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Radiation Protection in Pediatric Imaging

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Radiation Protection In Pediatric Imaging

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The effects of medical radiation exposure in childhood can last a lifetime. As more American children are exposed to repeated diagnostic imaging examinations, concerns have been raised about the potential harm from early medical irradiation. Radiologic technologists play a central role in radiation protection of children. This Directed Reading reviews the biological effects and risks of ionizing radiation in children and protection practices that can minimize medical radiation dose to the pediatric population.

This ASRT Directed Reading Classic was originally published in Radiologic Technology, *May/June, 2011, Volume 82/Number 5.*

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

- Identify the mechanisms of potential biological harm to children from ionizing radiation.
- Compare and contrast various paradigms of radiation risk.
- Discuss the principles of radiation protection.
- Explain the roles of image optimization, immobilization and shielding in pediatric radiation protection.
- Describe the role of distance, duration and protection in implementing the ALARA principle.

Children are more vulnerable than adults to the harmful biologic effects of radiation exposure.[1,2] Compounding that vulnerability are the facts that cancer risk from medical irradiation accumulates across the lifespan and that radiation-related cancers may involve latency periods lasting years or decades after exposure. Both factors leave children far more likely to develop radiation-related malignancies within their lifetimes.[3]

The frequency of diagnostic imaging examinations for patients of all ages in the United States has increased by 10-fold since 1950.[3] Recent years have seen a particularly dramatic increase in high radiation doses for pediatric computed tomography (CT) applications.[3,4] According to the World Health Organization International Conference on Children's Health and the Environment, the use of CT scanning has been increasing in the United States, Europe and Asia.[3,5]

In 2015, 75 to 80 million CT scans were performed in the United States.[6,7] According to the National Cancer Institute, 5 to 9 million CT scans are performed on American children each year, which is an 8-fold increase since 1980.[8] The American Academy of Pediatrics estimates that up to 33% of U.S. pediatric scans are performed on children younger than 10 years of age.[9]

Radiation doses from chest CT scans are up to 190 times higher than those delivered for a routine chest radiograph. A 2007 study suggested that up to 2% of cancers among individuals of all ages in the United States may be attributable to CT scans,[10] and recent population-based studies indicate that pediatric CT examinations also increase the risk of developing cancer.[11,12] According to a 2009 study at Baylor University Medical Center, the average effective radiation dose from a CT head scan is 32 times higher than that of a head radiograph, which is equivalent to 65 chest radiographs. Abdominal CT scans that include the pelvis involve radiation doses 5 times higher than radiographs equivalent to 2280 chest radiographs.[13]

Multidetector CT (MDCT) scanners are increasingly available and widely used, which further compounds the challenge of radiation dose control. Radiation doses from MDCT scans were up to 50% higher than those from single-slice CT scanners in the 1990s, but technological improvements in the 2000s have addressed issues with MDCT and dose.

It is not surprising that many recent studies of pediatric radiation protection have focused on CT scans rather than on traditional radiography.[14] Balancing the need for high-quality medical images of suspected pathologies with the need to minimize children's exposure to ionizing radiation is the central challenge of pediatric imaging. But pediatric exposure to medical ionizing radiation is rarely monitored or restricted, which complicates the tracking of patients' cumulative doses.[15]

Furthermore, despite a century of methods development in dosimetry, shielding and radiation epidemiology, adequate understanding of contemporary radiation dose control issues is far from widespread among referring clinicians. It is the responsibility of radiologists and diagnostic imaging teams to convey these issues to clinicians, patients and their caregivers.

Radiation Exposure Awareness

Epidemiological research has shown occupational risk to radiologists and registered radiologic technologists (R.T.s) from cumulative exposures to diagnostic radiation. This research sparked additional protection innovations, from the widespread use of lead gloves and aprons to dose tracking with personal monitoring devices. But with the increasing availability and routine use of imaging modalities including high-dose CT scans, the cumulative effect of patient dose has reemerged as a concern for patients, particularly children.

For most radiologic imaging examinations, even among children, the potential clinical benefits almost certainly exceed the radiation risk from a given examination. However, high-dose imaging has become more common, and safety lapses and imaging errors lead to repeat examinations and unnecessary radiation exposure to patients and health care workers. Particularly in the context of increasing radiologic imaging across the lifespan and higher average doses associated with the frequent use of CT scanning, it is imperative to minimize children's exposure to unnecessary irradiation. Despite growing concerns over the exposure from CT scans, recent studies show there is limited awareness and discussion among both patients and physicians regarding radiation dose and the associated risk of cancer.[16-18]

Troubling gaps exist in the implementation of medical radiation protection programs. For example, inconsistently implemented quality control (QC) programs can contribute to dramatic variation in the radiation doses delivered by different imaging equipment. The radiation doses delivered during the same CT procedure can vary up to 13-fold among patients at the same institution.[19]

Also, risks regarding the radiation doses associated with imaging examinations are not well understood among health care workers, particularly referring pediatricians and clinicians. Surveys reveal frequent lapses in compliance with radiation safety protocols and procedures, and many referring clinicians are unfamiliar with radiation risks and radiation protection practices.[15,20-22] A German analysis among 137 referring pediatricians assessing their understanding of radiation doses from traditional chest radiographs and CT scans revealed that only 39% correctly estimated the effective dose of an average newborn chest radiograph (0.01-0.1 mSv), and 54% underestimated the effective radiation dose of an infant chest CT scan (10-100 mSv).[14]

The majority of interventional radiology staff underestimate the radiation doses of common diagnostic procedures, according to a 3-hospital study published in 2007.[23] Emergency department physicians rarely receive warnings about the increased radiation dose delivered by CT vs radiographic imaging, and therefore they rarely communicate the relative risks and benefits of CT scanning to patients or their parents.[24]

More troubling is the fact that only 15% of pediatricians completing the survey from the German analysis previously mentioned were familiar with the "as low as reasonably achievable" (ALARA) principle of radiation dose minimization — a cornerstone of contemporary radiation protection.[14] A 2010 systematic review of data from 14 such studies similarly showed important gaps in clinicians' knowledge of CT radiation doses and health risks, with "only a minority" of clinicians being deemed "well informed" about most of the published studies reviewed.[25]

Awareness regarding alternatives to irradiating imaging modalities also is inadequate. One 2004 study that surveyed physicians about whether magnetic resonance (MR) imaging and sonography posed ionizing radiation risks revealed that 28% of physicians surveyed believe that MR poses such risks, and 10% believe that sonography poses such risks.[24]

Image Gently

To address this knowledge gap, several organizations including the American Society of Radiologic Technologists (ASRT) formed the Alliance for Radiation Safety in Pediatric Imaging. In 2008 the Alliance launched the Image Gently campaign to promote awareness of the need to "child-size" medical radiation doses. Today, the Alliance has expanded to 91 organizations worldwide.[26] The Image Gently campaign has emphasized the effects of increased radiation dose from CT scanning. This campaign recommends that clinicians order scans for children only when necessary and that R.T.s avoid repeated scanning, scan only indicated anatomic regions and optimize imaging to achieve adequate quality while minimizing radiation dose.[27]

