Pause and Pulse: Ten Steps That Help Manage Radiation Dose During Pediatric Fluoroscopy

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OBJECTIVE. The Image Gently Campaign of The Alliance for Radiation Safety in Pediatric Imaging seeks to increase awareness of opportunities to lower radiation dose in the imaging of children. Pause and Pulse is the most recent phase of the campaign, addressing methods of dose optimization in pediatric fluoroscopy.

CONCLUSION. This article discusses 10 steps that can be taken for fluoroscopic dose optimization in pediatric diagnostic fluoroscopy.

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Although the positive impact of medical imaging on medical care is undeniable [1–6], its importance is paralleled by its increasing use. According to data from the National Council on Radiation Protection and Measurements, the proportion of radiation dose from artificial sources compared with all sources has increased from 18% in 1987 to 48% in 2006 [7]. The bulk of the artificial sources are CT and interventional fluoroscopy in children; however, routine radiography and diagnostic fluoroscopy represent approximately 10% of the artificial total.

The introduction of newer procedures and cross-sectional imaging techniques, such as endoscopy, CT, and MRI, has reduced the dependence on fluoroscopy in pediatric diagnostic imaging [8]. For example, endoscopy has largely supplanted the barium enema for the detection of colonic polyps, and ultrasound has eliminated the need for upper gastrointestinal studies in the imaging diagnosis of pyloric stenosis [9, 10]. Yet, fluoroscopy remains a critical part of the diagnostic armamentarium of the radiologist caring for critically ill children. For example, voiding cystourethrography (VCUG) remains an important test in the evaluation of patients with urinary tract infection [11]; the fluoroscopic evaluation of gastroesophageal reflux and aspiration in patients who present with history of apparent life-threatening events is also a component of the medical assessment of this patient population [12]. A 2001 survey of European hospitals reports the mean number of annual fluoroscopies per hospital to be 1073, with a maximum of 9091 [13]. Data compiled for 2007 by the Society of Chairmen of Radiology at Children's Hospitals indicate that the mean annual number of fluoroscopies per hospital is 4296, with a maximum of 16,361. The Society of Chairmen of Radiology at Children's Hospitals data include only fluoroscopic procedures performed by pediatric radiologists in pediatric hospitals; they do not include fluoroscopic procedures in unassociated outpatient imaging centers or in adult-focused hospitals. Fluoroscopic procedures performed by other subspecialty services, such as gastroenterology, cardiology, and orthopedics, are not included in these numbers.

The efforts of the U.S. Food and Drug Administration to reduce radiation exposure during medical imaging include fluoroscopy as one of the important modalities to target in its recent initiative to reduce unnecessary radiation exposure [14]. The Food and Drug Administration continued these efforts by conducting a public hearing held in March 2010 with one session devoted to the appropriate use of fluoroscopy [15].

The Society for Pediatric Radiology has also addressed concerns over fluoroscopy dose optimization and dose reduction in pediatric patients; it conducted an As Low as Reasonably Achievable (ALARA) conference on this topic in 2006 [16]. More recently, the Alliance for Radiation Safety in Pediatric Imaging, sponsor of the Image Gently campaign, has launched its Pause and Pulse initiative, which is focused on promoting awareness of the need to lower radiation dose to pediatric patients during fluoroscopy (Fig. 1). This new

phase of the campaign has developed an array of educational materials for reference by radiologists, radiologic technologists, and medical physicists available on the Image Gently Website.

The American College of Radiology (ACR), one of the founding members of the Alliance for Radiation Safety in Pediatric Imaging, has established guidelines for the performance of fluoroscopic procedures in the pediatric population, in collaboration with the Society for Pediatric Radiology [17]. These valuable guidelines continue to be updated and now include guidelines in the performance of fluoroscopic examinations, including the upper gastrointestinal tract, small-bowel series, contrast enema, and VCUG in pediatric patients.

