Fluoroscopy and Radiation Safety
Content for Radiologists
Marta Hernanz-Schulman MD, FAAP, FACR
Keith Strauss, M.Sc
Ishtiaq H. Bercha, M.Sc

Primary Objective: Review Pediatric fluoroscopic procedures, geared towards understanding the source of radiation, radiation reduction and effect on image quality

Additional Objectives: After reviewing this material, the individual will be able to:
1. Be familiar with the scope of fluoroscopic procedures in pediatric radiology
2. Be familiar with the basic units to describe fluoroscopic radiation dose
3. Be familiar with the various methods available to reduce radiation dose during a fluoroscopic procedure.
4. Be familiar with the effect of these methods on image quality
5. Be familiar with the various clinical settings in which dose reduction can be successfully applied.

Scope of use of Fluoroscopy
Since the discovery of the roentgen ray in 1895, radiography and fluoroscopy remained the mainstay of diagnostic radiology for decades. More recently, in adult patients the availability of endoscopy and CT has resulted in a marked decline in fluoroscopic procedures [1, 2] Yet, despite the choice of diagnostic imaging modalities available today, fluoroscopy remains an important and frequently used procedure in the pediatric patient, particularly in the US. A 2001 European survey[3] reports the mean number of annual pediatric fluoroscopies per surveyed hospital as 1,073, with a maximum of 9091. Approximately 35% of these were voiding cystourethrogram, 30% upper gastrointestinal studies, and 7% contrast enemas, with miscellaneous categories comprising the remainder. Although a similar published work for U.S. examinations was not found in a literature search, a survey of pediatric radiologists conducted by SCORCH (Society of Chairmen of Radiology in Children’s Hospitals) in 2007 indicates that the mean number of annual fluoroscopies reported per surveyed hospital is 4,296 with a maximum of 16,361. In addition to Diagnostic Imaging in Radiology departments, there are several other sources of fluoroscopic radiation, including fluoroscopy for orthopedic procedures, fluoroscopy in the OR for central line placements and other procedures, and fluoroscopy by other services, including Gastroenterology and Cardiology.

Although endoscopy has reduced the number and indications for some pediatric procedures, such as the barium enema to evaluate for colonic polyps, there is a variety of other factors influencing the use of fluoroscopy. Among these is expansion of other indications, such as assessment of vesicoureteral reflux in patients with urinary tract infection; and indications for UGI which include vomiting and epigastric pain, often translated into evaluation for reflux, some hesitation to use upper endoscopy in infants, and the potential role of reflux in patients with aspiration and apparent life-threatening events (ALTE)[4] as well as expectations of parents and referring physicians that something tangible be done to evaluate infants with vomiting/reflux. Patients with chronic conditions posing a risk for aspiration (video swallow and UGI), patients with congenital heart disease (cardiac catheterization and gastroesophageal reflux studies), and
patients with abdominal pain (enema to diagnose and treat intussusception) are additional populations with high use of fluoroscopic examinations.

Basic measurements and units to describe radiation produced by the equipment and imparted to the patient

- **Exposure** is the term used to express the intensity of energy produced by x-ray equipment in air per unit time. When x-rays travel through air, their interactions with the air molecules liberate electrons. If one collects these electrons and calculates the ratio of the electrons (Coulombs) to mass of air (kg) in which the electrons were collected, one has measured exposure in units of Roentgens. The output of fluoroscopic equipment is expressed as R/time, with specified settings of kVp, mA, distance, and filtration. The legal limit for radiation output of fluoroscopic equipment is 10R/min 30 cm in front of the image receptor for normal mode, and 20R/min for high dose mode. Since fluoroscopy time is unregulated, the amount of radiation that a patient might receive is unlimited.

- The term **kerma** refers to the kinetic energy released per unit mass, of a specific material, produced by the charged particles liberated by photons. This is the same concept as exposure, except kerma is defined for any media while exposure is limited to interactions in air. Measuring air kerma is the same process as measuring exposure except air kerma is expressed as joule/kg, and its metric SI (International System) unit is the Gray. Air kerma has replaced exposure in publications since only air kerma is expressed in terms of SI units; 8.7 mGy of air kerma is approximately equal to 1 Roentgen of exposure.