Repeated scanning is often unnecessary. Any radiation that does not benefit the patient is by definition unnecessary and should be avoided. The potential benefits and potential risks (ie, harmful biologic effects) of a particular diagnostic imaging examination for a patient must always be considered; the examination should only be undertaken when the potential benefits clearly and convincingly outweigh the potential risks.[28]

Child-sizing radiation doses and procedures is an obtainable goal. Empiric studies of image optimization have yielded surprising evidence that the clinical use of an imaging examination can frequently be achieved with substantially lower radiation doses, especially for more radiosensitive tissues. For example, for pediatric cranial CT scans, the standard recommended radiation doses may be reduced by 40% without substantially degrading the clinical value of images.[29] Infant pelvic anteroposterior (AP) radiography is another radiation dose "problem procedure" commonly entailing unnecessarily high radiation doses. In the late 1990s, it was found that increasing x-ray tube potential from 50 to 56 kVp can allow a 38% reduction in effective radiation dose.[30]

Radiobiology

Animal studies and several epidemiologic studies of occupationally exposed populations, survivors of nuclear weapon detonation and the Chernobyl nuclear power plant meltdown indicate that even relatively low doses of ionizing radiation can cause cancer, particularly leukemia and myeloma, as well as blood disorders such as aplastic anemia.[15] Energy from ionizing radiation can directly disrupt chemical bonds in DNA and protein molecules and may indirectly disrupt these bonds by releasing free radical ions. The resulting tissue damage may be *deterministic* or *stochastic (probabilistic)*. Short-term tissue damage is deterministic and includes skin burns and hair loss. Long-term stochastic damage is more probabilistic and can involve carcinogenesis when the genes that control cell division (mitosis) or programmed cell death (apoptosis) are damaged.

Stochastic effects are considered probabilistic because a given exposure may damage genes in a manner that triggers carcinogenesis or increases the risk that subsequent carcinogenic exposures will cause carcinogenesis.[19,31] Not all radiation damage to DNA results in cancer, and not all radiation exposures above a given threshold will result in carcinogenesis. Whether the converse is true (ie, whether dose thresholds exist below which radiation is never carcinogenic) is contested terrain.

Paradigms of Radiation Risk

The biological effects of radiation have become better understood over the past century.[28] Improved safety protocols and equipment designs have reduced the overall risks of medical irradiation.

Because of radiation's stochastic effects on cancer risk, it is conservatively assumed that no threshold dose exists below which radiation exposures are completely safe.[31] This linear/no-threshold model of radiation risk predicts that the greater the cumulative exposure to radiation, the greater the opportunity for carcinogenic mutations and, therefore, the probability carcinogenesis will occur. This model assumes that DNA-repair enzymes do not substantially moderate the increasing risk of carcinogenesis with increasing radiation doses (ie, risk increases linearly with increasing exposure). Some critics have questioned that assumption, suggesting that as radiation or other toxic exposure increases, compensatory DNA-repair mechanisms are activated to moderate genetic damage and risk to health.

Based on the linear/no-threshold model, ALARA has become a centerpiece of radiation safety. The ASRT has officially endorsed this model to minimize patient and occupational radiation exposures. Radiation doses should always be minimized, involving only exposures that are absolutely necessary to achieve specific medical goals.

However, it is important to note that some vocal dissenters reject the linear/no-threshhold model of radiation risk, which they claim overstates the risks of low radiation doses and unnecessarily constrains medical irradiation. Proponents of this controversial but increasingly influential "radiation hormesis" hypothesis argue that known and quantified risks from radiation and other toxic exposures cannot be extrapolated to low doses and assume that as-yet unquantified dose thresholds exist, below which exposures are either benign or beneficial.[33,34] This proposition is generally based on the absence of low-dose research documenting harm as well as in vitro and animal studies suggesting that low-dose radiation and low-dose exposures to other toxins might induce increased DNA repair and immune defense activity in irradiated tissues. Based on these studies, a few hormesis proponents have even argued for a relaxation of government regulations regarding nuclear and toxic waste management and related occupational exposures.[33,34]

Age Effects

Radiosensitivity varies throughout the lifespan, with developing organisms such as a fetus or child being more sensitive than adult organisms. Rapidly developing and growing organisms undergo rapid cellular division, and their DNA is more frequently uncoiled for replication and vulnerable to damage by ionizing radiation. Therefore, radiation likely represents a greater risk of genetic damage and later cancers to fetuses and children than to adults. Radiation-induced teratogenesis (disruption of normal fetal development other than carcinogenesis) can cause brain abnormalities, slowed head and body growth and mental retardation in fetuses as young as 2 weeks gestation.[35] Between 8 to 15 weeks gestation, fetal development is believed to be particularly vulnerable to the teratogenic effects of radiation, particularly doses greater than 200 mSv.[36]

Overall, children are up to 10 times more sensitive to radiation damage than adults, and thus children can be expected to be more sensitive even to low levels of radiation. Even a single CT scan is estimated to significantly increase the lifetime risk for fatal cancers.[37] For example, a single abdominal CT scan of a 1-year-old child carries an estimated lifetime cancer risk of 1 in 1000.[36] Yet for decades, children have been imaged using adult CT protocols.[38,39]

Pediatric CT examinations are increasingly common in the United States, accounting for 7 to 9 million CT scans per year.[8,9] Some pediatric patient populations, such as children with inflammatory bowel diseases, routinely receive CT scans despite the long-term risks. For example, in a 2-year study of 965 children with Crohn disease and ulcerative colitis, 34% and 23% of patients, respectively, received moderate doses of medical radiation. CT scans accounted for 28% of Crohn disease patients' imaging examinations and 25% of ulcerative colitis patients' examinations, which led the authors to express concern over long-term radiation risks faced by children with these diseases.[40]

Latency Periods

Age at the time of exposure might modulate radiation-induced cancer risk in another way: probable lifespan following irradiation. Radiation-induced cancers other than childhood leukemias tend to have long latency periods; decades can pass between irradiation and cancer diagnosis. This leaves older adults with the lowest risk of surviving long enough to develop cancers attributable to radiation and children with the highest risk.

Body Size

Children are smaller than adults, and younger children tend to be markedly smaller than older children. Because of smaller body mass and surface area, smaller children can receive larger effective doses than larger children or adults. Proportionately greater anatomic volumes and skin surface areas are irradiated, and radiation dose to a particular organ is frequently higher for smaller-bodied patients because more of the organ falls within the irradiated volume. Because of their body size, irradiation risk is most pronounced among neonates.[36]

Tissue Radiosensitivities

In addition to the age effects on tissue radiosensitivity, there is intrinsic variation in the radiosensitivity of different tissues. All tissues and organs are not equally susceptible to radiation damage. Tissue weighting factors allow radiation dose planning to reflect tissue-specific vulnerabilities to minimize potential harm to the patient.

Tissue weighting factors represent the relative radiosensitivities of different tissues, allow for the calculation of effective radiation doses, and allow doses to be adjusted to reflect tissue-specific vulnerabilities. For example, reproductive tissues are more sensitive to radiation than lung tissue or bone marrow, and bladder and liver tissues are less radiosensitive than bone marrow or lung tissue (see **Table**). The higher the tissue weighting factor, the more radiosensitive the tissue. Tissue weighting factors have not been established for embryos and fetuses.