The Accreditation Council for Graduate Medical Education and the Radiology Review Committee include pediatric fluoroscopy as one of the critical manual and interpretative skills in the training of radiology residents and subspecialty trainees in pediatric radiology. The American Board of Radiology includes interpretation of pediatric fluoroscopy as a component of board certification as well as maintenance of certification.

This article is part of the Pause and Pulse campaign's educational materials in pediatric fluoroscopy, urging medical professionals who use diagnostic fluoroscopy to pause to consider the appropriateness of the examination and nonradiation alternatives and to use pulsed fluoroscopy routinely as a dose-saving measure. We discuss 10 steps that can be taken to reduce radiation dose in pediatric patients undergoing fluoroscopic imaging studies, their effect on image quality where applicable, and the various clinical settings in which such dose reduction can be successfully applied. Some of these steps are common sense, and many take place before one sets foot on the fluoroscopy pedal.

Know Your Equipment and How to Use Dose-Saving Features

The output of fluoroscopic equipment is measured as Roentgens (coulombs per kilogram per minute); the legal limit for operation at normal mode is an exposure rate of 0.00258 C/kg/min (10 R, 174 mGy/min air kerma rate) 30 cm in front of the image receptor. However, some equipment is configured to operate at "high-dose-rate" mode, which doubles the output to a maximum allowable exposure per air kerma rate of 0.00516 C/kg/min (174 mGy/min air kerma rate) at the same distance. This quantity is

Fig. 1—Poster for the Image Gently campaign. Reproduced with permission of the Alliance for Radiation Safety in Pediatric Imaging.

used routinely by medical radiation experts for quality control and regulatory compliance assurance.

There are audible tones that indicate to the operator that the equipment is being used in high-dose-rate mode and when fluoroscopy time exceeds a specific length, but there are no legal proscriptions against use of the high-dose-rate mode or unlimited fluoroscopy time; there are no legal specifications as to selection of the fluoroscopy settings or configuration of the fluoroscope, nor are there specifications applicable to pediatric patients. The responsibility rests on the operator to optimize radiation dose as outlined by the ALARA principle, which recognizes that radiation should consist of, and not exceed, the amount needed for diagnostic acumen.

The radiation dose associated with fluoroscopic procedures is highly variable and dependent on multiple factors. Total patient dose varies with the number of images obtained (fluoroscopic and radiographic) and the amount of radiation used to generate each image [18–21]. The radiation used for each image, in turn, depends on patient size and the radiation dose delivered to the image receptor of the fluoroscope. Fluoroscopy time should not be used to estimate the radiation dose to the patient, if other types of doses are displayed on the imager [22, 23]. As already discussed, in addition to fluoroscopy time, total patient dose is a function of the size of the patient and the technique and

number of radiographic images created during the case, which are not tracked by fluoroscopy time. If fluoroscopy time is the only metric available, the qualified medical physicist must estimate the radiation dose of the recorded images in addition to the radiation dose during fluoroscopy.

Most modern fluoroscopy systems provide information on a given procedure's cumulative air kerma in a radiation dose report that can be a part of patient record. Depending on the patient's size and other settings, a qualified medical physicist can estimate entrance skin dose (milligrays) and effective dose (millisieverts) using appropriate conversion factors. The physicist must know at what point relative to the entrance plane of the patient the imager quantifies the air kerma. Without this information, a medical physicist can only provide very broad radiation dose estimates at best. The need for this information illustrates that a strong, direct, and collaborative role and relationship between vendors of imaging systems and users is necessary.

The air kerma–area product, also referred to as dose-area product, is the product of the x-ray field area (centimeters or meters squared) at the entrance plane of the patient and the corresponding air kerma (milligray or microgray) at the same location. Because the radiation intensity decreases according to the inverse square law and the area of the x-ray beam increases according to the square law with increasing distance from x-ray source, the quantity air kerma–area product or dose-area product remains constant as one moves from the source. Air kerma can be approximated from air kerma–area product by dividing air kerma–area product by the area of the x-ray field.

