Enhancing Radiation Protection During Pediatric Fluoroscopy
Welcome to the online education module “Image Gently: Enhancing Radiation Protection During Pediatric Fluoroscopy.” This module is designed to educate radiologic technologists about best practices when using fluoroscopic equipment on children. Fluoroscopy is a diagnostic tool that provides important information to guide the medical care of children. Since the discovery of x-rays in 1895, fluoroscopy has remained a mainstay of medical imaging despite the development of other diagnostic tools available today, such as magnetic resonance imaging (MRI), computed tomography (CT) and ultrasound.

Medical imaging is critical in diagnosing illness in children and ultimately improves patient outcomes. However, medical imaging professionals must ensure that radiation exposure to children is optimized. The International Commission on Radiological Protection (Publication 103, 107) recommends x-ray examinations “use techniques that are adjusted to administer the lowest radiation dose that yields an image quality adequate for diagnosis or intervention (i.e., radiation doses should be ‘As Low as Reasonably Achievable’ (ALARA).” The United States Food and Drug Administration (FDA) notes:
• Equipment should be designed for patients of all sizes, both adult and pediatric patients.
• Technique factors should be chosen based on clinical indication, patient size, and anatomical area scanned.
• Equipment should be properly maintained and tested.

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What is the purpose of this module?

To provide radiologic technologists with:

- A full understanding of the safe operation of fluoroscopic devices on pediatric patients to reduce radiation exposure.
- Knowledge to act as leaders in radiation protection for children.

The purpose of this module is to educate radiologic technologists to ensure that they have a full understanding of the principles of safe operation of fluoroscopic equipment on pediatric patients, with particular emphasis on properly managing radiation exposure. While useful for any member of the imaging team, the goal of this module is to equip the radiologic technologist to act as a leader in radiation protection for children through dissemination of this content in the workplace. By understanding the steps needed to reduce radiation exposure for a particular piece of equipment and the basic role of each team member, the radiologic technologist can serve as a resource for the entire clinical imaging team. The content of this module should be supplemented with training on specific equipment models provided by the manufacturer to ensure safe operation. Additional information on the justification for use of fluoroscopy and the care of pediatric patients before, during and after the examination will be discussed in more detail in another online module (available at www.imagegently.org). These topics are critical to ensuring radiation protection in pediatric fluoroscopy.
The module builds on two recent Image Gently campaigns: Pause and Pulse for general fluoroscopy and Step Lightly for interventional fluoroscopy.
What members of the health care team will benefit from this module?

- Radiologic technologists.
- Radiologists.
- Radiology trainees.
- Other physicians (cardiologists, orthopedists).
- Qualified medical physicists.

While the content of this module is directed at radiologic technologists, these educational materials may also benefit radiologists, radiology trainees and other physicians (e.g., pediatric cardiologists or orthopedists) who perform fluoroscopy. Qualified medical physicists (QMPs) may find the module beneficial for teaching in a clinical setting. For radiologic technologists who are a critical and direct link to the patient, this module is intended to support both experienced pediatric radiologic technologists and those who perform pediatric exams less frequently.
Learning Objectives:

1. Identify areas of fluoroscopic practice that can reduce radiation dose to the pediatric patient during fluoroscopy.
2. Explain why children are more susceptible to radiation than adults.
3. Describe radiation quantities that can be used to estimate patient dose for fluoroscopic procedures.

After completion of this module, the participant will be able to:

1. Identify areas of fluoroscopic practice that can reduce radiation dose to the pediatric patient during fluoroscopy.

2. Explain why children are more susceptible to radiation than adults.

3. Describe radiation quantities that can be used to estimate patient dose for fluoroscopic procedures.
Why is radiation safety in fluoroscopic imaging of special concern for pediatric patients?

- Pediatric patients:
  - Some organs in children are more radiosensitive than those in adults.
  - Have a longer expected lifetime for the effects from radiation exposure to potentially develop into cancer.
  - Receive a larger radiation dose than is necessary to produce a useful image when the fluoroscope uses x-ray equipment settings designed exclusively for adults.

Radiation protection is of particular concern during pediatric fluoroscopy studies because:

- Children are more radiosensitive than adults for about 30% of cancers (e.g., leukemia, thyroid, skin and brain). The younger the child, the more sensitive his or her body is; an infant is even more sensitive than a teenager to the effects of radiation for the same dose.
- Children have a longer expected lifetime for the effects from radiation exposure to potentially develop into cancer. The fact that children will likely live longer after an imaging study that uses ionizing radiation increases their risk in comparison to adults. For example, the cancers that developed in Japanese children after the atomic bomb took 10 to 40 years to occur.
- Children receive a larger radiation dose than is necessary to produce a useful image when the fluoroscope uses x-ray equipment settings designed exclusively for adults.
How is the clinical benefit to the patient and risk from ionizing radiation properly managed?