Table

Radiation Dose Weighting Factors for Specific Tissues

Tissue	Wt[a]
Reproductive tissues	0.20
Bone marrow	0.12
Lung	0.12
Stomach	0.12
Colon	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Brain	0.01
Salivary glands	0.01
Bone surface	0.01
Skin	0.01

[a] *Wt = weighting factors. Data derived from Furlow B. Radiation dose in computed tomography.* Radiol Technol. *2010;81(5):437-450 and Wrixon AD. New ICRP recommendations.* J Radiol Prot. *2008;28(2):161-168.*

Cancer Risks

The causes of childhood cancer are poorly understood. They frequently appear to be multifactorial, involving multiple acquired genetic mutations caused by prenatal and postnatal carcinogenic exposures. These genetic insults frequently occur sequentially, during prenatal development and subsequently during early childhood.[41-43]

Ionizing radiation is a well-established risk factor for childhood cancers.[44] Prenatal exposure to x-ray beams has consistently been found to be a risk factor for childhood leukemia, although the strength of an association between diagnostic radiation and adult leukemia is less conclusive.[44-46] In the absence of definitive evidence, the conservative interpretation of available evidence (eg, data from atomic bomb survivors in Japan) is that children are generally more sensitive to radiation leukemogenesis and radiation carcinogenesis compared with adults.[47]

The cancer risks associated with CT examinations remain unclear and contested, but generally exceed the risks associated with radiography. The cancer risk associated with a single CT scan is relatively small for adults. Overall, it is estimated that 1 patient in 2000 will develop a fatal cancer from any CT scan compared with an overall lifetime risk of fatal cancer of 1 in 5 in the United States.[35] But some examinations involve higher doses than others and correspondingly greater lifetime cancer risks. For 20-year-olds, cancer risks from CT scans are twice as high as for 40-year-olds, and it stands to reason that those risks for 10-year-olds are higher still.[1]

Cancer risk appears to vary by age during childhood. The estimated lifetime cancer risk attributable to pediatric head CT has been found to correlate significantly and negatively with patient age, with younger children facing greater lifetime risks than older children.[50] Although most CT examinations are justified, in an unknown but not trivial proportion of these procedures, the risks of radiation doses outweigh clinical benefits or image quality justifications.[51,52]

Given 5 to 9 million pediatric CT scans are performed each year in the United States, researchers have cautioned that, collectively, even a relatively small individual cancer risk can — at the population level — result in hundreds or even thousands of additional cancer cases. Thus observance of the ALARA principle is a crucial public health goal.[36] Some epidemiologists have called for a nationwide effort to survey fetal and childhood radiation doses from CT and other diagnostic imaging modalities to generate data from which pediatric and lifetime cancer risks attributable to these procedures can be estimated.[44] Unfortunately, a national registry of medical radiation exposures does not yet exist.

Communicating Risk

As mentioned earlier, many referring physicians do not adequately understand the potential risks of unnecessary or repeated radiologic imaging. Clearly communicating radiation risk to referring clinicians, patients and their caregivers represents an important part of observing the ALARA principle of radiation protection. Securing informed consent from caregivers should be taken seriously and not viewed as a red-tape procedure. If a caregiver expresses concern about radiation risk or asks if there are viable alternatives to radiologic imaging, the medical imaging staff should take the time to clearly and honestly address them.

Ultimately, referring physicians must change their habits and come to appreciate the risks of medical radiation fully for the public health benefits of radiation protection to be fully realized. In addition to being frequently unaware of the radiation doses and risks of different imaging procedures, referring physicians tend to underappreciate the stochastic risks of radiation exposure.[20-22] When viable alternatives to high-dose imaging examinations are readily available, they should always be pointed out to referring clinicians.

Referring physicians are usually more familiar with and trusted by a child's caregivers than the R.T.s. Therefore, the referring clinician's warnings to caregivers regarding the risks of avoidable pediatric irradiation may be better received than warnings from an R.T. immediately before an imaging procedure. Although imaging personnel benefit from educating referring clinicians about those risks, it remains the R.T.'s responsibility to remind patients' caregivers of them as well. Patients' caregivers and teenaged patients should be made aware of the calculated dose of the planned examination, the relative radiosensitivities of target organ tissues, the effects of age and sex on risks, and the clinical justification for the examination.

Recent news media coverage regarding the risks of CT will alarm some caregivers and might cause them to question referrals for CT scans. The risks of CT imaging and the availability of viable alternative imaging modalities should be clearly described. Caregivers should be reassured that the ALARA principle is being strictly observed, and these assurances should always reflect real-world precautions taken to protect the patient and attending medical personnel. Clinicians and R.T.s should educate patients and their caregivers about their right to ask physicians for radiologic imaging histories and to ask the doctor to explain the benefit of a repeated examination and why it outweighs the risk of contributing to the patient's cumulative radiation dose.

Pediatric Radiation Protection Considerations

Day-to-day implementation of ALARA involves multiple safety and dose-management practices, starting with eliminating unnecessary imaging examinations and recognizing when alternative imaging modalities are available to meet clinical objectives. Medical dosimetry and dose planning, equipment maintenance and calibration, "child-sizing" exposures and optimizing image acquisition, patient preparation and positioning, and shielding and immobilizing patients all play important roles in minimizing a child's radiation dose. A summary of some important considerations for pediatric radiation protection can be found in the **Box**.

Box

Considerations for Reducing Pediatric Imaging Radiation Doses

Confirm need and potential benefits of examination.
Identify alternative modalities (eg, ultrasound and magnetic resonance imaging).
Identify clinically required image quality.
Avoid repeated or redundant examinations.
Use child-size doses, irradiated target volumes and radiation doses.
Use tight collimation with narrow margins.
Shield breasts, eyes, thyroid and gonads.
Properly position patients to reduce proximity of nontarget tissues to x-ray tube.
Immobilize young patients.

It is important to avoid unnecessary radiation exposure by ensuring the quality and proper calibration of imaging equipment and the qualifications of imaging staff. A patient's medical records also must be reviewed before examination for recent imaging examinations that may have yielded images that can address a referring physician's clinical question. Medical record reviews might also reveal lower dose (eg, radiographic) or nonradiologic imaging alternatives to high-dose examinations, such as ultrasound or MR. Because referring clinicians are frequently unfamiliar or inadequately familiar with radiation dose concerns, it should never be assumed that radiographic or CT imaging referrals are justified. Delaying the examination is also sometimes an option.

Children's smaller body sizes and level of maturity (ie, their ability to follow instructions and to hold still) frequently complicate effective radiation dose control efforts. Patience and careful planning to reduce the incidence of repeated image acquisitions are both key to pediatric imaging.

