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ALARA

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Practice of ALARA in the pediatric interventional suite

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Abstract As interventional procedures have become progressively more sophisticated and lengthy, the potential for high patient radiation dose has increased. Staff exposure arises from patient scatter, so steps to minimize patient dose will in turn reduce operator and staff dose. The practice of ALARA in an interventional radiology (IR) suite, therefore, requires careful attention to technical detail in order to reduce patient dose. The choice of imaging modality should minimize radiation when and where possible. In this paper practical steps are outlined to reduce patient dose. Further details are included that specifically reduce operator exposure. Challenges unique to pediatric intervention are reviewed. Reference is made to experience from modern pediatric interventional suites. Given the potential for high exposures, the practice of ALARA is a team responsibility. Various measures are outlined for consideration when implementing a quality assurance (QA) program for an IR service.

Keywords Interventional radiology · Radiation dose

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Introduction

The implementation of ALARA in an interventional radiology (IR) setting presents challenges over and above its implementation in a standard radiography room. Minimizing radiation exposure requires a two-pronged approach, as it is necessary to optimize the radiation dose for the patient as well as the IR staff, whose dose is cumulative over many procedures and years [1–5]. Patient and operator doses are linked, with staff dose being proportional to the scatter from patient dose. Therefore, by monitoring and reducing patient dose, scatter radiation is reduced and the staff dose is decreased.

Pediatric interventionalists take care of patients from tiny premature infants to adult-size teenagers. This challenge requires creative approaches to achieve ALARA. The aim of this paper is to (1) describe practical ways that the members of a pediatric IR team can implement ALARA focusing on patient, operator and staff, (2) outline some known doses recorded in pediatric IR settings, and (3) suggest quality assurance (QA) measures to encourage adherence to ALARA principles.

Unique features of pediatric interventional radiology

Pediatric IR has unique issues related to patient size. Patient size varies widely from as small as 450 g to in excess of 100 kg, with the age and weight distribution of patients in a tertiary center usually skewed toward the lower range. To gain access to the small child, it is frequently necessary for the interventionalist to come close to or on occasion enter the beam. The operator's hands might be directly in or immediately adjacent to the beam during the normal course of a procedure such as a central line or abscess drainage, or they might enter the beam urgently when an unexpected event or complication occurs.

Another unique feature in pediatric IR, and a potential cause of increased radiation exposure, is the large size of image intensifiers (II) relative to infant size. In neonates and small children the II will completely cover the patient, thereby bringing the interventionalist close to the radiation source and potentially exposing a large portion of the child's body to radiation. There is also a greater need to use magnification in children. This results in a severalfold increase in patient radiation dose during fluoroscopy and image acquisition. Furthermore, children are more sensitive to radiation than adults, especially at younger ages [6]. Because children live many years after their radiation exposure, there is a greater opportunity for the deleterious effects of the radiation to become manifest.

Reducing dose to the patient in the interventional suite

There are two fundamental principles that apply to pediatric intervention in the context of ALARA: first, a procedure should only be performed when absolutely indicated; second, when a procedure is performed one should minimize or avoid radiation whenever possible (e.g., use US guidance rather than fluoroscopy or CT, use last-image hold, etc.). When radiation is necessary during an indicated procedure, the examination should be performed while practicing ALARA concepts. Complex procedures such as angiography with embolization or TIPS have been shown to reach high effective and skin doses in both adults and children, frequently exceeding 2 Gy. Procedures with this total dose are associated with deterministic adverse effects (Table 1) [7–14]. Therefore, education and awareness of radiation and its deterministic and stochastic effects are essential knowledge for anyone practicing image-guided procedures.

It is clearly important to institute all available measures to protect the patient and interventional worker during diagnostic and interventional procedures; the challenge is to develop the methodology and materials to do so in the pediatric interventional suite [1, 15].