Whenever a patient receives a clinical imaging examination involving ionizing radiation, care is required to ensure that the risk from ionizing radiation is minimized. The challenge for the operator in pediatric fluoroscopic imaging is to optimize the performance of the fluoroscope along with the control of the fluoroscope so that the child receives a properly managed radiation dose. Reduction of the radiation dose helps ensure that the clinical benefit to the child outweighs the small risk from ionizing radiation. However, radiation dose reduction must be carefully managed. If the radiation dose is so low that image quality is of limited diagnostic value, the risk to the patient remains with little or no clinical benefit.

The image on the right is a fluoroscopic image of a 5-year-old child with leukemia. Fluoroscopy revealed the abnormal placement of the PICC line (red arrow). The PICC line was subsequently repositioned.
The primary biologic effect of ionizing radiation is damage to a cell's DNA. Dr. Eric Hall, a highly regarded health physicist states, “These biologic effects include cell killing, carcinogenesis and mutations.” As x-rays pass through the patient's body, they interact with tissue molecules. The kinetic energy given to electrons by these interactions causes the electrons to move. The negative charge of the electron ionizes other molecules in its path. The ion track that is created may or may not result in DNA changes in the nucleus of the cell. In the vast majority of interactions between radiation and cells, the cell suffers no harm. When damage to DNA occurs, most of it is repaired within 24 hours.
Tissue effects (formerly called deterministic injury) occur when a large numbers of cells are damaged so severely that they either die immediately or are unable to reproduce. Multiple cells in the human body must be affected to result in a tissue effect. As the radiation dose increases, the severity of the injury increases. Examples of tissue effects are:

- Skin erythema (redness) and ulceration.
- Hair loss (epilation).
- Cataracts.

Except for the lens of the eye, there are relatively fixed values of radiation dose (referred to as threshold doses) above which tissue effects occur. The time it takes for tissue effects to occur is variable, but they tend to occur in days or weeks to months, and occasionally, even a year after the radiation event.
Tissue effects are unlikely to occur at radiation doses from routine diagnostic exams (e.g., voiding cystourethrogram or upper gastrointestinal exam). However, tissue effects can occur during complex interventional fluoroscopy procedures, more typically on large "adult sized" patients where the fluoroscopic radiation dose rate is elevated. This figure shows a 7-year-old boy who developed radiation dermatitis as a result of extensive fluoroscopy during an interventional radiofrequency ablation procedure.

Multiple radiation doses separated by time (multiple days to years) have a cumulative effect that may result in tissue effects.
A stochastic effect, or injury, represents random (similar to the value that comes up when rolling dice) damage that occurs to a single cell. Radiation-induced cancers are stochastic effects. The cell is able to reproduce, but due to DNA damage, mutations may be carried into subsequent generations of cells. This may result in cancer years later. Because of the random nature of the injury, a threshold dose does not exist for stochastic injury. Although the severity of the injury is not proportional to the radiation dose, the likelihood of an injury does appear to be proportional to the radiation dose.

The risk of stochastic effects is greater in children than adults because a child typically has a longer lifetime after irradiation in which the stochastic effect can be expressed. One cannot be certain that cancers are a direct result of the radiation doses received from medical imaging. However, the committee on the Biological Effects of Ionizing Radiation (BEIR VII) states “... the risk of cancer...
increases in a linear fashion from lower doses to higher doses." This theory states that even low doses of radiation at levels used in clinical imaging may have the potential to cause cancer.
Does ionizing radiation used in medical imaging cause cancer?

The 2,500 circles represent individuals who had an imaging study using ionizing radiation.
The red star represents the risk of one excess cancer due to ionizing radiation.
The solid blue circles are baseline cancers.

There is much debate in the imaging community about whether levels of radiation used in diagnostic medical imaging cause cancer. Studies of large groups suggest that the lifetime risk of cancer incidence is higher for those who were exposed to radiation as children. However, the potential for cancer in one individual is a chance occurrence. This chance of a radiation-induced cancer is similar to your chances of winning the lottery; it is extremely unlikely that you will. If you purchase two lottery tickets, the chance of winning with each ticket is identical. However, the likelihood of winning does appear to be proportional to how many tickets you buy.

The figure illustrates this situation. The circles represent 2,500 patients. If each patient is exposed to the same radiation dose from an examination that uses ionizing radiation, one individual may eventually develop a fatal cancer as a result. That person is indicated by the red star in the figure. However, it is impossible to predict which individual of the 2,500 will be affected. In addition, over the course of their lifetime, more than 500 individuals will contract a fatal cancer from other causes not associated with exposure to ionizing radiation. These individuals are represented by the colored circles at the bottom of
the figure. The figure does not show the thousands of patients whose lives were enhanced or saved as a result of the medical care received as a result of a diagnostic examination.