- **Absorbed dose** refers to the energy deposited within the tissue in the form of kinetic energy transferred to the tissue from the energy carried by the photon, due to interactions of the photons as they travel through the tissue. If one estimates the energy transferred in Joules divided by an estimate of the mass of the tissue (in kg) in which the energy was deposited, one has determined absorbed dose. The unit of SI measurement is the Gray (non-SI unit is the rad; 1 Gray = 100 rad; 1 rad = 10 mGy).

- The **dose equivalent** scales the absorbed dose to take into account the biological effect of the type of radiation. The scaling factor is called the **quality factor** (QF). X-rays, Gamma rays, and beta particles (electrons) all have a quality factor of 1. Heavier particles, e.g. protons, neutrons, alpha particles have quality factors greater than 1. The unit of the dose equivalent is the Sievert. 1 Sievert (Sv) = 100 rem; 1 rem = 10 mSv.

- **Effective dose** is that radiation dose which, if delivered to the whole body of the patient, would have the same risk as the actual radiation dose which was delivered to the subset of the patient’s body associated with a clinical examination with ionizing radiation. The effective dose is estimated by addressing the specific radiosensitivities of the organs being irradiated by assigning a tissue weighting factor (WT) to each sensitive organ. The effective dose calculation is the sum of the doses to each organ x its respective weighting factor.

\[ E = \sum W_T \times H_T \]

where E is the effective dose, \( W_T \) is the weighting factor, and \( H_T \) is each different organ dose from the clinical examination. Effective dose has the same unit of measure as the dose equivalent.

- The dose-area-product is estimated by calculating the product of the patient’s skin dose and the area of the patient’s skin irradiated within the collimated radiation field. This quantity is typically measured by a large area ion chamber located between the X-ray source and the
patient. Dose-area-product is typically expressed in units of dose area, e.g. \( \mu \text{Gy} \text{m}^2 \) or \( \text{cGy cm}^2 \).

Please note that air kerma or dose-area-product are typically measured by a qualified medical physicist when ‘dosimetry’ measurements are performed. Absorbed dose, dose equivalent, and effective dose are estimated by qualified medical physicists by scaling these two measured quantities appropriately.

**Relevant amount of radiation resulting from fluoroscopy**

The amount of radiation resulting from fluoroscopic procedures is highly variable. The total patient dose from a fluoroscopic clinical exam is dependent upon how much radiation is used to generate each image, both fluoroscopic images and recorded radiographic images. The amount of radiation used for each image depends on the patient size and the required image detail dictated to a large degree by the type of clinical study. Typically, a qualified medical physicist works with the radiologist and the manufacturer of the imaging equipment to configure and set up the imaging equipment to insure that the radiation dose associated with each image is optimized.

Optimizing the radiation dose associated with each acquired image is only the first half of the process needed to insure that the patient’s radiation dose is ‘as low as reasonably achievable’ (ALARA). Patient dose is also dependent on the number of fluoroscopic images and radiographic images created during the examination.[4] Correct operation of the machine by properly trained operators reduces the duration of time of fluoroscopic radiation. The experienced operator also reduces the number of recorded exposure images to the minimum number that properly documents necessary diagnostic detail, with recording of fluoroscopic, or “fluoro-save” images used for documentation of findings as much as possible. This Fluoroscopy Initiative is limited to the diagnostic imaging procedures routinely performed in Pediatric Radiology and excludes interventional procedures.

The VCUG is one of the most common fluoroscopic procedures performed in children, for indications that include detection of reflux and of congenital anomalies, in patients presenting with urinary tract infection or abnormalities typically identified at sonography. Bolch et al [5], analyzing VCUG examinations, reports the following data:

- in a 3 month old 6.35 kg male the authors found that with 90 seconds (senior resident) of fluoroscopy time (2.2 mGy) and 6 spot films (1.3 mGy), the dose was 3.5 mGy, or 0.35 rads, and the effective dose was 0.47 mSv (47 mrem).
- in a 1 month old 4.31 kg female using 197 seconds (first year resident) of fluoroscopy time, the fluoroscopy dose was 3.8 mGy, and 6 spot films exposure of 1.5 mGy, the total dose for the study was 5.3 mGy (0.53 rad) and the effective dose was 1.4 mSv (140 mrem).

In another study Pazik et al [6] evaluated dose with digital fluoroscopy
- in 5 girls aged 4-66 days with fluoroscopy times ranging between 47 and 148 seconds, with 5 spot images. Effective dose values ranged between 0.6 and 3.2 mSv, with a mean of 1.8 ± 0.9.