Fluoroscopy

One strategy for minimizing the radiation dose during fluoroscopy is to optimize positioning by keeping the fluoroscopy table as far from the source as possible (to reduce skin entry dose), and yet close to the II (to maximize image capture). This can be an issue if the operator prefers to sit during a certain procedure (e.g., neonatal PICC insertion). Compromise can be achieved by altering the table level during the procedure, such as sitting for the US component of the procedure and standing for the fluoroscopy portion. A solution to minimizing scatter radiation emanating from below the table is to install a lead drape like that used around the II. If lead is used for patient protection, it needs to be strategically placed under the patient because of the under table tube position. This can be a challenge and might not be appropriate when following a catheter dynamically. Lead wraps around the patient are considered counterproductive because of the associated increase in scatter. Another consideration is the use of a new generation of sterile drapes impregnated with bismuth or other materials. These drapes can markedly reduce both patient and operator dose. They have been shown to reduce operator hand/wrist doses by up to 90% and can also be positioned to protect the interventionalist from the waist down [16].

There are several ways that interventionalists can minimize radiation during a procedure. Fluoroscopy should only be used to evaluate a moving target or structure, and fluoroscopy time should be limited. An important dose-minimizing strategy is pulse fluoroscopy. In many situations 3.5 pulses/s or 7.5 pulses/s provide adequate guidance and monitoring of a procedure. Still images for review of findings should be studied using last-image hold and not on live fluoroscopy. The II should be positioned over the relevant anatomy before fluoroscopy is commenced rather than panning during fluoroscopy. Tight collimation to the relevant anatomical area is important as the interventionalist follows the wire, catheter, or other equipment. Magnification should be kept to a minimum, increasing only where needed and dropping back to non-magnified fluoroscopy whenever possible. Attention should be given to angulating the beam away from radiosensitive areas (eyes, thyroid, breast, gonads) and collimating such areas out of the field. The technologists play an important role in warning against any unnecessary or inadvertent fluoroscopy. Alarm bells for fluoroscopy beyond a certain time (e.g., 5-minute warning bell) or live readouts in the room are useful reminders to limit fluoroscopy time.

Table 1 Potential clinical effects of radiation exposure

Skin effects	Threshold dose (Gy)	Time of onset
Early transient erythema	2	2–24 h
Main erythema reaction	6	1.5 weeks
Temporary depilation	3	3 weeks
Permanent depilation	7	3 weeks
Dermal necrosis	>12	>52 weeks
Eye effects		
Lens opacity	>1–2	>5 years
Cataract	>5	>5 years

Image acquisition

Image acquisition by digital angiography (DA) or digital subtraction angiography (DSA) accounts for the largest radiation dose during many interventional procedures [8]. Therefore, each run should be necessary for diagnosis or to assess outcome after a procedure, planned to the fewest number of frames per second and obtained on the lowest magnification needed (remembering magnification by postprocessing is possible). It is important to be aware of proximity of the skin to the X-ray source in the lateral or oblique view, as it might become closer than recommended or even permitted in the PA view, resulting in increased patient skin dose and on rare occasion skin burns. After the C-arm is put in the lateral position, the patient should be distanced from the source and approximated to the II. Field overlap in different runs should be minimized to reduce unnecessary duplication and to avoid excess focal skin dose. Tight collimation should always be practiced to include only the relevant anatomy.

Reducing dose to the staff in the interventional suite

Although all members of the pediatric interventional team should be mindful of the radiation protection afforded by the inverse square law, the operator is usually most at risk, with his/her body and hands close to and sometimes in the beam. It is important to measure staff dose with one badge under the apron and a second over the apron at the collar [17]. The use of radiation ring badges is also important, with the highest doses generally recorded on the ring and fifth fingers, tips of fingers or left hypothenar eminence, depending on the type of procedure, the position of the operator's hand, operator technique and fluoroscopy time [18–21]. Slight angulation of the beam off the hands, strict collimation, and careful attention to finger positioning can aid in reducing operator exposure. Awareness of room geometry with respect to the X-ray source during a case is imperative. The operator should stand on the side of the II and team members should step back and use the inverse square law.