In the United States, cancer affects 40% of the population. Currently, it is impossible to determine with certainty whether a patient's cancer is a result of his or her own biology, environmental effects, including natural sources of radiation, or as the result of a clinical procedure involving x-rays.
When should the medical imaging team communicate with patients and caregivers about their radiation concerns associated with a fluoroscopic study?

- It is best if families receive information describing their child’s imaging study before the day of the examination.
- Informational brochures are provided on the Image Gently website: www.imagegently.org
  (See the Parent tab).

Families should receive information describing their child’s imaging study before the day of the examination. The physician who requests the examination or the hospital or facility personnel should provide this information at the time of scheduling. Providing parents with simple brochures before the procedure has been shown to improve parents’ understanding. Informational brochures are provided on the Image Gently website (www.imagegently.org – See parent tab). Separate brochures for parents on interventional radiology and 4 common diagnostic fluoroscopic procedures also are available.
How should the medical imaging team talk to patients and caregivers about their radiation concerns?

- Answers to questions from parents should be simple and direct.
- Reassure parents the exam will be "child sized."

Parents’ questions should be answered simply and directly. The radiologic technologist can inform parents that the study is being performed to provide specific answers to their doctor’s questions. The radiologic technologist can describe the examination in simple terms and reassure the parents that the medical imaging team will “child size” the radiation dose and do everything possible to make the procedure as brief and painless as possible. Typically, parents are grateful for the information and the opportunity to have their questions answered.
What should the radiographer do if the parents want more information?

While radiologic technologists should not hesitate to address concerns about ionizing radiation, they should feel comfortable stating that they do not know the answer to a particular question outside their area of expertise. In these cases, the radiologic technologist should refer the patient or family to the imaging physician or qualified medical physicist.
Who are the members of the medical imaging team?

Key members of the fluoroscopic imaging team:

- Radiologic technologist.
- Radiologist or other physician.
- Qualified medical physicist.
- Fluoroscopic manufacturer's representative.

The key members of the fluoroscopic imaging team are the radiologic technologist, radiologist or other physician who uses imaging in his or her practice, a qualified medical physicist and the representatives of the fluoroscopic equipment manufacturer. The imaging team members must understand the design and configuration of the fluoroscope's controls well enough to properly manage the radiation dose to the patient while maintaining diagnostic image quality. That is, all team members must know how to adjust dose settings, collimation, pulse rates and widths, voltage and filter selection, etc. Technique factors must be selected that provide only the necessary dose for the clinical task at hand.
What is the role of the radiologic technologist?

The radiologic technologist is responsible for:

- Immobilization, and communicating with the anesthesia team in patients who are sedated.
- Proper equipment settings, which is a joint responsibility with the imaging physician.
- Availability and use of protective apparel.
- Aiding the imaging physician in operating the fluoroscopic equipment to use dose-saving features.
- Static images before and after the exam.

The radiologic technologist's role is ensuring that the patient is properly prepared for the procedural parts of the examination as well as addressing the patient's emotional stress. The radiologic technologist is responsible for:

- Immobilizing the patient (or communicating with the anesthesia team in patients who are sedated).
- Selecting proper fluoroscopic equipment settings (a joint responsibility with the imaging physician).
- Ensuring availability and use of protective apparel.
- Preparing supplies such as contrast media or catheters.
- Aiding the imaging physician in operating the fluoroscopic equipment to utilize dose-saving features.
- Static imaging before and after the exam.
What is the role of the radiologist or imaging physician who uses medical imaging in his or her practice?

The imaging physician and technologists also are responsible for:
- Documenting and monitoring patient dose.
- Ensuring the images are properly archived.

The radiologist or other physician who uses medical imaging in his or her practice will be referred to as an “imaging physician” in this module. The imaging physician must ensure the procedure is appropriate and consider alternative lower dose options such as ultrasound or MRI in consultation with the referring physician. During the fluoroscopic procedure, the imaging physician must ensure that the lowest dose settings and the shortest amount of fluoroscopic time are used while providing the necessary diagnostic information.

The imaging physician and technologist also are responsible for:
- Documenting and monitoring patient dose.
- Properly archiving the images.
What is the role of the medical physicist?

- Collaborate with equipment manufacturer to properly configure the fluoroscope for use with children.
- Perform acceptance testing before clinical use.
- Monitor equipment for quality improvement purposes.
- Manage radiation doses and improve image quality in collaboration with the medical imaging team.

The qualified medical physicist (QMP) is a practicing medical imaging physicist certified by the American Board of Radiology, American Board of Medical Physics or Canadian College of Physicists in Medicine in the field of diagnostic medical physics. The QMP should work with the manufacturer of the fluoroscope during the installation of the unit to ensure that the fluoroscope is properly configured for children. Prior to first clinical use, the QMP should complete acceptance testing of the fluoroscope to verify the correct operation of all features likely to be used clinically. In addition, the QMP periodically monitors the equipment over its lifetime for quality improvement purposes. This individual should also work with the medical imaging team to clarify dose-saving steps that can be taken during fluoroscopic procedures.
What is the role of the manufacturer?