Image Gently recommendations promote optimal scanning strategies for children:

- Image when there is a clear medical benefit.
- Use the lowest amount of radiation for adequate imaging based on the size of the child, ie, reduce tube output (kVp and mAs).
- Image only the indicated area.
- Avoid multiple scans.
- Use alternative diagnostic studies such as sonography or MR imaging when possible.[27]

Neonatal Radiography

Neonatal CT scanning should be avoided if at all possible. Obtaining diagnostic radiographs of newborns is a challenging discipline, requiring a radiologist's thorough understanding of normal anatomies and radiologic signs of pathology that may differ from those seen in older children, as well as the technologist's awareness of how best to modify imaging techniques to accommodate neonatal behavior, needs and anatomy. Neonatal imaging frequently requires the technologist to adjust equipment in a small space, such as oxygen support devices and incubators. Mobile radiography units are a common modality for imaging neonates who cannot be moved to a radiology department. Specialized neonatal mobile units are available that are designed to accommodate incubators and incubator rooms. Conceptually, the radiation protection principles described in this Directed Reading apply to infants as well as older children.

Quality Control and Quality Assurance

Even for the same imaging procedures, radiation doses frequently vary significantly between hospitals and machines.[50,53] Imaging departments are therefore required to maintain quality assurance (QA) and QC programs, and radiology departments should regularly employ or contract with medical physicists to confirm equipment function and verify scanner calibrations.

QA programs assess the effects of human performance of procedures on image quality and patient dose, whereas QC ensures proper functioning of imaging equipment. Manufacturer software updates, along with ensuring that dose-reduction equipment is in use and regular protocol review meetings to discuss dose-reduction practices and procedures, will improve a facility's QA, QC and adherence to the ALARA principle.[54]

A QA program should track staff credentials and qualifications, and document regular continuing education on medical dosimetry, radiation protection and equipment performance.[54] Quality assurance programs also should include annual facility reviews of CT study types, numbers and doses and the comparison of trends in these factors over time.[38]

Regular maintenance, cleaning and calibration of imaging equipment is crucial to effective dose management. A medical physicist should establish reference radiation levels for the facility's more common procedures.[55] Continuous or day-to-day QC practices should be established and readily available in written form, and an on-site R.T. should be designated as the day-to-day QC coordinator. QC monitoring of equipment performance should be routinely performed.[54]

Optimizing CT techniques, procedures and utilization guidelines to balance image quality needs with ALARA is an ethical imperative, particularly for young patients. The need for a given level of image quality should always be reviewed and balanced against radiation dose considerations, with the ALARA principle kept in mind.[5] Radiation dose error review committees should meet to identify the causes of errors and take corrective action.

A dose reduction committee should consist of R.T.s who work in radiography and CT as well as a qualified medical physicist. This committee should periodically review patient protocols and the CT dose index (CTDI) values of examinations.[38] Unfortunately, staff medical physicists are rare, particularly in an era of cost-cutting, and consulting medical physicists might only be available for annual meetings. These meetings should be scheduled to coincide with annual equipment reviews by the medical physicist so the physicist can report any equipment problems that were identified and corrected.

Regular equipment maintenance and performance monitoring are essential to dose management. Imaging equipment should always be evaluated by a qualified medical physicist at the time of installation. After installation, a medical physicist must monitor equipment performance periodically (at least annually) and prepare a written report that is filed in the imaging department.[54,56] State and local government regulations also should be reviewed because they might require more frequent monitoring.

The periodic equipment performance review must determine patient radiation dose from each scanner and independently confirm manufacturers' monitor display CTDI measurements.[54,56] Head, abdomen and pelvic examination doses should be assessed and compared with available, published reference doses to ensure that a facility's CT scanners are not systematically overexposing patients to ionizing radiation.[54] Equipment also must be checked by a medical physicist to confirm performance after service, repair and tube or detector assembly replacements or other events that could change radiation dose or image quality.[56]

Routine QC monitoring should confirm the accuracy of alignment lights, CT number uniformity (ensuring that CT values for pixels are the same across different regions of a homogeneous phantom) and include:

- Image localization from scanned projection radiograph (localization image).
- Table incrementation accuracy.
- Radiation beam width (collimation).
- Reconstructed image thickness.
- Acquisition workstation display.
- Dosimetry (radiation output of CT scanner and patient radiation dose estimate for representative examinations).
- Limited protocol review, including head and abdomen protocols for adult and pediatric patients and protocols for very high-dose procedures; items that should be documented include kVp, mA, rotation time, detector configuration, pitch, reconstructed image thickness, the use of automatic exposure control, and the dose indicies for each examination.
- Safety evaluation (visual inspection, work load assessment, scatter and stray radiation measurements, audible/visible signals, posting requirements).
- Other tests required by state or local regulations.[56]

QC monitoring also includes ensuring image quality, which allows more precise image optimization. High-contrast spatial resolution, low-contrast sensitivity and resolution, and artifact and noise evaluations should be included.[56]

Measuring Radiation Dose

Radiation refers to the energy emitted by an ionizing radiation source, whereas radiation *dose* is a quantification of the ionizing radiation energy delivered to a given volume of tissue (or other mass). Several units of measure are used to describe radiation levels. The unit of absorbed radiation dose is measured in gray (Gy), or the delivery of 1 joule of energy to 1 kg of mass.[38] The gray unit replaced an older unit of measure, the radiation absorbed dose or rad; 1 Gy is equal to 100 rad.

Exposure refers to ionization interactions with matter (eg, cells) within the radiation field. *Entrance skin exposure* refers to dose at the area through which the x-ray beam initially enters the patient.[57] *Effective dose* is an estimate of the total amount of radiation absorbed through heterogeneous tissues, calculated as the weighted sum of the dose to irradiated organs and tissues.[38] Effective dose, once expressed as roentgen equivalent man (rem), is now expressed in sievert (Sv) or millisievert (mSv).

Radiation exposure can be directly measured with a film badge consisting of x-ray-sensitive film chips or reusable thermoluminescent dosimeters mounted on badges or strips. Thermoluminescent dosimeter badges contain lithium chloride crystals that release light energy after absorbing x-ray energy; the light wavelengths are proportional to the ionizing energy absorbed.

CT scanners pose challenges to the quantification of radiation dose, because of factors such as complex beam contours and patient movement through a CT machine's x-ray beam. Tissue adjacent to the target tissue is exposed to some radiation regardless of slice thickness. Most scanners use a fan-shaped beam with a narrow cross-section, and the dose distribution is usually wider than the nominal slice width.[53]

A single image slice acquisition involves a bell-shaped distribution of radiation with marginal "tails" known as penumbra, which contribute significantly to an examination's overall radiation dose where the penumbra overlap — up to 50% greater than a single scan's peak dose. However, this dose varies substantially with slice thickness and intervals.[38,53] The cumulative dose represented by the penumbra regions of each CT beam creates an oscillation-like dose curve. The midpoint or average of the curve is known as the multiple scan average dose, which can be estimated using plastic cylinder phantoms. The radiation dose distribution of a single slice yields the most common CTDI.