State-of-the-art digital fluoroscopes typically offer two modes of fluoroscopy: continuous and pulsed. In the continuous mode, the x-ray beam is on without interruption whenever the foot pedal is depressed. Thirty frames of fluoroscopic images are produced each second such that each fluoroscopic image is acquired over 1/30 or 33 milliseconds of time. The large number and length of images increase the patient dose; 33 milliseconds duration of each image fails to freeze patient motion in the images. The pulsed mode, discussed later in this article, allows the operator to improve image quality and reduce the dose to the patient.

Proper shielding apparel should be worn by the operator, technologists, and nurses in the

procedure room during procedures. The lead shielding around the image intensifer should rarely be removed. Because of the need for staff to restrain small children and be close to the origin of the scatter radiation from the patient, additional shielding devices may be helpful, as illustrated in Figure 2. Fortunately, scatter radiation rates from the smaller body of pediatric patients are significantly less than scatter rates from an adult patient.

Fig. 2—Young child undergoing fluoroscopic procedure. Note lead strips around fluoroscope, appropriate shielding of operators, and smiles and distractions of staff, helping to establish communication with child and enlist her cooperation. Reprinted with permission of Cincinnati Children's Hospital.

Pause to Determine Whether the Requested Examination Is Best Suited for the Clinical Indication and Whether an Alternative Imaging Modality Can Be Used

Review the requisition, review pertinent history, and assess the suitability of the fluoroscopic examination to the clinical situation. Foreknowledge of the clinical question to be answered is important in planning the most efficient examination, with the highest diagnostic yield at the lowest possible radiation dose. For example, if an upper gastrointestinal tract fluoroscopic examination is requested in a patient with abdominal distention and multiple dilated loops of bowel on radiography, a contrast enema would be a more appropriate examination, and such a request should result in a telephone call and further discussion with the referring physician. Similarly, a small-bowel follow-through has specific indications and is not a typically necessary adjunct to the upper gastrointestinal tract examination in many circumstances.

Availability of the radiologist for consultation, referral of our clinical colleagues to informative Websites, such as the Image Gently and ACR Appropriateness Criteria and Guidelines, and teaching conferences and rounds with the clinicians can go a long way toward ensuring that the correct examination is done at the right time each and every time [24].

There are multiple instances of appropriate alternatives to fluoroscopic examinations. For example, a child in the appropriate age group with nonbilious vomiting can be referred for sonography to assess for pyloric stenosis, rather than for an upper gastrointestinal tract fluoroscopic examination. Sonography in the appropriate hands is highly effective and avoids fluoroscopy, which can be protracted in a patient with gastric outlet obstruction [9, 10]. MR enterography can be used to evaluate patients with inflammatory bowel disease in certain cases, particularly when perianal or perirectal disease is a major concern [25, 26]. Similarly, in patients

with clinical or radiographic concerns of intussusception, ultrasound instead of contrast enema as the initial diagnostic tool avoids the radiation of an unnecessary enema in the approximately 50% of patients who do not have intussusception, may detect lead points, may detect other conditions such as colitis, in which enema would be contraindicated [27–33], and may also decrease the radiation during therapeutic enema because the presence and location of the intussusception are already known.

Pause to Properly Plan and Prepare for the Study

In reviewing the medical and surgical history, identify whether any unusual anatomy will be encountered. Before performing a VCUG, review the previous ultrasound to determine whether you expect posterior urethral valves or complications of a duplex system. Such preparation can save valuable fluoroscopy time during the examination and will obviate a potential requirement for repeat examination. Similarly, in a patient with bilious vomiting presenting for upper gastrointestinal tract fluoroscopic examination, spending a great deal of time in evaluation of the esophagus and swallowing mechanism would be counterproductive and potentially lead to loss of ability to delineate the duodenojejunal junction. It is also important, in preparation for the procedure, to assess the child and determine the best way to ensure the child's cooperation whenever possible (Fig. 2), as well as the potential need for immobilization during the procedure. The approach to each child will differ depending on the patient's age and the type of procedure to be performed.