Lead aprons (0.5-mm equivalent) should be well-fitted (down to the knees), with arm wings to protect the axillary tail of the breast for female workers, a snug thyroid collar, and a full front and back apron for those circulating in the room. Lead glasses with side shields reduce radiation exposure to the eyes of the operator by 90% and also protect staff from biohazardous fluid splashes. Prescription and non-prescription (even bifocal) lead glasses are available and should be encouraged [22]. Radioprotective gloves (using lead and other ingredients) can reduce scatter by 40%–50% but are counterproductive if placed inadvertently in the beam. Studies have shown that even though they are slightly thicker than regular sterile gloves, these gloves do not increase fluoroscopy time or procedure time [21]. They are useful for protection of anesthesiologists' hands, which might be exposed to scatter while using a mask to ventilate a patient. Mobile lead shields for circulating team members and anesthesia personnel are also useful.

Foot and leg doses for the operator are increasingly receiving attention as interventional procedures become longer and more complex. Lead table skirts or newer compound material drapes reduce scatter to legs and ankles by almost 20-fold [23]. Overhead ceiling mounted shields assist in reducing head and neck doses, and though they can be awkward during times of needle, catheter or wire manipulation, they are useful during acquisitions (DA, DSA) because they can reduce cervical radiation doses by up to 15-fold [23, 24]. In an adult study, the use of a power injector instead of hand injecting contrast material was shown to be the single most effective way to reduce operator dose during angiography [25]. Whenever possible, the operator should use a power injector and step back away from the II and/or behind a mobile shield during contrast injections. When manual injection is necessary, maximizing the distance from the source as much as catheter length will permit is important to minimize radiation dose [25].

Dosimetry studies in a modern pediatric IR suite

Although recent articles have described radiation exposure in children undergoing cardiac catheterization and neurointerventional procedures, there have been no published dosimetry studies specifically evaluating pediatric IR [7–9]. However, this last year physicists and radiologists from Duke University and Cincinnati Children's Hospital Medical Center performed a dosimetry evaluation of a modern pediatric IR suite, calculating effective dose (ED) and specific organ dose of digital pulsed angiography and fluoroscopy (Frush D.P., unpublished data). The following data are in various forms of analysis for separate publication.

All studies were performed on a Philips Integris Allura biplane angiointerventional system. High-sensitivity diagnostic MOSFET and AutoSensor probes (Thompson-Nielsen, Ottawa, Canada) were placed in a 5-year-old anthropomorphic phantom (CIRS, Norfolk, Va.). Calibration was performed with a RadCal ion chamber and monitor (Monrovia, Calif.).

Typical single-plane DSA abdominal aortography protocols were performed using a 9-inch and 12-inch II in AP, lateral, and oblique projections. Cerebral angiography was evaluated with a 9-inch II in AP/lateral biplane and a 9-inch II in lateral and oblique single plane. Abdominal and cerebral fluoroscopy was evaluated in AP and lateral projections at the three commercially available settings (low, normal, and high). Fluoroscopy was performed with no collimation, simulating a worst-case scenario. Using MOSFET probes appropriately placed in the anthropomorphic phantom it was possible to evaluate specific organ dose and subsequently estimate ED.

ED from abdominal aortography ranged from about 0.5 mSv to 2.5 mSv, depending on II size and projection. ED from cerebral angiography was much less (as expected secondary to decreased patient mass). Typical abdominal fluoroscopy was about 1 mSv/min.

A few salient points can be drawn from this preliminary data and applied to clinical practice. First, abdominal angiography acquired in the lateral projection resulted in approximately four times the ED when compared to AP. Second, ED increased in the 9-inch mode as compared to the 12-inch mode. This occurs because a built-in algorithm drives tube current (mA) up as II size decreases from 12 inches to 9 inches. In other words, ED increases with magnification. Third, it is important to note that during fluoroscopy ED increases nearly threefold when moving from low- to high-dose settings.

Other work evaluating skin entry doses in children during neuroangiography has shown that therapeutic endeavors such as embolizations are associated with greater radiation exposure than diagnostic angiography and that the greatest proportion of the dose results from DA and DSA. The frontal projection incurs twice the dose of the lateral. In addition, in the worst-case scenario high doses, >1.6 Gy, occur in these children [8].