The dose length product is the total absorbed patient dose for the complete CT examination. It is the product of CTDI and the examination length or range, measured in mGy × cm. The CTDI and dose length product for every patient's CT scan should be recorded. Modern CT equipment displays and automatically records these values with the patient protocol for each examination.[38,53]

Few CT dose guidelines exist, but the American College of Radiology lists a reference CTDI of 20 mGy for pediatric abdominal examinations.[55] The CTDI is a calculated approximation or index, not an actual measurement of radiation dose. For pediatric imaging, however, CTDI does not take into account individual patient anatomic variations, such as target organ volumes. Actual CT radiation dose for children may be as much as 600% higher than doses indicated by the CTDI display.[38,58] Also, CTDI does not reflect tissue-specific radiosensitivities or resulting radiation risks.

Complex, probabilistic mathematic models called Monte Carlo simulations are used to calculate effective dose; these simulations involve the radiation beam, target scan volume, gantry motion and weighting factor values that quantify the different radiosensitivities of target organs.[38] The calculated radiation dose delivered to each organ volume is multiplied by the relevant weighting factors; the sum of these products is the effective dose. Even at the same settings and with the same patient undergoing the same CT examination, dose distributions and intensities commonly vary among scanners.[53]

Cumulative Dose Tracking

Ultimately, cumulative lifelong tracking of patient doses will be necessary to accurately weigh the relative risks and benefits of imaging procedures throughout the patient's lifetime. ASRT has formally adopted the position that all imaging facilities should document patient exposure.[59] Several health information technology mechanisms have been proposed for reminding referring clinicians and radiologic technologists to consider patient radiation doses. One recommendation is to simply enlarge or otherwise make more prominent the dose index readouts on CT scanner displays.[38]

Digitally archived imaging examinations should ideally include radiation dose information, but some hospital electronic medical records systems do not track irradiation histories or calculate cumulative patient doses, let alone automatically alert doctors to cumulative doses at the time of referral. To encourage data collection and protect the public, states such as California, Texas, and Connecticut recently passed laws mandating radiation dose reporting for CT scans and other x-ray procedures.[60] An additional impetus for dose tracking came in 2014 when the Joint Commission began requiring dose-recording software as part of the accreditation process.[61]

Even more sophisticated mechanisms, such as automatic notifications to referring clinicians and imaging department staff regarding patients' cumulative doses, are likely to become available in the near future. These systems, which reduce unnecessary medical expenditures, have been identified as a national priority by policymakers.[62] Ideally, electronic records should include not only patient doses but also the type and technique of examination to avoid unnecessarily repeating previous procedures.[38]

Balancing Image Quality and Radiation Dose

Image quality refers to how accurately the medical image depicts actual anatomical features. Clinical image quality must be carefully balanced against the increased radiation doses involved in higher-precision diagnostic imaging. The anatomical detail of an image frequently comes at the cost of increased radiation dose. The central trade-off between radiation dose management and the ALARA principle stems from the fact that image quality correlates positively with radiation dose. Slice thickness, mA and pitch all modulate both image quality and radiation dose.[38] Increased image precision (ie, sharpness) requires a higher radiation dose because it involves smaller sampling intervals.

Diagnostic efficacy is an operational concept that considers ALARA in assessing whether an imaging referral is justified. Efficacy refers to the ability to minimize radiation exposure while still producing optimal images for the clinical assessment goal (ie, the ability to confirm or rule out a suspected disease process or pathology). Image optimization is the process of maximizing diagnostic efficiency. The minimal amount of anatomical detail required for a specific clinical purpose should determine imaging modality and examination parameters. But clinicains also must keep in mind that dose reduction reduces image precision and thus potentially its diagnostic value. Poor-quality images will require repeated examinations, increasing patients' cumulative radiation doses. Image quality can be degraded by efforts to reduce dose and patient positioning errors.[38] Compromised image sharpness can also result from poor calibration and evaluation of spatial resolution, which is performed using high-contrast line bar pattern phantoms. Compromised image sharpness illustrates the complex relationships between QC, image quality and dose reduction.

CT scanners are designed to acquire detailed data from large volumes rapidly rather than to facilitate operator restraint and dose minimization. The full capabilities of scanners are frequently unnecessary.[38] Manufacturers have recently incorporated dose-reduction mechanisms into scanner design, such as beam mA modulation to accommodate differences in patient volumes. However, those involved in research and development continue to emphasize improved image quality and expanding applications rather than reduced radiation doses or the avoidance of unnecessary radiologic imaging.

Image contrast refers to the visualization of small x-ray attenuation differences between or within target tissues. CT scanners, with 4 to 6 times more contrast visualization than traditional radiography, often offer superior diagnostic utility. However, as with sharpness, increased image contrast requires higher radiation doses. Image noise is inversely proportional to the square root of dose, so reducing image noise by half in CT examinations would increase dose by 400%.[38,63] However, it is important to note that image noise also drops with decreasing patient body mass, which allows reduced radiation doses for comparable image quality with smaller patients.

Distance and Duration

Radiation exposure is a function of exposure rate and examination duration. Therefore, reducing scan time and increasing distance each can reduce radiation dose to patients. Radiographic examination times have dropped over recent years with the widespread adoption of digital radiography. Faster image acquisition reduces radiation dose in 2 ways. First, it reduces the dose of a given examination. Second, it facilitates the acquisition of quality images in children who are able to remain still for only short amounts of time, reducing the incidence of repeated examinations.

When performing radiographic or fluoroscopic examinations, increasing the distance between the radiation source and an individual reduces radiation intensity in a manner described by the inverse square law. Intensity (I) declines at a rate equal to the inverse of the distance (d) squared ($I=l/d^2$; see **Figure 1**).

During a fluoroscopy examination, the child's skin should never be closer than 30 cm from the radiation source and should not be farther away than 38 cm from the source.[57] Removable spacer assemblies should always be used with mobile C-arm equipment during pediatric fluoroscopy. Image intensifiers also can help block scatter radiation.

Examination times should be kept as brief as possible without risking low-quality images that require reexamination. High-speed image receptor systems allow for reduced x-ray tube currents.

Collimation

Scatter radiation increases total radiation dose without improving image quality; in fact, it frequently reduces image quality and should be avoided. Beam collimators and image intensifiers reduce field areas

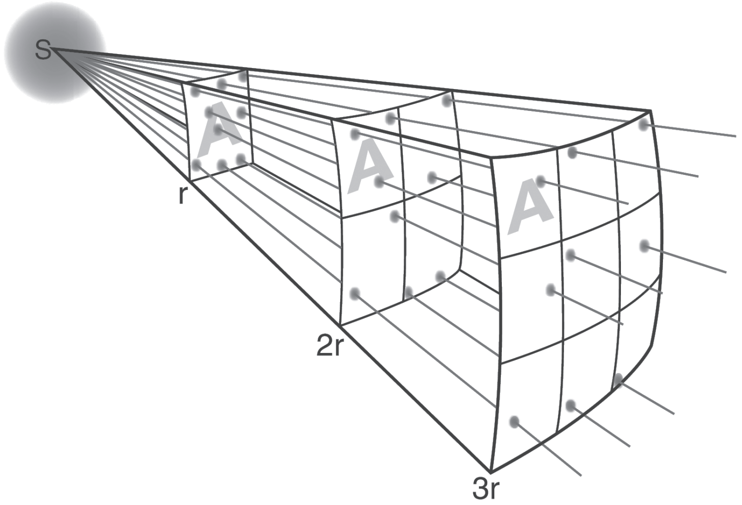

Figure 1. *Schematic illustration of the inverse-square law. The radiation intensity decreases proportionally as the square of the distance increases from the radiation source (S). (Here, radiation intensity at distances 1, 2 and 3 are represented as r, 2r and 3r.) The ray spacing reflects radiation intensity; the radiation dose for area A is greater at distance r than 3r. Image in the public domain courtesy of artist Borg. Retrieved from http://creativecommons.org. Accessed February 27, 2011.*

and radiation exposure both by reducing scatter radiation and by reducing irradiated volumes (and hence, effective doses). CT collimation reduces the width or height of a beam's dose distribution curve.[53] Collimators help limit irradiation to the patient's target anatomy and reduce radiation exposure to other tissues. Careful planning should ensure that the margins around target tissues are always as narrow (as close to the edge of targeted organs) as possible without compromising the clinical usefulness of the resulting images.