In postmenstrual patients, screening for pregnancy should be performed. Institutional policy should be followed in the documen-

tation of pregnancy status in minors before a fluoroscopic examination. The ACR Practice Guideline on imaging the pregnant patient is a useful reference [17].

Pulse the X-Ray Beam at Lowest Frame Rate Needed for Each Portion of the Examination

In the pulsed mode, the x-ray beam is switched on and off once during each fluoroscopic image; the pulse width, or duration, of each fluoroscopic image is shorter than the 33 milliseconds used in continuous fluoroscopy and typically ranges from 3 to 20 milliseconds; such shorter pulse widths (Fig. 3) reduce motion unsharpness of moving objects in the fluoroscopic image [34, 35] (Fig. 4). The manufacturer should use technology that allows rapid starting and stopping of each pulse to avoid the tails (i.e., the "ramp-and-trail effect"), which effectively increase the pulse width with an associated decrease in motion sharpness and increase in patient dose (Fig. 5).

Simply pulsing the x-ray beam improves image quality but does not necessarily result in dose reduction to the patient. Although the pulse width during pulsed fluoroscopy is significantly shorter than 33 milliseconds during continuous fluoroscopy, the tube current that controls the number of x-rays produced per unit of time is increased so that the number of x-rays used during a pulsed fluoroscopy frame is the same as that used during a continuous fluoroscopy frame. This is required to maintain the necessary signal-to-noise level in the image that is required to maintain satisfactory image quality. The opportunity for patient dose savings with pulsed fluoroscopy comes instead from significantly reducing the number of fluoroscopic images produced per second, typical-
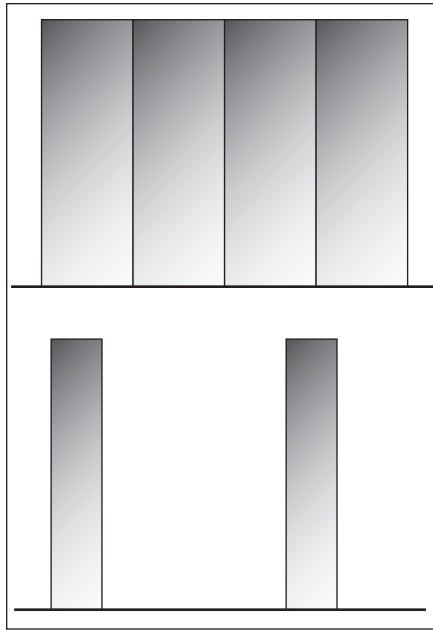
Fig. 3—Comparison of continuous fluoroscopy at pulse width of 33 ms (*top*), with pulsed fluoroscopy at pulse width of 20 ms (*bottom*).

Continuous Fluoroscopy　　　　**15 Frames/s**

Fig. 4—Image on left is still image obtained during motion while on continuous fluoroscopy; image on right was similar image capture, with fluoroscope set on pulsed fluoroscopy at 15 frames/s.

ly 1–6 images per second, compared with the 30 images per second from continuous fluoroscopy [22, 23, 36, 37].

Because the pulse rate can be changed by the operator during the examination, the appropriate pulse rate must be used during specific examinations and specific portions of examinations. For example, during intussusception reduction, the lowest pulse rate can be used while monitoring progress of the reduction; during evaluation of diaphragmatic motion, a higher pulse rate may be required, which can then be lowered to continue with an upper gastrointestinal tract examination on the same patient.