The RadiologyInfo.org website cites
• an effective dose for a VCUG of a 5 – 10 year old child at approximately 1.6 mSv. 
www.radiologyinfo.org/en/info.cfm?pg=voidcysto&bhcp=1#part nine

In a more recent study Ward et al [5] evaluated dose with a digital fluoroscope optimized for children compared to a fluoroscope without modifications
• in 75 girls and 70 boys ranging in age from 3 days to 8 years the average fluoroscopy time ranged from 115 – 140 seconds with or without grid controlled pulsed fluoroscopy.
• Skin doses for a continuous mode fluoroscope ranged from 3.4 – 5.7 mGy with associated effective doses of 0.59 – 0.45 mSv respectively as a function of patient size. Similar numbers for the optimized pulsed fluoroscopy unit ranged from 0.39 – 0.58 mGy skin doses and 0.07 – 0.05 mSv.
• Patient doses during VCUGs can be dramatically reduced if the imaging equipment is optimized for children.

The UGI is also one of the most common fluoroscopic procedures performed in children, for indications that include vomiting, respiratory problems, and abdominal pain. Staton et al analyzed the effective dose received during UGI examination[7]
• in 5 patients aged 1.8 – 5.7 months, and found that this ranged between 1.2 mSv to 6.5 mSv, with a mean of 3.1 mSv, with 80 to 95% of the dose imparted during the fluoroscopic portion of the examinations.

The RSNA website, RadiologyInfo.org, cites the effective dose for the UGI
• at approximately 6 mSv for an adult patient. 
www.radiologyinfo.org/en/info.cfm?pg=uppergi&bhcp=1

The American Nuclear Society website estimates the effective dose for the UGI
• at approximately 6 mSv for an adult patient
www.ans.org/pi/resources/dosechart/

The contrast enema is another procedure that is relatively common in pediatric patients. This study is done for a variety of reasons, including evaluation of lower tract obstruction, and therapeutic procedures, such as non-operative treatment of meconium ileus and intussusception.

The RadiologyInfo.org website cites the effective dose for the barium enema
• At approximately 8 mSv for adults 

The American Nuclear Society website estimates the effective dose for the contrast enema
• At approximately 8mSv for adults www.ans.org/pi/resources/dosechart/

How do the doses for these most common pediatric fluoroscopic examinations compare to other parameters? First let us consider background radiation, with no medical radiation. Background radiation at sea level is approximately 3 mSv/year. This increases to 5 to 6 mSv at an elevation of 5000 feet (e.g., Denver, Boulder and Colorado Springs area ref: http://www.colorado.edu/EHandS/hpl/RADHandbook/Introduction.html). As a rough rule of thumb, one can assume a doubling of radiation dose for each mile of elevation gained. Each 1 mSv of effective dose received from a clinical radiation examination is equivalent to about 4 months of annual natural background radiation that is received every year of each person’s life. An abdominal CT in a child should not exceed 2 – 3 mSv of effective dose provided the radiologic technique factors are optimized for pediatric imaging. www.imagegently.com
**Potential risks resulting from radiation exposure**

There are two types of deleterious radiation effects: deterministic and stochastic. Deterministic effects require injury to multiple cells and have a threshold dose, below which the effect is not expressed. These injuries include (threshold dose in parenthesis) skin erythema (2 Gy), epilation (temporary 3 Gy, permanent 7 Gy), ulceration (10 Gy), which can be sufficiently severe to require skin transplantation.[8] These threshold doses can and do occur during fluoroscopy, but are limited to complex and complicated interventional procedures typically on large adult sized patients on which the fluoroscopic radiation rate is elevated.

Stochastic effects can occur from an injury to a single cell; the probability of the effect is proportional to dose. Stochastic effects typically exhibit a latent period after irradiation prior to development of the effect that can exceed 20 – 25 years for solid tumors. Radiation-induced cancers are expressions of stochastic effects.

The risk of stochastic effects is greater in children than adults. This occurs because a child’s tissues are more radiosensitive, because radiation is cumulative over their lifetime, because children have a longer lifetime in which these late effects can develop, and also a longer lifetime to accumulate further exposures. The committee on the Biological Effects of Ionizing Radiation (BEIR) VII states “... the risk of cancer proceeds in a linear fashion at lower doses without a threshold and ... the smallest dose has the potential to cause a small increase in risk to humans.” Deterministic effects are less often seen in children because their small bodies result in relatively lower dose rates compared to those of adults. Conversely, deterministic effects are more common than stochastic injuries in adults because of the large body size of an adult and because the adult’s life expectancy may be shorter than the latent period required for the development of a stochastic injury.