Other Parameters

Beam collimation, distance and examination duration are just 3 of several operator-controlled parameters affecting image quality and patient radiation dose. These parameters also include:

- Low x-ray tube current (mA).
- Optimal x-ray tube voltage (kVp) for organs to be imaged.
- Optimal patient target size (target area or volume planning).
- Pitch (in helical CT scanning).

QC reviews should include periodic reviews of scan protocols to identify opportunities to reduce mA, and the necessity of pitch factors less than 1.0 should be carefully scrutinized.[38] Postprocessing or real-time noise-reduction algorithms for digital radiography, CT and fluoroscopy have been developed (and continue to undergo refinement) to allow calculation of low-noise visualization at reduced radiation doses.[64]

Scout Imaging

A scout image is used to identify target anatomy and plan the full CT examination. Scout images are obtained with the gantry table in a fixed position, a configuration that yields a simple radiograph-like image. Scout images should be used sparingly and should be performed at the lowest mA settings possible that produce images demonstrating anatomic landmarks.[65] CT scout images typically represent between 4% and 20% of total CT scan radiation dose. But as dose-reduction protocols are used increasingly for CT examinations, the proportion of total dose represented by scout images will likely climb.[66] A 2001 European study found that dose reductions of up to 88% could be achieved without compromising the utility of the scout image.[65]

A 2010 study also identified scout images as an opportunity to reduce patient dose. This survey of radiologists in Baltimore found that R.T.s perform most scout images to make sure the target anatomy is covered in planned diagnostic scans, but that scout images themselves rarely are consulted in clinical interpretations of diagnostic images. The study also found that 63% of radiologists never or almost never consult scout images. The most common scout image setting (120 kVp, 115 mAs) is equivalent to 10 conventional chest radiographs.[66]

Because the function of scout images is to identify the location of landmark anatomy within the target region, significant reductions are theoretically possible. However, most CT scanners do not allow operators to adjust scout image settings below 20 to 30 mA to reduce radiation dose. The study just cited suggested that scout CT imaging could be reduced to as low as 3 mA, achieving radiation doses similar to chest radiography without compromising the usefulness of the images. The authors called for CT equipment vendors to allow the mA for scout mode scanning to be adjusted downward.[66]

Patient Preparation

Ideally, referring physicians explain the goals, benefits and risks of an imaging examination to patients and their caregivers. However, not all physicians have an adequate understanding of the radiation dose and risks of a given modality or procedure. In real-world practice, patients and caregivers often first hear a realistic description of the procedure and its risks, benefits and alternatives from imaging personnel.

The first step in every pediatric examination is proper pateint identification. Then confirmation with caregivers regarding referring physician information is necessary. Hospital-issued patient identifiers (eg, wrist bands) are assigned. The patient's age also should be confirmed because age is a potentially important indicator of expected levels of skeletal maturity and other developmental factors relevant to the radiologist's interpretation of images. Proper positioning and the removal of jewelry should be emphasized with the patient and caregiver to avoid the need for repeated examinations.

Be friendly and patient. Children will not always clearly communicate their anxiety and may frequently arrive at the radiology unit traumatized or afraid. Impatience or unintentional cues of disapproval by staff may compound the child's anxiety, reducing his or her ability to comply with instructions. Imaging personnel commonly have less time to build rapport and trust than the child's pediatrician or referring physician and may need to rely on environmental cues (eg, stuffed animals or child-friendly wall art) for encouraging safety. Eye contact, a gentle voice, a smile and reassurance rather than subtle or unintentional rebukes when faced with uncooperative behavior can minimize the child's distress. These R.T. behavioral techniques also can improve the probability of a successful imaging examination.

If immobilization or sedation is planned, immobilization and intravenous infusion equipment should be shown to the child and caregivers. Also, the purpose of each modality should be explained using nonthreatening words and a calm demeanor and tone of voice.

Children frequently observe their parents or other caregivers when assessing their safety. Therefore, when preparing a child for a diagnostic imaging examination, health care staff must use a dual communication approach. They must clearly explain the goal of the examination and how the child must behave to ensure its successful completion. At the same time, providers must inform caregivers about the benefits and risks of the planned procedure; the explanation should include the diagnostic goals and justification for the examination, along with a description of shielding and other efforts to minimize the radiation dose. Acknowledging the inherent risks of radiation and explaining how the ALARA principle is observed frequently reassures caregivers when simply dismissing radiation risk as minimal does not. Patients and their caregivers can be encouraged to visit online tutorials or view instructional videos at the imaging facility to learn what to expect during an imaging examination. Those resources also can explain dose minimization goals for certain procedures.

Health care staff should warn caregivers if a child is likely to experience discomfort or distress during an examination. For mobile radiography examinations, caregivers also should be cautioned to remain at least 8 feet from the x-ray tube.[67] In some circumstances, parents might have to comfort the child verbally rather than physically.

Because caregivers frequently accompany the patient during imaging, they also must be cautioned about potential exposure (eg, from scatter radiation). Shielding equipment, including 0.5-mm lead aprons, gloves and thyroid and eye shields, must be provided to each adult staying with the child during the examination and must cover at least 75% of the adult's body containing active bone marrow.[67] Women of childbearing age should be discouraged from being present during the examination, and pregnant women should not be permitted to do so. Caregivers who do stay with the child should do so only once if multiple examinations are performed. Most institutions have policies regarding staff members who accompany the child during the exam. Different adults should comfort and assist the child during each examination to minimize the potential exposure to each adult.

Like children, caregivers can experience high levels of anxiety during the examination, so staff members should

Figure 2. *A radiologic technologist places a flat, triangular-shaped lead shield to protect the gonads of a young female patient.*

Figure 3. *A radiologic technologist positions a mobile lead shield to protect a young male patient before a posteroanterior chest examination.*

be patient and reasonable. The goals and benefits of an examination and an honest description of the potential risks should be reiterated in a calm, respectful manner as needed throughout the examination.