- Provide fluoroscopic equipment that is "optimized" to image children.
- Provide adequate instructions and training on the safe operation of the device.
- The radiologic technologist, imaging physician, qualified medical physicist and manufacturer's application specialist all serve as technical experts for the equipment.

The manufacturer has two primary roles. First, the manufacturer should provide fluoroscopic equipment that is "optimized" to image children. This means that the equipment is designed to operate at low dose settings while providing diagnostic image quality for the clinical task. Fluoroscopic units are primarily configured for adults and must be modified, particularly for small children, through consultation between the QMP and the manufacturer's representatives. Second, the manufacturer has a role in providing adequate instruction and training on the safe operation of the device for different-sized patients. Such model-specific information provided by the manufacturer should supplement the contents of this general online module.

The radiologic technologist, imaging physician, QMP and manufacturer's application specialists all serve as technical experts for the equipment and should share this information prior to using the equipment for the first time.
How can a standardized approach to pediatric fluoroscopy improve patient care?

- A standardized approach has been shown to provide safer care of patients and result in less error.
- Room setup, default techniques for patients as determined by size, radiographs and images.
- Each imaging team member should clearly understand who is responsible for ensuring appropriate fluoroscopic settings.

A standardized approach has been shown to provide safer care of patients and result in less error. The medical imaging team should establish a protocol that states equipment configurations and technique settings for different patient sizes in order to improve radiation dose management. A standardized approach expressed in written guidelines and agreed upon by the medical imaging team should include room setup, default technique for patients based on size, and all images required for a routine fluoroscopic study. Staff members should monitor these guidelines, altering procedures to address specific circumstances and patient imaging needs.

A protocol that ensures patient doses are monitored during the examination allows patients at risk of possible injury due to their dose to receive appropriate follow-up care. Each imaging team member should clearly understand who is responsible for ensuring appropriate fluoroscopic settings during the examination. No one should assume another team member is doing so.
This standardized approach ensures that a patient who has repeat exams one month apart would have a nearly identical study and, consequently, an identical radiation dose as long as the clinical indication for the procedure is the same.
Fluoroscopy is an imaging method that uses x-rays to create a sequence of images for the purpose of observing real-time motion in the human body. This technique is most useful in evaluating organs and blood vessels and for guiding both diagnostic and interventional examinations. Fluoroscopy demonstrates motion by creating a series of images at a rate of 30 images per second. In pediatric fluoroscopy, an additional goal is to balance image quality with the radiation dose necessary to produce a clinically useful image.
What are the major components of a fluoroscope?

Major components include:
- The x-ray tube.
- The generator.
- A table.
- The grid.
- Image receptor.
- Display devices.

Major components of a fluoroscope include the x-ray tube, the source of the x-rays; the generator, which produces and controls the energy supplied to the x-ray tube; a table for patient positioning; the grid, which removes scatter radiation; the image receptor, a flat panel detector or image intensifier; and devices to display the created images.
How are x-rays produced?

- Changes in tube current change the number of x-rays produced.
- Changes in voltage applied to the tube change the energy carried by each x-ray.

X-rays are created when a high-energy electron beam is stopped by a collision with the anode of the x-ray tube converting a portion of the electron beam's energy into energy carried by x-ray photons. Changing the tube current or the tube voltage alters the energy of the x-ray beam. Increasing the tube current increases the number of x-rays, while increasing the voltage applied to the x-ray tube primarily increases the energy carried by each x-ray.
What does the equipment used for a general fluoroscopic study look like?

- Typically has the x-ray tube mounted under the table inside a tub assembly to hide the hardware.
- The image receptor is mounted above the table.
- The table tub, x-ray tube, table top and image receptor can be tilted as a single unit.

Fluoroscopic equipment used for general diagnostic purposes typically has the x-ray tube mounted under the table inside a tube assembly. The image receptor is mounted above the table. Both the x-ray tube and image receptor are aligned and move as a single unit. The table top on which the patient rests can be moved side-to-side or toward the head or feet of the patient. The table tub, which encloses the x-ray tube, table top and image receptor, can be tilted as a single unit. Fluoroscopic tables with the x-ray tube above the table top and the image receptor below (e.g., urologic units or remote controlled units), are not discussed in this module since they are seldom used for pediatric imaging. If the room also has an overhead x-ray tube, the diagnostic fluoroscopy machine will contain a digital radiography detector or a Bucky tray for a film-screen cassette or a computed radiography cassette.
What does a mobile C-arm fluoroscope look like?

- The main component of the unit is a rigid metal “C-shaped” arm with the x-ray tube and image receptor mounted on opposite ends.