**Fluoroscopic Regulations**

As stated earlier, there is a standard limit of 10R/minute exposure rate (87 mGy/min air kerma) 30 cm in front of the image receptor of a fluoroscope in the normal fluoroscopy mode. Some machines are configured with a high dose fluoroscopy mode that delivers up to 20R/minute exposure (17.4 mGy/min air kerma) 30 cm in front of the image receptor of the fluoroscope. When the fluoroscopy machine is operated in the high dose mode, an audible tone must be emitted by the fluoroscope whenever the exposure pedal is depressed, to remind the operator that the machine is delivering a higher than normal radiation level to the patient and staff. A timer during fluoroscopy, either normal or high level, alerts the fluoroscopist that five minutes of fluoroscopy time have elapsed, but the five minute time interval of actual fluoroscopy can be repeated without limit.

The selection of fluoroscopy settings by the operator is not regulated. No legal limit on the radiation dose delivered during any single examination, or during repeated examinations exists. The operator of the fluoroscope is expected to manage the fluoroscopic settings used during examinations and to manage the number of examinations an individual patient receives. Historically, all states in the United States allowed any licensed physician to operate a fluoroscope because radiologists performed the vast majority of fluoroscopic examinations and possessed appropriate training in radiation protection to ensure the safety of patients and staff. Today, non-radiologist physicians, without specific training in radiation protection, perform many fluoroscopic examinations. This has created the need for hospitals and imaging clinics to
develop privileging programs for physicians that require all fluoroscopic operators to demonstrate training and competency in the safe use of fluoroscopic equipment prior to the fluoroscopic examination of patients by the physician.

**Strategies for ALARA in Fluoroscopy: Dose reduction and image quality**

Concern over radiation exposure in the medical community and in the public sector has resulted in major innovations in fluoroscopic equipment which allow very significant reduction in dose while maintaining, and at times improving, image quality.

Such methods include choosing pulsed fluoroscopy, reduced pulse widths, reduced pulse rates, appropriate high voltage, beam current, and pulse width product, appropriate beam filtration, increased source to skin distance, the anti-scatter grid only when appropriate, proper field of view, reduced dose rate to image receptor, proper collimation, proper use of last image hold, proper use of fluoroscopy store, intermittent fluoroscopy, properly triaging patients, and applying proper image processing.

**Continuous vs Pulsed Fluoroscopy**

Historically, fluoroscopy was performed in the continuous mode. Whenever the fluoroscopy pedal was depressed, a continuous x-ray beam was produced. Since 30 fluoroscopic images were created per second, the duration of each image frame was 33 msec (1000/30=33). Unfortunately, significant patient motion and loss of sharpness in the clinical images can occur due to patient or organ motion during fluoroscopy.

Most state-of-the-art fluoroscopic equipment today offers an improved alternative to continuous fluoroscopy. When the fluoroscopic foot pedal is depressed, the x-ray beam is pulsed by the machine or turned ‘on’ and ‘off’ at a selected pulse rate. If the proper parameter settings are selected with respect to the size of the patient examined during pulsed fluoroscopy, the image quality can be significantly improved and the radiation dose to the patient can be significantly lowered as explained below.

**Pulse Width**

The pulse width determines the duration of time that the patient is exposed to radiation during the production of one fluoroscopic image. This duration affects the imager’s ability to ‘freeze’ any motion that occurs in the patient. Shorter pulse widths improve the sharpness in the fluoroscopic images, but also limit the number of x-rays used to form the image in the individual frame that increases the quantum mottle in the image. The need for a sharp image must be balanced against the need for more x-rays to penetrate larger patients and properly manage the quantum mottle in the fluoroscopic image. Pulse widths for children less than 10 years of age should ideally not exceed 5 msec while pulse widths for adult patients should ideally not exceed 10 msec. Continuous fluoroscopy, with an effective pulse width of 33 milliseconds, will tend to blur rapidly moving objects due to motion. Brown et al[9], utilizing a moving disc phantom, reported that continuous fluoroscopy was able to resolve the least number of moving objects, compared with pulsed fluoroscopy at various pulse rates.