Timing

Chest radiographs and certain CT scans such as evaluation of lobar emphysema should be acquired at maximal inspiration when the lungs are most full of air. (Air trapping studies of suspected asthma or bronchiolitis obliterans might also require CT imaging of expiratory phases of respiration.) For unsedated young children and infants, acquisition can be timed during infant crying when respiration is more complete. With rapid scan acquisition exams, crying bouts might therefore provide a natural opportunity to image maximal inspiration and expiration. If crying bursts can be exploited to improve inspiration volumes, caregivers must be cautioned to stifle their natural impulse to calm and quiet the infant.

Positioning and Shielding

Positioning errors are a common cause of repeated imaging examinations. Careful patient positioning keeps nontarget tissues, particularly radiosensitive tissues such as the reproductive organs, breasts, eyes and bone marrow, as far from the radiation field as possible. For example, lateral chest projections reduce irradiation of breast tissue and more readily allow breast shielding than AP or posteroanterior (PA) projection radiographs.

Shielding is a crucial component of radiation protection. Patients, their caregivers and medical personnel should be protected from the radiation source using all available physical barriers. Any nonradioactive physical obstructions between people and a radiation source are referred to as "shielding." Shields are placed directly on or suspended above the protected tissue and can be flat or contoured (see **Figure 2**).

Protective shields include personal body protection (eg, wraparound lead aprons, gloves and thyroid shields), as well as mobile shielding, such as disposable bismuth-antimony surgical drapes and lead-lined barriers around control consoles (see **Figure 3**). Particularly when patients are young, body shielding should always be used to protect the thyroid, breasts, eyes and reproductive organs.

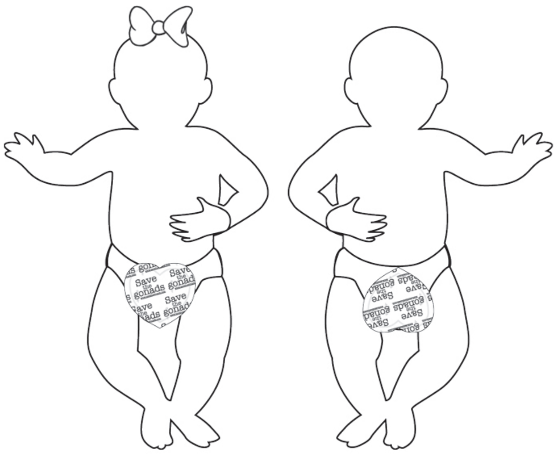

Figure 4. *Save the Gonads pediatric x-ray shields protect radiosensitive reproductive tissue in both boys and girls. Image courtesy of Natus Medical Incorporated, San Carlos, CA.*

Radiology department personnel should routinely protect themselves with lead aprons, gloves and thyroid shields.[68] Staff who do not wear lead shielding receive 10 times more measured dose than staff who wear protective equipment.[69]

Eyes

Visual tissues are extremely vulnerable to the harmful effects of ionizing radiation. In particular, eye lenses are believed to be among the most radiosensitive tissues in the human body. There is no known lower dose threshold below which radiation-induced opacities, including cataracts, are not a concern.[69,70] Even subtle opacities can degrade visual acuity. Because there is no established safe minimum radiation dose for the lens, patients' eyes should be shielded. CT and fluoroscopy staff should protect their eyes using leaded glass lenses or, if the face is close to the x-ray beam, lead-acrylic window face masks.[69]

Eye shielding for patients is well tolerated among children but is not as effective for dose reduction as thyroid shielding, although the reasons for this remain unclear.[70,71] Bismuth eye (and thyroid) shielding appears to be less effective than lead shielding.[71] Eye shielding can interfere with CT and radiographic neuroimaging, which is one more reason that alternative, nonradiologic modalities should be used for children. One study of 60 consecutive pediatric neuroimaging CT examinations showed that overall 55% of scans contained artifacts attributable to eye shields.[70]

Although eye shields do not harm patients and should be used for any head and neck radiography or CT examinations, eye protection is best achieved through collimation, gantry tilting and other positioning techniques that minimize irradiation of the eyes. Examination duration also should be minimized.[72]

Thyroid

Except for dental radiographs, pediatric thyroid shielding with lead or bismuth barriers is largely limited to chest radiography in which airway visualization is unimportant, such as the assessment of rib fractures.[67]

Reproductive Cells

Sperm cells and ova have no known radiation dose threshold below which radiation is safe. Genetic mutations in these cells, particularly in ova (because at birth girls already possess all the ova they will produce in a lifetime) can be passed on to patients' future offspring. Imaging modalities that do not use radiation, such as MR, should be used when target tissues are within 5 cm of the gonads. Whenever the legs or abdomen are imaged, gonadal sheilding is indicated. Gonadal shields should involve at least 0.5-mm thick lead barriers (see **Figure 4**).

Breast Tissue

Childhood scoliosis exams involve irradiating breast tissue. Even before puberty, breast tissue is more radiosensitive and prone to radiation-induced carcinogenesis than other tissues and should be shielded whenever possible. Cancer risk is greater for younger patients and patients with smaller bodies.[67]

Immobilization

Children younger than 5 years of age and children who are panicked or experiencing pain might be unable to follow instructions and remain still during imaging. Patient movement during image acquisition can degrade image quality and require re-examination. Effective immobilization strategies can improve image quality and reduce radiation dose (eg, through decreased examination duration) by employing equipment that helps the child maintain desired body positions. Immobilization

Figure 5. *The Olympic Circumstraint child immobilizer is one of many devices designed to minimize child movement and reduce the need for repeat examinations. Image courtesy of Natus Medical Incorporated, San Carlos, CA.*

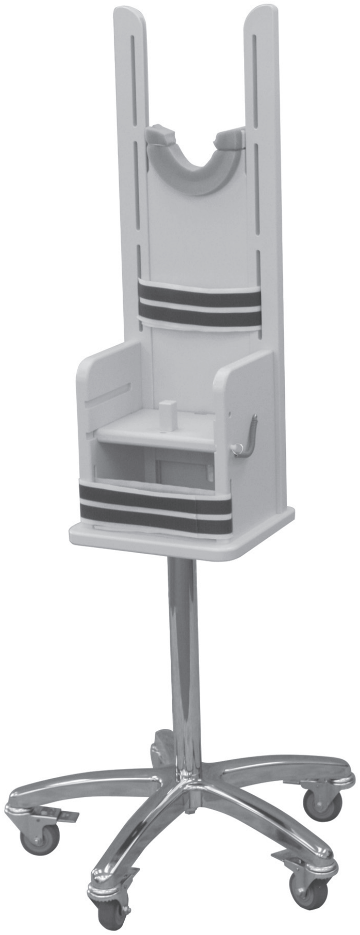

Figure 6. *The Pediaposer immobilization chair is constructed of radiolucent polyethylene. The chair adjusts to hold children of various heights and rotates to accommodate different examination positions. A bench seat is used for toddlers up to small 4-year-olds. Nonstretch Velcro straps secure the child's arms in the desired position, and a chin strap (not shown) can be used to tilt and immobilize the head. Image courtesy of Clear Image Devices, Ann Arbor, MI.*

is distinct from and typically more effective than manual physical restraint of the child by caregivers or staff and remains a standard practice in the diagnostic imaging of infants and children younger than 5 years of age.