The mobile C-arm fluoroscope is designed to be used in multiple locations, such as operating rooms in a surgery suite. As indicated by its name, the main component of the unit is a rigid metal “C-shaped” arm with the x-ray tube and image receptor mounted on opposite ends. The C-arm can be rotated, raised and lowered, or swiveled to better evaluate the body part of interest.
What does the equipment used for an interventional fluoroscopic study look like?

- Designed to better manage dose delivered to the pediatric patient.
- Provide one or two planes of imaging on the same patient.
- Biplane configurations are common in pediatric interventional fluoroscopic rooms due to the limited amount of iodine contrast material that can be tolerated by a small child.

Fluoroscopic equipment used for angiography or other complex interventional procedures is designed to provide precise control of x-ray production with special features, many of which are designed to better manage the dose delivered to the pediatric patient. While these units also use “C-shaped” arms, they are permanently installed within the room. The design permits positioning the C-arm with greater flexibility, control, and speed. These units are designed to provide one or two planes of imaging on the same patient; biplane configurations are common in pediatric interventional fluoroscopic procedure rooms due to the limited amount of iodine contrast material that a small child can tolerate.
What two types of image receptors create an image?

- The image intensifier.
- The flat-panel detector.

There are two types of image receptors that absorb the x-rays that exit the patient’s body and convert this energy into clinical images. The image intensifier converts the energy of the x-ray beam to a visible light image, which is coupled and focused on the lens of a high-definition TV camera, which digitizes the image. A newer technology, the flat-panel detector, converts the energy of the x-ray beam to a digital format without the need for a TV camera. Both types of image receptors create a digital image that is processed (manipulated) to improve image quality prior to display.
What is radiation dose?

- Radiation dose is the amount of radiation absorbed by a patient.
- The unit of radiation dose is the gray (Gy).
- Methods to quantify dose:
  - Air kerma.
  - Kerma area product.
  - Absorbed dose.
  - Equivalent dose.
  - Effective dose.
  - Background radiation dose.
  - Cumulative dose.
  - Peak dose.

The radiation dose is the amount of radiation energy absorbed by a patient. The unit of radiation dose is the gray (Gy). There are numerous methods for quantifying dose. The quantification method depends on which aspect of the topic one chooses to communicate: air kerma, kerma area product, absorbed dose, equivalent dose, effective dose, background radiation dose, cumulative dose or peak dose. For this module we will focus on only the dose descriptors that will impact patient care or the radiologic technologist’s understanding of the equipment and the dose delivered to the child.
What two factors affect radiation dose to the patient during fluoroscopy?

- The design and configuration of the fluoroscopic machine. (Left side of the diagram.)
- Fluoroscopic machine operation by the fluoroscopist. (Right side of the diagram.)

There are two fundamental factors, excluding patient size, that affect the patient’s total radiation dose and require careful management. They are 1) the design and configuration of the fluoroscopic machine and 2) its operation by the fluoroscopist. Machine design and configuration determine the patient’s radiation dose rate during fluoroscopy and the radiation dose used to create each recorded image. The operation of the machine, specifically taking advantage of the design features of the fluoroscope, has a significant effect on the number of fluoroscopic and recorded images that are created during the examination. The product of the number of images created and the dose delivered to the patient for each image determines the total radiation dose delivered to the patient.
What is air kerma?

- Kerma stands for kinetic energy released in a mass.
- The unit of measurement is the gray or milligray.
- Specifies the intensity of x-rays at a given position in space (air) at a known distance from the source of x-rays.
- Air kerma replaces the former quantity of "exposure."

Kerma is an abbreviation for kinetic energy released in a mass. The unit of measure for kerma is the gray (Gy), but it is typically expressed in milligray (mGy), a unit equal to one thousandth of a Gy. Air kerma specifies the intensity of x-rays at a given position in space (air) at a known distance from the source of the x-rays. As shown in the diagram, air kerma is delivered to the small mass at the center of the square area located in air some distance from the source of the radiation production. In the case of a fluoroscope, the source of the x-rays is the focal spot of the x-ray tube (see the red circle in the drawing). Air kerma replaces the former quantity of "exposure." If you know the air kerma at a given distance from the focal spot, you can calculate the air kerma at a different distance by using the inverse square law. When QMPs perform dosimetry measurements on an x-ray or fluoroscopic unit, they are typically measuring air kerma. Air kerma, along with related patient factors, can be used to perform dose calculations. All of the doses defined in this module are typically estimated by applying appropriate conversion factors to the air kerma value that was measured.
What is kerma area product (KAP)?

- Kerma area product is the mathematical product of air kerma and the cross-sectional area of the x-ray beam at the entrance surface of the patient.
- Equipment manufacturers express the units of KAP as $\mu$Gy m$^2$, cGy cm$^2$, mGy cm$^2$.
  - Note: $1 \mu$Gy m$^2 = 1$ cGy cm$^2 = 10$ mGy cm$^2$.
- KAP helps assess stochastic risk to the patient.