**Pulse Rate**

The selected pulse rate determines the number of fluoroscopic image frames that are generated by the machine per second. Depending on the application of the machine, the available pulse rates range from 30 pulses per second (interventional equipment) to as low as 1 or 0.5 pulses.
per second. When an object is moving, the distance it travels between successive pulses is inversely proportional to the pulse rate. This phenomenon is called temporal resolution that increases as the pulse rate increases.[10] Due to rapid motion, interventional studies typically require 15 - 30 pulses per second. For example, if a catheter needs to be manipulated in real-time within a moving structure, a faster frame rate may be needed to more rapidly update temporal changes; when assessing diaphragmatic motion, a faster frame rate is typically required. Barium Swallow studies typically require 7.5 – 15 pulses per second. Upper and lower GI studies and VCUG studies are typically performed at frame rates less than 5 pulses per second depending on the degree of motion that is present. Adjustable frame rates at the tower can be changed to suit the temporal resolution needs of each portion of the examination. Carefully manipulated frame rates offers optimal imaging and potential reduction in radiation dose.

Boland et al[11] studied temporal resolution and its effect upon the visualized image and operator perception, by changing the pulse rate during segments of a variety of common fluoroscopic procedures. They found no difference in image quality in study segments performed with 30 frames per second vs. frame rates of 7.5 and 3.75 frames per second, although they did detect a non-significant trend towards greater operation satisfaction with higher pulse widths especially in examinations involving moving objects, such as catheter manipulations. The authors concluded that some initial training may be required to gain acceptance of lower pulse rates by some users.

**Voltage (kVp), Tube Current (mA), and Tube Current/Pulse Width Product (mAs)**

Since the penetration of the x-rays increases as the kVp increases, fewer x-rays are needed at higher kVp to obtain the proper number of information carriers at the image receptor. This results in less patient dose. Higher kVp values, however, decrease the contrast in the fluoroscopic image. The tube current determines how many x-rays are generated per unit time in the machine. The pulse width determines how long x-rays are produced for each image. The product of the pulse width and tube current determines how many x-rays are produced to create each fluoroscopic image, determining the quantum mottle in the images. If the pulse width is decreased to improve sharpness in the image, this decrease must be offset by an increase in the tube current to keep the total number of x-rays used for each image (same quantum mottle in image) the same. The maximum value of the tube current is determined by the focal spot size and design of the x-ray tube. If the mAs product at the preferred pulse width and maximum mA is too limited to produce the desired quantum mottle in the image, either the pulse width or kVp must be increased. The proper choice depends on whether overall image quality is limited by motion unsharpness or contrast, respectively.

**Beam Filtration**

Beam filtering refers to the removal of low-energy x-rays. Since these low-energy x-rays cannot penetrate the patient and reach the image receptor, they cannot contribute to image formation. All their energy would be deposited in the patient’s tissues increasing the patient’s radiation dose. With added filtration, effectively the energy of these x-rays is deposited in the added filtration to the beam instead of the patient’s tissues.

Beam filtration has significantly improved in the last decade[10] with state-of-the-art units containing multiple thicknesses of filters that the machine may automatically select, depending on the imaging task. The use of thicker filters to reduce patient dose (more low energy x-rays attenuated in the filter) requires more x-ray production for each image. The need for more
photons with the thicker filter may require an increase in the pulse width for each image. This causes manufacturers to set their machines to use pulse widths greater than 5 msec. When children are imaged, the desire to reduce patient dose with thicker filters must be balanced against the need for shorter pulse widths to freeze motion during pediatric imaging. You may need to ask the equipment manufacturer to change the standard default settings in their automated program settings, such that shorter rather than longer pulse widths with reduced filter thickness, is selected for pediatric imaging.

**Source to Skin Distance (SSD)**

The inverse square law states that the intensity of the x-ray beam is inversely proportional to the square of the SSD. Therefore, anytime the SSD is increased during fluoroscopy, the patient’s radiation dose will decrease. This also requires that the radiation output per unit time of the x-ray tube must increase to maintain the same quantum mottle in the fluoroscopic image.

Typically, the SSD on standard fluoroscopic tilt table is ~ 50 cm. At least one manufacturer sells an option for their unit that allows the operator to switch between a SSD of either 50 and 64 cm. If this feature is available, all pediatric imaging should be performed at the longer SSD. The facility’s heaviest adult patients may need to be examined at the shorter SSD to prevent photon starvation at the image receptor.