The ability to pulse the beam during fluoroscopy can significantly reduce the dose during the examination, as explained elsewhere [34–36, 38, 39]. Properly configured and applied pulsed fluoroscopy is considered to have "the greatest potential for maintaining radiation exposure at low levels" [40]. However, one must not overdo a good thing. Thirty images per second are required to be flicker-free to the human eye; for an image to be flicker-free requires that the same image be duplicated and presented on display to the extent necessary such that 30 images are displayed per second, even if only one to six different images are created per second [28]. Although duplicating images eliminates flicker, pulse rates less than 6 im-
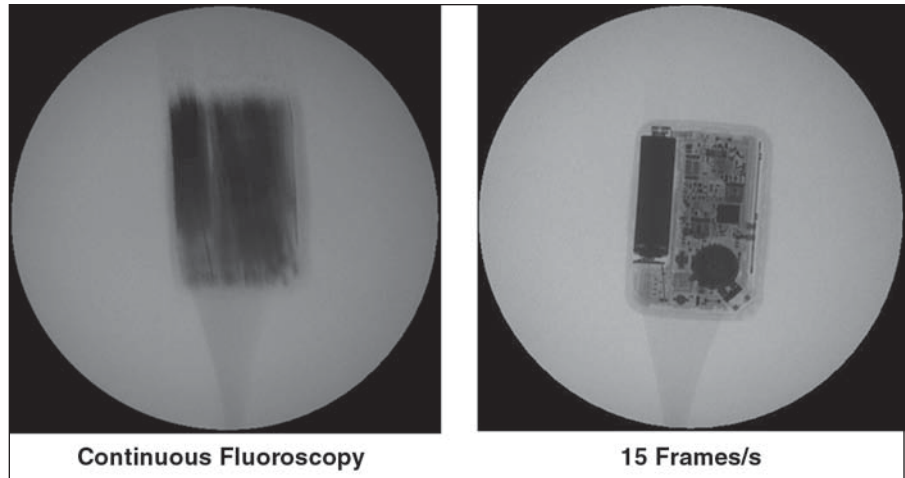
ages per second diminish temporal resolution, causing any rapidly moving objects in the field of view to move across the image in jerky as opposed to smooth motion. Also, enough x-rays must be used for each fluoroscopic frame to adequately control the level of noise in the image.

Remove the Antiscatter Grid When Imaging Small Patients

The antiscatter grid is necessary for patients over 40–50 pounds (18–23 kg; 4–5 years old) to attenuate scattered radiation, which improves contrast in the image. Using a 15-cm acrylic phantom that models a 50-lb

(23-kg) child, investigators found visualization of more low-contrast test objects with the grid in, compared with less of the same test objects with the grid out [35]. The antiscatter grid should be removed, however, for smaller patients because their smaller bodies do not generate enough scatter to significantly degrade the image, particularly when visualizing high-contrast objects, such as barium or iodinated media. When this small amount of scattered radiation is not removed because the grid is removed from the beam, the scatter contributes to the required dose at the image receptor, reducing the number of primary x-rays required (patient radiation dose) by a
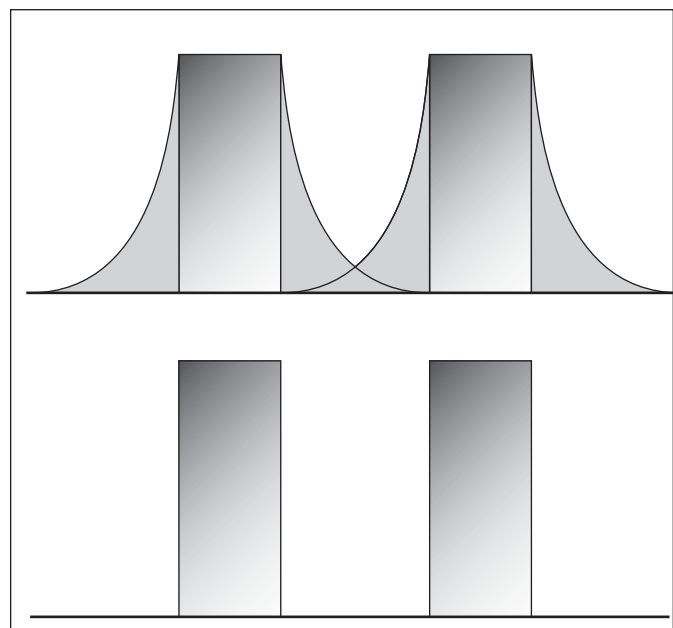