Kerma-area product (KAP) is the mathematical product of air kerma and the cross-sectional area of the x-ray beam at the same location in space. In the diagram, the air kerma associated with the blue square is multiplied by the area of the x-ray beam. Unlike air kerma, KAP is not affected by the distance from the focal spot. The intensity of the beam decreases at the same rate with distance, as the area of the x-ray beam increases. Equipment manufacturers express the units of KAP as $\mu$Gy m$^2$, cGy cm$^2$, or mGy-cm$^2$. Note that $1 \mu$Gy·m$^2 = 1$ cGy·cm$^2 = 10$ mGy·cm$^2$. Therefore, the radiologic technologist must pay close attention to the units used by the manufacturer of the fluoroscope when recording kerma area product values in the patient's medical record. This dose descriptor helps to assess stochastic risk to the patient from procedures using ionizing radiation.
Absorbed dose is the energy imparted per unit mass by ionizing radiation to matter at a specific point. In the diagram, the sphere intersected by the plane, for example, might represent the mass of an organ within the patient (e.g., the liver). (The rest of the patient's organs and body are not shown in the diagram for simplicity.) In general use, “absorbed dose” often is used interchangeably with the term “radiation dose.” This is the most basic and common type of dose discussed. The unit of measure for absorbed dose is the Gy or mGy.
Equivalent dose is the absorbed dose value multiplied by a quality factor, which is determined by the type of particles or rays that carry the radiation energy through space. For example, the diagrams A – C illustrate that positive-charged particles, negative-charged particles and x-rays all are capable of transporting ionizing radiation. Occupational dose reports, generated from measurements by the radiation monitors worn by technologists and fluoroscopic operators, are reported as equivalent dose. Because the quality factor for x-rays is 1, equivalent dose and absorbed dose are equal for x-rays. For this reason, absorbed doses of x-rays, other than in occupational dose reports, are typically not expressed as equivalent dose. The unit of measure for equivalent dose is the sievert (Sv) or mSv.
What is background radiation dose?

- Background radiation is the radiation that comes from the environment around us.
  - Sun.
  - Earth's crust.
  - Foods we eat.
- Background radiation results in the whole body absorbed dose of approximately 3 mSv annually.

Background radiation is radiation that comes from our environment. The sun continually emits high-energy x-rays, called cosmic rays, and trace amounts of naturally occurring radioisotopes with long half-lives are found in the earth's crust. Human beings are dependent upon food sources rooted in the earth's crust, so much of the food that we eat is slightly radioactive. All this radioactivity results in the whole-body absorbed dose of approximately 3 mSv annually. Radiation doses from fluoroscopic examinations are commonly compared to background radiation doses to provide patients or their caretakers with a frame of reference with respect to the risk.
What is entrance skin dose?

- Entrance skin dose (ESD) is the amount of radiation dose absorbed by the skin where the x-ray beam enters the patient.
- The skin dose is highest where the beam enters the patient.

Entrance skin dose (ESD) is the amount of radiation dose absorbed by the skin where the x-ray beam enters the patient. The skin dose is highest where the beam enters the patient, typically on the back.
What is cumulative skin dose?

- The cumulative skin dose is the absorbed dose where the beam enters the patient’s skin over the length of the procedure.
- The cumulative skin dose overestimates the possibility of tissue effects unless only one skin port is used.
- Many fluoroscopes today display the total amount of radiation produced, air kerma.
- From total air kerma, a qualified medical physicist can calculate an estimate of the total skin dose.

The cumulative skin dose is the absorbed dose where the beam enters the patient’s skin summed over the duration of the procedure. The cumulative skin dose assumes that all radiation enters the body through one skin “window,” or port. Since the x-ray beam is typically moved to different areas during a procedure, as illustrated by the four beam areas in the figure, it is unlikely that any single area of skin would receive a radiation dose as high as the cumulative skin dose. However, the cumulative skin dose is important for determining the potential for skin injury or other tissue effects that result from high skin doses delivered during the procedure.

Today, many fluoroscopes display an indication of total air kerma, the total amount of radiation production, at a known distance from the source. From this total air kerma, a QMP can calculate an estimate of skin dose during the procedure.
What is peak skin dose?

- The peak skin dose is the maximum dose that any patch of skin of the patient receives during a clinical procedure.
- Peak skin dose is typically significantly less than the cumulative dose.
- Peak skin dose helps predict the likelihood of tissue effects (deterministic effects).