**Removal of anti-scatter grid**

The anti-scatter grid attenuates scattered radiation and prevents it from reaching the image receptor. In large patients, removal of scatter is mandatory to preserve subject contrast in the image and reasonable overall image quality. However, the removed scatter did contribute to the brightness of the fluoroscopic image on the monitor. When this scatter radiation is removed, it must be replaced by primary radiation at the image receptor which increases the radiation dose to the patient by a factor of 2 or more.[11]

The image below (Figure 1) shows the decrease in exposure that can be gained by removing the antiscatter grid and using pulsed fluoroscopy, as measured in phantoms simulating 1, 3 and 10 year old patients.[12]

![Entrance Dose: Grid In/Out and Frame Rate 1-10 year phantom](image.png)

Brown et al.[9] did not find an appreciable difference in object detection using a 10 cm phantom (simulated pediatric patient) with the grid in or out. This occurs because the small body of the pediatric patient generates reduced levels of scatter. Therefore, the grid minimally improves image quality at a dose penalty to the patient relative to imaging without a grid. In general,
children under the age of 3 – 5 years can be imaged with the grid removed, obtaining similar image quality at a reduced dose.

Field of View
Most fluoroscopes allow the operator to select from three or more Field of Views (FoVs) on the display monitor. The ‘normal’ mode provides the biggest FoV and irradiates the entire surface of the image receptor. Additional modes, e.g. mag 1, mag 2, etc, use smaller x-ray beam areas at the image receptor. Since these smaller areas are expanded to fill the entire display monitor, the image of the anatomy on the monitor is electronically magnified for smaller FoVs. Typically, the image sharpness is also improved in the magnified FoVs. The operator, however, should be aware that as the desired FoV becomes smaller, the radiation dose rate during fluoroscopy increases. Depending on the design of the machine, dose 1/FoV or dose 1/FoV^2. In the first case, halving the FoV doubles the radiation dose rate at the image receptor while in the second case the radiation dose rate increases by a factor of 4.

Dose Rate to Image Receptor
Most fluoroscopes allow the operator to adjust the dose rate to the image receptor during the procedure to the level commensurate with the necessary fluoroscopic detail. Low contrast image quality (soft tissue differentiation) is primarily determined by the amount of quantum mottle in the image.[10] The level of quantum mottle in the fluoroscopic image is inversely related to the square of the radiation dose rate. This means that a relatively large increase in dose rate to the image receptor (and to the patient), factor of 4, is required to reduce the quantum mottle in the image by a factor of 2.

While significant increases in dose rate at the image receptor may be needed to improve low contrast images, the image quality of high contrast images, such as examinations of bone, or of soft tissue with a significant contrast enhancer such as Barium or Iodine, is primarily dependent on the sharpness of the images. In fact, elevated dose rates to the image receptor for high contrast images may actually degrade overall image quality. Decreased quantum mottle in these high contrast images does not improve overall image quality, while the fluoroscope may be forced to select a longer pulse width (less sharpness in the image) to deliver the elevated radiation dose rate to the image receptor.[10]

In the same vein, Ward et al[13] investigated subjective image quality and measured entrance skin exposure rates on a porcine animal model, utilizing an optimized fluoroscope, with pulse width set at 5 msec for the smaller animals, 10 msec for the larger animals, and user-selectable pulse rates preset at 1.88, 3.75 and 7.5 frames per second. They found a 4.6 – 7.5 difference in radiation exposure when compared with continuous fluoroscopy on non-optimized equipment, with essentially no significant difference in image analysis.

Collimation
Radiation risk is a function of the radiation dose rate and the area of the x-ray field at the entrance plane of the patient. If either of these parameters increases, risk to the patient increases. This behooves the operator to take steps to reduce both the radiation dose rate and the area of the x-ray beam during fluoroscopy to minimize the risk of patient irradiation. The x-ray beam is automatically collimated to the size of the displayed Field of View (FoV) on the display monitor, e.g. normal, mag 1, mag 2, etc. This x-ray beam size, however, on small pediatric patients may provide a larger FoV than necessary. The FoV should be limited to
include only the anatomy pertinent to the examination by manually adjusting the position of the collimator blades. Some state-of-the-art fluoroscopes provide a graphical display of the collimator blade position on the display monitor. This allows the operator to adjust the blades and limit the FoV off the image on the monitor, without additional fluoroscopy to position the collimator blades.