Immobilization can be as simple a procedure as swaddling or using sandbags to position a child. It can involve a wide variety of more complex, commercially or custom-designed equipment, including radiotransparent immobilization boards with adjustable Velcro straps, adhesive tape and shaped Styrofoam or Plexiglas blocks and strips. Equipment employing straps and fasteners must minimize target tissue movement and facilitate proper patient positioning without constraining patient respiration or blood circulation. Head-and-neck cradles and headrests position and immobilize the head or neck. Chest and torso boxes allow immobilization for AP and lateral radiography. Radiology departments should always maintain a supply of variously sized swaddling sheets, sandbags, blocks and headrests, as well as whole-body immobilization devices (see **Figures 5** and **6**).

Some of the more widely used whole-body immobilization devices include:

- The Tame-Em immobilizer (Tayman Industries, Severna Park, Maryland) consists of a radiolucent fiberglass baseboard with 2 alternative sizes of attachable restraining boards (26 inches long for infants and 36 inches long for children younger than 5 years of age). The restraining boards are attached to the base with stainless steel thumbscrews. This device uses adjustable Velcro-secured straps to immobilize the patient's arms and legs, and can be used with supine AP or lateral chest radiography. A lead apron covers the child's lower abdomen and gonads.
- Octagonal-design immobilizers, such as Octostop and Octoroll devices (Octostop, Quebec, Canada) are composed of a padded radiotransparent wooden board with octagon endplates that can be arranged, as the name suggests, in 8 different positions.
- The Pigg-O-Stat immobilization device (Modern Way Immobilizers, Clifton, Tennessee) allows upright pediatric radiography.

Sedation

Pediatric sedation and anesthesia involve intrinsic risks and should always be avoided, if possible.

Sedation failures are not rare and can extend examination times or lead to repeated examination. However, successful sedation, typically using barbiturates or hypnotics, can better immobilize the patient than external devices. Ultimately, sedation can reduce radiation dose and repeated examination rates, particularly with young children undergoing longer-duration examinations such as angiography. When procedures involve discomfort or pain, inhaled nitrous oxide or local anaesthetic agents such as procaine, tetracaine, lidocaine, ropivacaine and articaine may be used for pain management.[73]

In U.S. pediatric hospitals, radiology departments frequently are responsible for more than half of all hospital sedation procedures, although much of that trend is because of MR use rather than modalities such as radiography or CT.[74] Multidisciplinary pediatric sedation teams for diagnostic imaging, including pediatric sedation nurses, can dramatically reduce the incidence of sedation failure from that seen with radiology department-only sedation teams.[75]

Sedation can be minimal or "conscious," which does not affect airway patency, or "deep," which can affect the.[67] General anesthesia is a more profound and less frequently used type of sedation for imaging examinations, involving unconsciousness, amnesia and muscle relaxation throughout the body.[74] Minimal sedation (anxiolysis) is always preferred because it involves fewer intrinsic risks to the pediatric patient; the use of more profound depths of sedation should be medically justified and avoided, when possible.

The patient's respiration rate, blood oxygen level and heart rate should always be monitored during sedation and anesthesia, and general anesthesia requires respiratory support. Sedation can be delivered intravenously, via inhalation, or through oral or rectal suppository. Chloral hydrate, a hypnotic drug and one of the more common pediatric sedatives, is delivered as a suppository and is used to sedate young children weighing less than 25 lb. It takes up to 30 minutes for chloral hydrate to induce sedation lasting 60 to 90 minutes. Intravenously administered pentobarbital, a barbiturate, induces nearly instantaneous sedation lasting from 1 to 4 hours.[67] Both chloral hydrate and pentobarbital are used as single-agent sedatives and have become popular since the 1970s because they reduce the risk of respiratory depression seen in previously used combination-agent sedatives.[74]

In recent years, intravenously administered dexmedetomidine has become more widely used as a single-agent sedative for diagnostic imaging. Dexmedetomidine involves a smaller risk of respiratory depression; induces an average sedation time of approximately 1 hour; and depending on dose can produce different depths of sedation that resemble natural sleep. Low-dose sedation with dexmedetomidine has been found to fail as a sole-agent sedative for MR procedures.[76] Researchers at Harvard University Children's Hospital in Boston reported that a series of 62 children undergoing CT were successfully sedated with relatively high doses of dexmedetomidine, but they noted a 16% incidence of cardiac arrhythmias.[74]

Preparation for sedation should follow the SOAPME approach to ensure that the proper equipment is available:

- **S** (suction): size-appropriate suction catheters and apparatus.
- **O** (oxygen): adequate oxygen supply and functioning delivery system and flowmeters.
- **A** (airway): size-appropriate, functioning airway support equipment, such as laryngoscope blades, endotracheal tubes and face masks.
- **P** (pharmacy): life-support drugs and sedative antagonists in case of emergency.
- **M** (monitors): functioning pulse oximeter with size-appropriate probes, noninvasive blood pressure monitor, electrocardiography equipment, stethoscope, etc.
- **E** (equipment): defibrillator and other special equipment or medications that may be needed for a particular child.[73]

The patient should fast for 6 hours before scheduled sedation; 4-hour fasting is required for patients on breast milk. All pediatric patients should not drink fluids (water, tea or fruit juice) for 2 hours before sedation.[73] Contraindications to sedation, including sedation with dexmedetomidine, are active gastric reflux or vomiting (aspiration risk); recent history of apnea, pneumonia, exacerbated asthma or bronchitis; cardiac malformations, serious cardiac arrhythmias or dysfunctions; and congenital craniofacial anomalies that complicate mask fit for positive-pressure ventilation.[74]

Conclusion

Improvements in the safety of radiologic imaging equipment and procedures have reduced the risks of medical radiation and incidence of radiology-related conditions over the past century. However, the increased use of high-dose imaging modalities and procedures such as CT — particularly the increasingly routine referral of children for multiple scans — are raising cumulative medical radiation doses and attributable cancer risk among U.S. patients. Observing radiation safety procedures and practices and better QA and QC represent basic but important components of reducing risk to patients and staff.

Many referring clinicians are insufficiently aware of the radiation risk posed by CT scans. Two medicolegal and ethical imperatives, the principles of ALARA and informed consent, require that referring clinicians, patients and caregivers know about the relative and, when possible, cumulative radiation risk associated with medical imaging.

CTDI readouts on CT scanners offer only an approximation of likely patient radiation dose from a given examination and might dramatically underestimate doses to children. These approximations should not be mistaken for actual patient-specific radiation doses. Patient doses should be calculated using tissue-weighted radiosensitivities, and the dose should be minimized through shielding, positioning and tight collimation.

Future developments in dose management and cumulative dose tracking will help identify and avoid unnecessary radiologic imaging, but constant vigilance by imaging department personnel remains the single most crucial element of universal implementation of the ALARA principle to protect the smallest patients.

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The information in this article was reviewed and updated in January 2016. The content was generally accepted as factual at the time the article was posted online. However, the ASRT and the author disclaim responsibility for any new or contradictory data that may become available after posting. Opinions expressed in this article are those of the authors and do not necessarily reflect the views or policies of the ASRT.

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