The peak skin dose is the maximum dose that any patch of the patient’s skin receives during a clinical procedure. Since multiple skin ports are typically used either from moving the patient or repositioning the x-ray tube, the peak skin dose is typically significantly less than the cumulative skin dose. The size of the reduction factor between the peak skin dose and cumulative dose is a function of how many skin ports were used and if any of the skin port areas overlapped with one another. In the diagram, four different skin ports were used during the procedure. Because skin ports labeled 2 and 3 overlap, the region of overlap creates a new distinct skin port. Let’s assume a total cumulative skin dose of 2,000 mGy was delivered during the case equally spread among the four skin ports. This means skin ports 1 to 4 would each receive a skin dose of 500 mGy and skin port 5 would receive 1,000 mGy. Despite the overlap of skin ports 2 and 3, the peak skin dose is less than the cumulative skin dose by a factor of two. Knowledge of the peak skin dose is important for determining the likelihood of tissue effects (deterministic effects).
What is the variation in pediatric patient size?

- Variation of size in pediatric patients ranging from the smallest premature infant weighing less than two pounds to the 250-pound teenager.
- As x-rays penetrate patients of different sizes, the concept of half value layer (HVL) is important to understand.

There is significant variation in the size of pediatric patients, ranging from the smallest premature infant weighing less than two pounds to the 250-pound teenager. Some think pediatric hospitals only specialize in the health care needs of infants and small children, but some adolescents are "adult-sized." Tiny neonates can have a body thickness of less than 6 cm at their abdomen while the largest teenage abdomens can exceed 35 and 45 cm for anterior-posterior (AP) and lateral dimensions respectively. The majority of pediatric patients fall somewhere between these two extremes. This difference in tissue thickness has significant implications for both the equipment and the operator during pediatric fluoroscopy.
How does the half value layer (HVL) help us understand the requirement for the number of x-rays?

- HVL is the amount of tissue that will reduce the quantity of x-rays to half the original number.
- At 70 kV an increase in patient thickness by 3 cm doubles the number of x-rays required to penetrate the patient.

Half-value layer (HVL) is the amount of tissue that will reduce the quantity of x-rays to half their original number. Because the HVL of soft tissue at 70 kV is approximately 3 cm, an increase in patient thickness by 3 cm doubles the number of x-rays required to penetrate the patient provided the kV and added filtration in the x-ray beam remain unchanged. A difference of more than 10 HVLs between the smallest and largest pediatric patients, as illustrated in the scale drawing of the transverse plane of the abdomens of smallest to largest patients, requires a dynamic range of 1,000 times the number of photons. Fluoroscopic equipment must be capable of providing acceptable images over this very broad range of patient sizes. The required high rate of x-ray output (air kerma rate) to image the largest adult patients drives many of the design features of fluoroscopes. The challenge remains to provide fluoroscopic configurations that reduce and properly manage the radiation dose rate for the smallest patients.
How does the air kerma rate required to image a pediatric patient compare to the rate required to image an adult?

- Fewer x-rays are needed to image children compared to adults.
- This provides opportunities to improve image quality and reduce the radiation dose to small children.
- Equipment should be configured to deliver the quantity of x-rays required by the patient’s unique size.

In the clinical practice of pediatric imaging, the number of x-rays (air kerma) required is significantly reduced compared to the air kerma required for imaging most adults. Therefore, there are opportunities to improve image quality and better manage patient dose for small children and infants. Achieving this requires appropriate configuration changes to the fluoroscope, which delivers the quantity of x-rays (air kerma) needed as determined by the patient’s size. For example, to image the largest teenage patients, the radiation output rate required during fluoroscopy can be 90 mGy/min or more. In contrast, a properly configured fluoroscope for a newborn delivers 1 to 2 mGy/min or less.
Can image quality be maintained when patient dose is reduced?

- Lower air kerma rates are sufficient to penetrate the small body of a child.
- Goal is the correct dose to the image receptor with a reduced dose to the patient.
- Managing dose to the image receptor manages overall quality of the diagnostic image.

Reducing radiation dose and maintaining image quality is difficult with large patients because of the higher air kerma rates needed to penetrate the patient. Lower air kerma rates are sufficient to penetrate the smaller pediatric body. This requires numerous changes to the control features of the fluoroscope, which are discussed later in this module. The goal is to deliver the required number of x-rays at the image receptor to maintain diagnostic image quality while reducing patient dose, particularly to the patient's skin. Maintaining appropriate air kerma rates at the image receptor avoids increases in noise in the image and maintains diagnostic image quality.
Subject contrast refers to changes in brightness of adjacent areas in the image and is due to the difference in transmitted x-ray intensity in one area of the patient compared to adjacent areas. It results from differences in the attenuation of the x-ray beam as it passes through different tissues in the patient. For example, bone ($z = 13.8$) compared to soft tissue ($z = 7.4$) transmits fewer x-rays and is more easily viewed in the image. Subject contrast depends on the:

- Difference in thickness of the body part imaged (e.g., neck vs. abdomen).
- Density difference between two body parts (e.g., air-containing lung vs. the abdomen).
- Differences in atomic number (e.g., bone vs. soft tissue).
- Quality of the x-ray beam (kV).