**Last Image Hold**
The Last Image Hold (LIH) feature of the imager allows the retention of the last fluoroscopic image on the monitor after the operator has released the foot pedal. Prior to the introduction of LIH, fluoroscopic images only appeared on the display monitor while the patient was irradiated with the foot pedal depressed. The LIH feature allows the operator to study the last fluoroscopic image of the previous fluoroscopy sequence as long as necessary without further irradiation.

**Fluoroscopy Store**
The Fluoroscopy Store (FS), feature of the imager. also known as “fluoro-save” or “fluoro-grab”, allows the operator to ‘grab’ or record a single fluoroscopic image during live fluoroscopy, or to select the Last Image Hold displayed on the monitor record it. Prior to the development of FS, a radiographic image (radiation dose 10 times greater than fluoroscopic image) had to be created to record the clinical findings during fluoroscopy. In order to record motion, such as esophageal peristalsis, rapid repeated imaging at elevated doses per image were necessary. More than one series was often needed, as coordination of the rapid-fire exposures and swallowing was not always possible.

FS allows the ‘ad hoc’ acquisition of the necessary fluoroscopic images without the penalty of increased radiation dose per image. Multiple images can be obtained during a contrast swallow, documenting esophageal peristalsis, a finding which is pertinent in specific patients, such as those who have had esophageal atresia repair. The progress of contrast across the duodenal C-loop can be documented, making evaluation of the position of the ligament of Treitz easier and more reliable. The progress of contrast through colonic loops can be documented, making tracing of pertinent anatomy and pathology possible after the study is completed. During a voiding examination, images of the male urethra can be recorded during a voiding cycle, ensuring full distensibility and optimal evaluation for the presence of obstructing valves or strictures. The erratic voiding pattern in such patients, such as the male newborn, can be circumvented, with successful evaluation of the urethra reliably accomplished.

**Intermittent Fluoroscopy**
Reduced rate pulsed fluoroscopy, LIH, and FS are all features that can be used to limit the number of fluoroscopic and recorded image production during an examination. However, these features in no way eliminate the need for the operator to depress the fluoroscopic foot pedal intermittently. Momentary depression of the foot pedal allows LIH and FS to be used more effectively to reduce the number of created images even if reduced pulse rates, e.g. 1 – 6 pulses per second, are used during fluoroscopy. Common sense maneuvers, such as placing the tower over the region of interest before turning on the fluoroscope, are also important.

**Radiation Dose Reduction**
The patient’s radiation dose during a fluoroscopic exam is determined in part by the radiation dose used to generate each image.[14] The radiation dose of each image, regardless of whether...
it is a fluoroscopic image or a recorded image, is determined primarily by the parameters previously discussed and is under the control of the operator. Typically, the patient’s radiation dose of one recorded radiographic image is approximately ten times greater than the patient dose of one fluoroscopic image. Moreover, if the image was obtained during necessary fluoroscopy, recording of the image is of no additional radiation to the patient. Operators and technologists associated with pediatric fluoroscopy should continue to work with their qualified medical physicists to leverage the parameters previously discussed to provide good, task oriented image quality at a reasonable, reduced patient radiation dose. This work is illustrated on the left side of Figure 2 below.

As Figure 2 illustrates, leveraging machine design to decrease the patient dose per image is only half the effort required to manage overall patient radiation dose. The operator must also take steps necessary to minimize the number of images that are created, both fluoroscopic images and recorded images (right side of Figure 1). Yes, the operator can use ‘Last-Image-Hold’ and ‘Fluoroscopy Store’ features provided by the imager to reduce the number of images created during the examination, but this is just the starting point. A team effort is required. The radiologist and referring physician should evaluate the validity of any requested clinical study involving ionizing radiation. Answering the clinical question with a study void of ionizing radiation is the most effective way to reduce radiation risk! Once the validity of the request is established, the operator of the fluoroscope must have appropriate training to ensure that he/she knows how to leverage the features of the imager to minimize the number of images generated during the study.[14]

**Image Processing**

The image displayed on the monitor of the imager undergoes significant processing prior to being displayed. Manufacturers ship their units with standard ‘protocols’ that control how the images will be processed. While these standard protocols generally provide good image quality for adult patients, additional protocols that optimize settings for pediatric imaging are necessary.
If present in the system, these protocols may not be accessible to the operator without special setup in the service mode at installation. In some cases, the manufacturer may not have previously developed protocols, requiring development of appropriate protocols on site. In either case, the radiologists, technologists, and qualified medical physicist should work closely with the application specialists and imaging specialists of the manufacturer prior to first clinical use of the machine, to insure that the imager is properly configured to perform quality pediatric imaging.