These studies show that it is possible to approximate patient ED and organ-specific doses through use of a phantom and MOSFET sensors. Similar dosimetry studies should be performed for CTA and conventional fluoroscopy so that relative dose comparisons can be made. Emerging technologies such as three-dimensional rotational angiography, flat detector systems, and CT-like imaging capabilities should be embraced, but only with concurrent dosimetry evaluations. In addition, the development of settings tailored to optimize image quality and minimize radiation dose specifically in the pediatric patient should be a priority.

Quality assurance

The goal of performing pediatric IR under ALARA guidelines is to achieve clinical success using the least amount of radiation consistent with adequate image guidance [26]. However, the reality is that many IR procedures require high-quality images, long fluoroscopy time, or both. In addition, there are no consensus guidelines to regulate radiation use; thus practices vary from institution to institution and even within an institution.

Therefore, each institution has a responsibility to address the issue of radiation dose in pediatric IR. There are many evaluation pathways that can be utilized, and each institution can tailor its approach to best meet its needs. However, certain common principles are worth noting. First, there needs to be a constant awareness of radiation exposure by the operator and team and acknowledgement of its importance. All team members should undergo comprehensive training in radiation biology, physics, and safety. This is especially important as the use of radiation-emitting equipment by personnel without formal radiation training increases. Some centers implement a compulsory credentialing program for use of radiation, while others have optional educational training. In the future, these credentialing courses could be standardized on a local, regional or national basis so that they comply with a set of medical and legal requirements.

The Society for Interventional Radiology developed a position statement encouraging the recording of patient radiation doses in whatever format available (DAP, PEMNET, DTCI, fluoro time) for the patient's record [27]. Although there is currently no accurate, meaningful measure of radiation dose calculated at the end of each examination, it is important that fluoroscopy time and any available radiation measure are recorded. Ideally, any procedure that involves radiation should have a dose estimate calculated and entered into the patient's record. Children who have multiple procedures should have their cumulative dose history documented in the medical record (DAP, Peak Skin Dose, CTDI, cumulative dose).

The physician–patient relationship should reflect the importance of optimizing radiation dose, as well. Prior to a procedure, patients should be asked about their history of radiologic procedures. As the interventionalist obtains consent for a procedure, it would be useful to include comments concerning the use, risks and alternatives of radiation. This discussion should include the short and long-term risks of radiation, as well as benefits of the procedure. An educational package for parents/patients regarding dose and its risks is an additional worthwhile measure. After the procedure, a 30-day follow-up visit should be scheduled if the radiation skin dose was 2 Gy or more or the cumulative dose 3 Gy or more. A call-back system for patients whose doses exceed a certain limit might also be used.

The medical physicist plays a key role in optimizing radiation exposure. Physicists who specialize in pediatrics are particularly insightful to the challenges faced in pediatric IR. The development of the lowest possible dose begins with the purchase of equipment and continues with maintenance protocols and oversight. The medical physicist can often work effectively with the manufacturer to tailor equipment to the pediatric setting and maintain this level of functioning by incorporating dose-reduction technologies and dose-measurement devices into the equipment.

Roles for the physicist might include the following: (1) help develop and approve equipment specifications for purchase; (2) make sure that the equipment produces diagnostic images at the lowest radiation dose; (3) make sure that dosimetry is accurately measured, calculated, and recorded; (4) help train interventionalists and other personnel in radiation safety and techniques to minimize dose to patient and staff while maintaining high image quality; (5) participate in the development and implementation of IR protocols, QA program, record-keeping and follow-up in children who receive deterministic doses.

Finally, there should be an ongoing effort to improve radiation safety and operator performance. A database of all patients, including procedural records and dose information, should be maintained. Procedural outcomes (including patient radiation dose) for each operator should be audited, and any information gained from those audits should be shared with the operators and additional training provided as needed. In addition, all staff should receive annual radiation safety education.

Radiation safety in the pediatric interventional suite is a challenge, but significant improvements can be implemented if it is made a priority. Close cooperation among interventional radiologists, physicists, and manufacturers is essential to ensure that ALARA concepts are integrated into clinical practice and future technologies. Our patients certainly deserve our best efforts in this area.

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