Fig. 5—Ramp-and-trail effect refers to increase and decrease in beam energy in each pulse when on-off switch occurs at generator, due to capacitance of cable from generator to x-ray tube (*top*). Elimination of ramp-and-trail effect results in decreased radiation dose, and sharper image (*bottom*). Adapted and reproduced with permission from Philips Healthcare.

factor of two or more [35, 41]. Figure 6 illustrates that changing from continuous fluoroscopy to a still relatively high pulse rate of 7.5 frames per second and removing the antiscatter grid can result in an 87% reduction in entrance dose in a 1-year-old child [42]. Therefore, when choosing equipment to be used for pediatric fluoroscopy, it is important that the antiscatter grid be easily removable for examinations on the appropriate patients.

Use the Largest Fields of View (Smallest Electronic Magnification) Possible

In pediatric imaging in particular, it is tempting to use electronic magnification to better visualize smaller structures. This is achieved by decreasing the field of view, which increases sharpness of the small structures and enlarges these structures on the display. However, this comes at a cost of increased radiation dose to the patient. On some equipment less than 5 years since manufacture, the patient dose doubles when the field of view is halved [37]. On older equipment, the dose typically quadruples when the field of view is halved. For example, a reduction of the field of view from 28 to 20 cm ($[28/20]^2$) increases the dose by nearly 100% [41, 43].

Collimate to the Area of Interest

Collimation is the reduction of the area of the x-ray beam to the patient's anatomy that requires visualization. Although collimation does not reduce the radiation dose to the patient's tissues irradiated by the x-ray primary beam, it is important in reducing the risk to ionizing radiation to both patient and staff in the procedure room. An x-ray beam that includes a smaller area of the patient produces less scatter radiation to the staff within the room. This smaller area x-ray beam also irradiates a smaller volume of the patient's tissues that significantly reduces the patient's risk.

In pediatrics, collimation and maintaining the patient positioning can be challenging because patient motion may place the area of interest outside the collimated field of view. Patient preparation and adequate immobilization are important to allow collimation to be effective; immobilization may be accomplished in various ways, which are age- and often patient-specific, and may include swaddling and use of available commercial devices, and are enhanced by staff experienced in working with children. Initial alignment of the patient's anatomy of interest within the area of the x-ray beam should be completed visual-

Fig. 6—Differences in measured entrance dose in phantoms with size simulating 1-, 3-, and 10-year-old patients, as function of pulse rate and antiscatter grid. For example, in 10-year-old patient, removal of grid and change from continuous fluoroscopy (*diamonds*) to pulse rate of 7.5 frames/s (*crosses*) results in 80% dose reduction; in 1-year-old patient, same changes result in 87% dose reduction. Squares indicate 30 frames/s; triangles indicate 15 frames/s. (Reprinted with permission from [42])
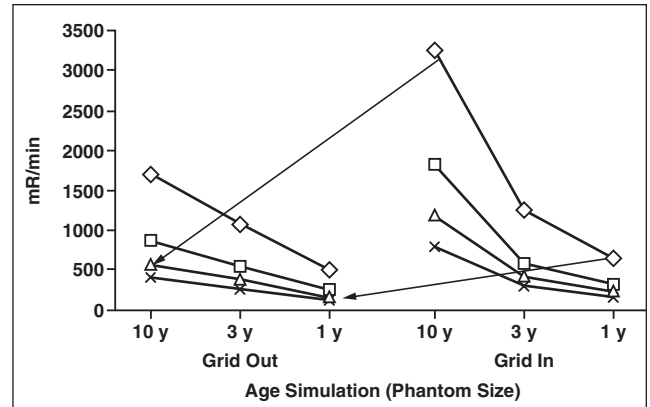
ly, not under fluoroscopic guidance with the x-ray beam on. Adjustment of the collimators on older fluoroscopes necessitates the use of fluoroscopy. However, newer imaging equipment may provide a graphical illustration of the collimator's blade's position superimposed on a "fluoro-hold" image on the monitor, obviating the use of fluoroscopy in the collimation process. Another feature in some equipment models is "preset" collimator blade positions, which can be preset for a specific study to be performed, (e.g., esophagram) before the beginning of the examination.

