expectancy (LLE) is a way of estimating the average risk of an activity and is used to compare the risk from radiation to other risks. Participating in a risky activity can potentially reduce a person's life expectancy, which is about 79 years in the United States.[50]

Many people consider skydiving a risky activity. In 1991 there were 4.8 million skydiving jumps, 74 of which resulted in death. If all the jumpers who died were 30 years old and on average they would have lived to age 70, each jumper killed is assumed to have lost 40 years or 26 million hours of life expectancy. This number is averaged over the 4.8 million jumps to yield an LLE of 5.4 hours per jump.[49]

Excess weight is another example of describing risk in terms of LLE. Being 15% overweight results in an expected loss of life of 770 days. An exposure of 10 mGy can be equated to an LLE of 1.5 days, based on the linear nonthreshold model of radiation response.[49,52]

The third way to describe the risk to the fetus from a medical imaging examination is to estimate the increased chance of developing a fatal cancer as a result of the exam. It is important to remember that these calculations are based on extrapolating the data from studies of exposure to high radiation doses and that radiologic examinations deliver much lower doses.[49]

Statistics for the natural incidence of fatal cancer or leukemia show that of 10,000 babies born each year in the United States, 2,000 will develop a fatal cancer in their lifetime. This is a fatal cancer incidence rate of 20%. A fetus is twice as sensitive to radiation damage as an adult. If 10,000 pregnant women receive a radiologic examination, the number of additional cancer deaths among their offspring caused by radiation exposure can be estimated. The cancer risk used in preparing these estimates is based on an assumption there will be an additional 10 cancer deaths per 10,000 babies exposed in utero to 10 mGy (1,000 mrad).[49]

CT and interventional fluoroscopic procedures deliver significant radiation doses. Normally, routine diagnostic examinations of nonpregnant patients involve negligible risk or hazard. However, diagnostic procedures that can produce fetal doses greater than 2 mGy (200 mrad) include abdominal and pelvic radiography, intravenous urography, barium enema, pelvic CT, lumbosacral spine radiography and interventional procedures.[49]

The risks from abdominal and pelvic radiographs are additive, and for examinations such as barium enemas and intravenous pyelography (IVP), the doses must be adjusted accordingly. If a patient undergoes more than one abdominal or pelvic radiographic examination, the risk from all the examinations must be added together to obtain the total risk. An abdominal, kidney-ureters-bladder (KUB) or pelvic radiographic examination delivers a fetal dose of about 2 mGy (200 mrad). In other words, the fetus receives the same amount of radiation from any of these examinations as the amount received from natural background sources over a period of 6 months. The fetus could lose 14 hours of life expectancy as a result of the examination. The natural incidence of cancer is 2,000 out of every 10,000 babies born. Of 10,000 pregnant mothers undergoing this examination, an additional 2 cancers can be expected in their children, for a total of 2,002 cancers.[49] See **Table 3** for additional estimates of fetal risk.

The risks associated with routine radiologic examinations during pregnancy are usually small, but repeat examinations resulting in additional exposures and the use of prolonged fluoroscopy time can significantly increase dose. Thus, alternative imaging modalities such as endoscopy, MR or sonography should be considered for pregnant patients. Medical necessity, urgency and lack of alternative imaging modalities should be carefully considered before performing an examination requiring ionizing radiation.[49]

Generally, it is not recommended to consider terminating a pregnancy for fetal doses less than 1,000 mGy (10 rad), which are rarely, if ever, needed during fluoroscopy. Additionally, performing a barium enema or IVP on a woman later discovered to be pregnant is never reason to terminate a pregnancy.[49]

Pregnant Workers

A teratogen is any agent that causes birth (congenital) defects. Ionizing radiation is one of the most potent known teratogens.[52] The rapidly dividing cells of an embryo or fetus require special consideration because they are highly sensitive to radiation, particularly in the first 20 weeks of pregnancy. Prenatal radiation doses can potentially cause growth retardation, small head and brain size, mental retardation and childhood cancer. At the current occupational dose limits, the probability of any of these effects occurring from occupational exposure of the pregnant worker is small.[1] If the embryo is irradiated in the first 2 weeks, it is likely to spontaneously abort if damaged. Therefore, the first trimester is the least safe period for irradiation.[52]

Conclusion

Radiation protection is a critical issue within radiology because technological advances have increased the use of medical imaging, particularly the use of fluoroscopy, interventional radiology and CT. These imaging modalities are associated with long exposure times and high radiation doses. The rise in radiologic procedures, especially CT, has increased the effective dose delivered to patients, making ALARA even more important to keep radiation exposure within acceptable limits.

The International Commission on Radiological Protection (ICRP) provides recommendations and guidance on all aspects of radiation protection.[23] The ICRP recommendations for reducing radiation dose include:

- Defining rigorous referral criteria.
- Improving the availability of images from previous examinations.
- Minimizing the number of radiographs per procedure.
- Minimizing fluoroscopic exposure.
- Improving QA and QC programs.
- Regularly assessing repeat rates.
- Shielding sensitive organs when possible.
- Choosing projections to minimize dose.

With respect to medical imaging equipment, the ICRP recommends:

- Thorough QC of processors.
- Increased use of digital image processing.
- Use of the lowest dose image recording device consistent with image quality.
- Use of pulsed fluoroscopy as appropriate.[20]

Real or imagined, radiation risk has an enormous influence on radiology. In any radiologic examination, practitioners strive to balance image quality and patient dose. Radiologist assistants and radiologic technologists must clearly understand the effects of radiation and learn how to apply radiation protection techniques in everyday practice. Methods to reduce radiation exposure during fluoroscopy include intermittent fluoro-scopy, collimation, proper technical factors, filtration, protective shielding and immobilization. All radiology personnel are responsible for complying with all applicable laws and regulations and institutional policies and procedures concerning radiation exposure.

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