In Figure A, the objects in the phantom are more prominent than Figure B due to the increased brightness of the objects compared to the background in the image. This is due to a change in the subject contrast of the objects within the phantom by reducing the thickness of the uniform slabs of the phantom from 22 to 3 cm. Within a given image, objects 1, 3, 4, 6, 7 and 9 are the same contrast; this
contrast is generated by 0.3 mm of aluminum thickness. In objects 2, 5 and 8, the squares increase from 0.1 to 0.2 to 0.4 mm thickness of aluminum as the number of the object increases. This explains why the contrast level of the objects in the first group of six objects is at a contrast level between that of object 5 and 8 and why objects 2 and 5 are more difficult to see. Please note in Figure A that some of the squares in the first group of six objects are missing corners. This is more difficult to see in Figure B due to less contrast of all the objects because the plastic phantom is 22 cm as opposed to 3 cm thick.
Subject contrast is different in children when compared to adults because of several factors. Subject contrast in the clinical image is determined primarily by the difference in the atomic number between two adjacent tissues. Since the atomic number of soft tissues varies little from its average value of 7.4, subject contrast of soft tissues is limited without the use of an external contrast agent. The subject contrast between bone and soft tissue in adult imaging is significant because the bone is fully calcified, with an atomic number of approximately 14. However, subject contrast between bone and soft tissue in the pediatric image is comparatively less because of incomplete calcification of the pediatric skeleton, a factor that changes with age.

Subject contrast diminishes as the energy of the x-rays increases, which occurs when the voltage (kV) used to produce the x-rays increases. This loss can be partially recovered by magnifying the subtle differences in subject contrast with digital image processing. Lower kV values can improve subject contrast, but increase patient dose. The desire for more contrast must be balanced against the increase in patient dose. Fortunately, the increase in patient dose is not as large in the small child compared to
the adult patient if small decreases in voltage are selected. In the image of the pelvis on the left, the shape and boundaries of the bladder are not imaged since the atomic number of the urinary bladder is similar to its surrounding tissues. In the image on the right, the urinary bladder is visualized because it has been filled with iodine, a contrast agent with an atomic number different from that of soft tissue.
A sharp image is essential in pediatric imaging to visualize small anatomical structures. For example, the size of a patient’s heart is approximately the size of the patient’s fist. For pediatric patients’ areas of interest, obtaining the sharpest image possible is extremely important.

A smaller focal spot improves the geometric sharpness in the image and can be selected for small patients because higher air kerma rates necessary for adults are not required during pediatric imaging. In both the images, the tip of the catheter is moving at the same rate. In the image on the left, the exposure time was 33 msec. In the image on the right, the exposure time was 3.3 msec. The shorter pulse width is necessary to freeze the motion of the catheter tip.
Quantum mottle is a form of noise that occurs when there is an inadequate air kerma rate (number of x-rays) arriving at the image receptor. As a result, the image will be grainy or speckled in appearance. An increase in quantum mottle in the image reduces low contrast resolution, or the ability to distinguish a single object with a contrast level slightly different than its background. Increasing the air kerma rate at the image receptor reduces quantum mottle. Therefore, the need for good, low contrast resolution in the image must be continually balanced against the required increase in radiation dose to the image receptor, which increases the radiation dose to the pediatric patient. Moving from left to right, the figure illustrates the loss of low contrast resolution as the quantum mottle increases. The center image illustrates a reasonable balance between good image quality and a properly managed radiation dose to the patient. The difference in dose between the left and right image is more than a factor of 100.
Learning Objectives:
1. Identify areas of fluoroscopic practice that can reduce radiation dose to the pediatric patient during fluoroscopy.
2. Explain why children are more susceptible to radiation than adults.
3. Describe radiation quantities that can be used to estimate patient dose for fluoroscopic procedures.

This concludes Image Gently: Enhancing Radiation Protection During Pediatric Fluoroscopy. You should now be able to:

- Identify areas of fluoroscopic practice that can reduce radiation dose to the pediatric patient during fluoroscopy.
- Explain why children are more susceptible to radiation than adults.
- Describe radiation quantities that can be used to estimate patient dose for fluoroscopic procedures.
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This module is now complete.

Please proceed to:

Image Gently: Steps To Manage Radiation Dose During the Examination

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10. Practice Standards for Medical Imaging and Radiation Therapy. Radiography practice standards


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16. Imaging Pediatric Patients [https://www.theonlinelearningcenter.com/course-catalog/Product/module/5055/103]
20. Paediatric Radiology [https://ipop.ieaia.org/ROPOP/ROpOContent/AdditionalResources/Training/1_TrainingMaterial/PaediatricRadiology.htm]
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