Most fluoroscopes today have an adaptive measuring field that can be set up in the service mode. The measuring field is a ‘sensor’ in the center of the image that determines the automatic brightness of the image on the monitor. If this measuring field is ‘adaptive’, the area of the field can be adjusted in the service mode. Measuring fields for pediatric imaging should be smaller than those used for adults, in proportion to the difference in body size to insure that the sensor area is completely covered by the patient’s anatomy. This smaller measuring field also allows the use of a more tightly collimated x-ray field for small patients, which reduces radiation risk to the patient. Without the smaller measuring field the collimated x-ray beam area could become smaller than the area of the sensor of the measuring field, resulting in excessive brightness of the image and substandard image quality. Therefore, the measuring field size is one parameter that needs to be adjusted when setting pediatric protocols.

As previously explained in the section ‘Dose Rate to Image Receptor’ image-processing parameters should be adjusted to the specific imaging task of the particular examination. Since the overall image quality of high contrast images (images containing bone or contrast media) are most sensitive to sharpness of edges, enhancement of these edges by image processing typically improves these images, despite the fact that the edge enhancement process also enhances the quantum mottle in the images. The degree of edge enhancement needs to be set in the service mode for each type of examination to be performed on the imager.

Overall image quality of low contrast images, images void of bone or contrast media, are most sensitive to the amount of quantum mottle in the images. Since quantum mottle in the images can be masked to some degree by reducing the sharpness of the image, this type of imaging process generally improves overall image quality in low contrast images. The degree of image smoothing needs to be set in the service mode for each type of examination to be performed on the imager.

Two other methods can be used to reduce quantum mottle in low contrast images, but each comes at a cost. First, since quantum mottle is inversely proportional to the square of the radiation dose to the patient, significantly increased patient dose reduces quantum mottle and improves low contrast image quality at the cost of increased radiation to the patient. The second method uses frame averaging or image integration, which improves image quality of low contrast images at the expense of high contrast images.

Image integration or frame averaging is the process of adding multiple images together to produce a single image. The process averages the quantum mottle of each image and reduces the quantum mottle in the final image. The reduction of quantum mottle is dependent on the number of images that are averaged together. Unfortunately, if any patient motion occurs during the acquisition of the multiple images, sharpness in the final image will be degraded.
Therefore, image integration carries both the penalty of increased patient dose and loss of sharpness, which significantly degrades high contrast images.

**SUMMARY**

Pulsed fluoroscopy offers a significant tool for radiation reduction in fluoroscopy, with image improvement in some cases, particularly in evaluation of moving objects. Marked reduction in frame rates, however, can result in loss of some temporal resolution; therefore it is important to have the ability to switch frame rates at the tower. Pulse widths for pediatric examinations should be reduced to “freeze” patient motion. Appropriate setup of high voltage, tube current, product of tube current and pulse width for each image, beam filter thickness as a function of patient size, SSD, FoV, and dose rate to the image receptor all have a significant effect on the patient dose per created image. Tight collimation reduces the patient’s radiation risk. Removal of the anti-scatter grid for small patients reduces patient dose with little loss of image quality.

Last Image Hold and Fluoroscopy Store capabilities allow methodical evaluation of images and documentation of temporal fluoroscopic information, without creation of additional images, thus decreasing the radiation dose to the patient. The number of radiographically acquired exposures at dose/image ten times greater than fluoroscopic images can be greatly reduced, and reserved for circumstances in which high detail, such as subtle mucosal abnormalities, is of particular importance. Proper training of the operator with respect to all the features of the fluoroscope reduces the number of images generated during the examination, which reduces the radiation dose to the patient.

In addition to the above techniques designed to reduce the radiation dose to the patient per image, the fluoroscope must be configured in the service mode to allow the imager to perform appropriate image processing for each type of clinical task that will be encountered by the operator. The operator must understand these protocols and which one to select for each imaging task encountered.

Finally, evaluation of indications as well as of alternative procedures, continue to be of importance in the pursuit of the ALARA principle in daily practice. Using an alternate imaging modality that does not use ionizing radiation to answer the clinical question is the most effective ALARA step of all.
REFERENCES