Finally, too much collimation—that is, collimated x-ray field areas less than half the area of the field of view displayed on the monitor—may increase the patient radiation dose. The fluoroscope measures the radiation dose reaching the image receptor by sampling typically 30–50% of the area of the field of view, depending on the configuration of the unit. If the collimator blades enter the sampled area, the correct dose rate to the image receptor appears to be too low because some of the detector area does not receive radiation. This causes the fluoroscope to increase the kilovoltage or tube current to compensate for this loss, which needlessly elevates the patient radiation dose rate. This can be avoided on units used for pediatric imaging by reducing the sampling area to no more than 30% of the field of view.

Position Patient Correctly Relative to Focal Spot and Image Receptor

The distance of the patient from the focal spot and from the entrance plane of the image receptor significantly affects the radiation dose rate the patient receives during the fluoroscopic examination.

First, the patient's skin dose rate decreases by the inverse square law with respect to the increase in distance between the patient

and the focal spot—that is, the source-skin distance (SSD). For example, if the SSD is increased from 51 to 65 cm, the patient's entrance dose rate decreases to 62% of its original value. At least one major manufacturer provides an option that allows the operator to select an SSD of either 51 or 65 cm from the tabletop [37]. The operator should always select the 65-cm SSD when imaging children, if this option is available.

Second, the dose rate to the patient's skin decreases as the source–to–image receptor distance (i.e., the distance from the focal spot to the entrance plane of the image receptor) decreases, again according to the inverse square law. The operator can reduce the distance between the entrance plane of the image receptor and the exit plane of the patient by lowering the image receptor tower closer to the patient. Decreasing of this distance, or air gap, decreases the source–to–image receptor distance and the dose to the patient. For example, if the SSD is 51 cm, the patient is 15 cm in diameter, and the air gap is decreased from 10 to 1 cm, the entrance dose to the patient's skin decreases to 78% ($[67/76]^2$) of its original value [23, 43].

Use Last Image Hold and Fluoroscopy Store

Last image hold, or "fluoro save," is the display of the last fluoroscopic image on the display monitor when the fluoroscopy pedal or hand switch is released to terminate the fluoroscopic run. By use of this function, the radiologist can spend as much time as necessary studying the anatomy and other findings, without incurring additional radiation dose to the patient. When the operator uses this capability of the fluoroscope properly, the patient is spared significant additional dose.

Fluoroscopy store, also known as "Fluoro Grab," allows the operator to permanently

store the fluoroscopic image on the monitor in the memory of the fluoroscope; this step permanently records the image. Because the radiation dose to the image receptor for a fluoroscopic image is more than 10 times lower than the radiation dose used for a recorded digital image [37], the stored fluoroscopic image will contain more than three times the noise of the recorded digital image. If this level of image quality is adequate, the additional recorded digital images and their relatively high dose to the patient can be avoided.

In general, recorded digital images are necessary when greater detail, such as mucosal features, visualization of small contrast leak, or depiction of features such as small structures, are needed (Fig. 7). In children, whose capacity for cooperation is often limited, being able to store fluoroscopic images can make the difference between a successful and an unsuccessful examination; this information could obviate repetition of the examination, with potential for even greater dose savings.

The ability to store fluoroscopic images acquired at no additional radiation dose allows documentation of fluoroscopic temporal details not previously possible. For example, esophageal peristalsis can be documented, not just described or recalled. The progress of the head of the contrast column in a complicated contrast enema can be recorded for later assessment of the significance of the course and anatomy of the colon. The progress of intussusception reduction can be followed, with more detailed documentation of successful reduction. The course of the duodenum can be better delineated by storing sequential images of the course of the contrast through the sweep.

Physicist Input for Fluoroscope Optimization and Maintenance

Radiologists should consult with the medical imaging physicists at their institution and review the dose-saving features of the fluoroscopic imagers in their departments. The imaging physicist should be able to explain the different design features and controls of the fluoroscope and how each can be managed by the operator to control pediatric patient dose during the production of good quality images. Proper configuration of pulsed fluoroscopy, the number of frames per second, pulse width, dose per pulse, spatial beam filtering, and dose monitoring must be understood by the operator to allow the operator to properly manage the patient's radiation dose [40].
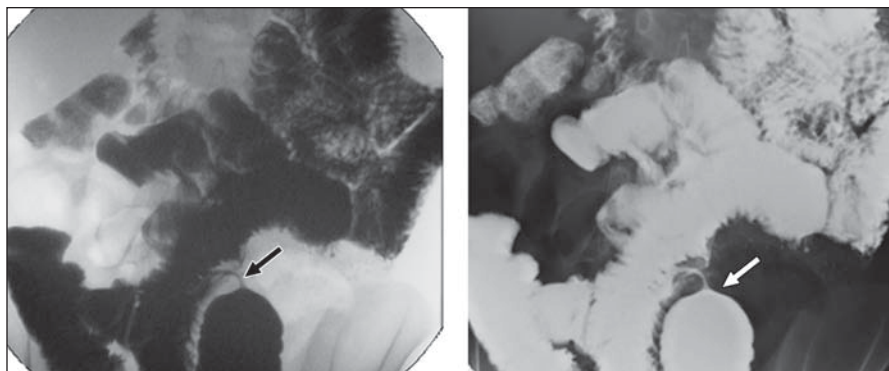

Fig. 7—Fluoro grab image (*left*) and radiographic exposure (*right*) of similar field of view in patient with bowel stricture (*arrows*). Note overall similar findings, but with improved mucosal detail in radiographic exposure.

The imaging physicist should conduct annual performance checks on fluoroscopes and oversee a periodic quality assurance program to ensure that the radiation output is properly controlled by the fluoroscope. The radiation output rates may be measured more than once a year if the system undergoes repairs that may affect radiation characteristics of the system. It is strongly recommended that institutions, particularly pediatric facilities, that do not have a medical physicist on staff, contract a qualified medical physicist for the inspections of their medical imaging systems. Qualified medical physicists are trained (graduates of academic and residency training programs accredited by the Commission on Academic Medical Physics Educational Programs) and American Board of Radiology–certified or equivalent diagnostic medical physicists.

The imaging physicist should annually verify the accuracy of displayed radiation doses by the system so this information can be used to estimate entrance skin dose (to quantify the possibility or severity of deterministic effects) or the effective dose to have an appreciation for the stochastic risks associated with the given radiologic procedure. Calibration techniques of the entrance dose to the image receptor of the fluoroscope and other setup calibrations necessary for pediatric imaging that may be useful to the imaging physicist have been discussed elsewhere [22, 23, 37]. Currently, national accrediting bodies have not developed accreditation programs for fluoroscopes.

Conclusion

The espousal of the ALARA concept by radiologists, radiologic technologists, and medical imaging physicists has resulted in innovative and improved techniques to lower radiation dose when performing fluoroscopy in pediatric patients. When implemented in daily practice, these practical steps of the Pause and Pulse campaign sponsored by The Alliance for Radiation Safety in Pediatric Imaging can significantly lower radiation dose while maintaining and, in some cases, improving diagnostic image quality during pediatric fluoroscopy.

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