WHITE PAPER

Best Practices in Digital Radiography

Tracy L. Herrmann, M.Ed., R.T.(R); Terri L. Fauber, Ed.D., R.T.(R)(M); Julie Gill, Ph.D., R.T.(R)(QM);
Colleen Hoffman, R.T.(R)(M)(CT); Denise K. Orth, M.S., R.T.(R)(M);
Paulette A. Peterson, M.Ed., R.T.(R)(M)(QM); Randy R. Prouty, B.S., R.T.(R);
Andrew P. Woodward, M.A., R.T.(R)(CT)(QM); Teresa G. Odle, B.A., ELS

©2012 ASRT. All rights reserved.
Published by the American Society of Radiologic Technologists, 15000 Central Ave. SE, Albuquerque, NM 87123-3909. ©2012 American Society of Radiologic Technologists. All rights reserved. ASRT prohibits reprinting all or part of this document without advance written permission granted by this organization. Send reprint requests to ASRT.

American Society of Radiologic Technologists

Best Practices in Digital Radiography

Tracy L. Herrmann, M.Ed., R.T.(R); Terri L. Fauber, Ed.D., R.T.(R)(M); Julie Gill, Ph.D., R.T.(R)(QM); Colleen Hoffman, R.T.(R)(M)(CT); Denise K. Orth, M.S., R.T.(R)(M); Paulette A. Peterson, M.Ed., R.T.(R)(M)(QM); Randy R. Prouty, B.S., R.T.(R); Andrew P. Woodward, M.A., R.T.(R)(CT)(QM); Teresa G. Odle, B.A., ELS

The amount of radiation Americans are exposed to as a result of diagnostic medical imaging increased about sixfold from 1980 to 2006, and for the first time in history, estimates of medical radiation exposure nearly equaled those for background radiation. The reasons for the increase were varied, and the highest percentage of collective dose (taking into account the effective dose and the size of the exposed population) easily was explained by the corresponding increase in computed tomography (CT) and nuclear medicine scanning over the same time period. All the same, the total number of medical imaging studies rose dramatically, and radiography was no exception. The number of radiographic and fluoroscopic studies skyrocketed from 25 million in 1950 to 293 million in 2006.

As reports on medical imaging use have been released, the focus on cumulative dose from regulatory bodies, clinical societies and the public has intensified, leading to concerns about utilization of medical imaging. Historically, radiation exposure from diagnostic medical imaging was not considered a problem, and there was no evidence that exposure to low doses of ionizing radiation increased cancer risk. The benefits of radiography have remained clear over the more than 100 years of diagnostic medical imaging's history. Another fact that has remained clear is the critical role that radiographers play in ensuring patient radiation safety during medical imaging procedures. Radiographers must adhere to the "as low as reasonably achievable" (ALARA) principle by keeping radiation dose as low as is reasonably achievable when performing digital radiography.

As radiographers have adjusted to the advent of digital radiography, they have had to refine exposure technique selection and pay closer attention to radiation protection. Newer digital technologies offer many benefits over film-screen technology, such as time savings, greater dynamic range, wider exposure latitude and postprocessing capabilities, plus advantages such as image manipulation that enable radiologists to adjust images at their workstations. As a result, there is a tendency to be less concerned about exposure technique and the opportunity to use more radiation than necessary, a trend that often is referred to as "dose creep." Exposure techniques that radiographers can use to ensure that digital images are of optimal quality and minimal patient radiation dose differ from those used for film-screen imaging. Because digital imaging technology is relatively new and rapidly changing, radiographers' skill levels vary, and resources often are scattered and even conflicting. Radiographers, and their patients, would benefit from a single source that offers background information, best practices and recommendations on optimizing digital radiography and patient radiation safety.

Digital Radiography Background

The first form of digital imaging, digital subtraction angiography, was introduced in 1977 and put to clinical use in 1980. Today, the term digital radiography is used in the literature and in practice to include computed radiography and direct digital radiography. Computed radiography (CR), is a system that replaced film with a storage phosphor plate as the image receptor. The latent image on the exposed plate is scanned by a laser beam and converted to digital data to produce the image. Direct digital radiography (DR), which also might be further classified as direct and indirect image capture, involves acquiring image data in digital format, without laser scanning to extract the latent image.

In CR, storage phosphor image plates were first used to record general radiographs in 1980. The direct capture of x-rays for digital images was introduced with DR using of a charge-coupled device in 1990. The technology evolved and improved over the next decade and by 2001, flat-panel thin-film transistor detectors could expose and display images in near real time. Growth in digital image receptors has risen slowly and steadily, and within a few years could increase to double-digit annual rates. Today's technology includes a variety of devices and materials such as storage phosphor plates, charge-coupled devices, thin-film transistors, photoconductors and x-ray scintillators. Cassette-based and cassette-less systems have blurred the lines between CR and DR. An analysis by the technologies market research firm Technavio reported that the global digital radiography market could increase by a compound annual growth rate of 3.3 percent through 2014. The complexity of the operation of these systems has created misconceptions about the best practices for the use of digital radiography.

In general, radiography examinations represent 74 percent of all radiologic examinations performed on both adults and children in the United States, and contribute to about 40 percent of radiation exposure. Although much attention in recent years has focused on lowering CT dose in particular, the prevalence of radiographic examinations, exposure and a rise in transition to digital image receptor technology necessitates a thoughtful and thorough examination of best practices for radiographers regarding digital exposure techniques and radiation safety.

Dose

When following the ALARA principle, radiographers should minimize patient exposure from digital radiography procedures. The use of digital image receptors can result in lower radiation dose than the use of film-screen image receptors, without loss of image quality. Using digital image receptors requires careful and consistent attention to institutional protocol and practice standards, however. Conventional film-screen radiation exposure techniques are based on the specific film-screen system and the conditions under which the radiographer processes the film. Digital radiography separates acquisition, processing and display, which enables a radiographer to produce an image that has acceptable diagnostic quality, but could be underexposed or overexposed. Adjustments to compensate for exposure technique errors can be made at the time of display, although doing so is not a best practice. **The best practice is to select the appropriate exposure technique factors for the patient's size and condition, based on a planned exposure system designed in collaboration with radiologists, to determine adequate image quality for diagnosis.**

Image quality depends heavily on contrast, or the relative differences in brightness or density in the image. Image contrast has two primary components, subject contrast and display contrast. Subject contrast is related to the absorption of the x-ray beam by the subject's tissues. Display contrast can be adjusted in postprocessing and by adjusting the monitor display's window width. Very low contrast (many shades of gray) makes it difficult for a radiologist to differentiate between structures and identify anomalies or pathologies; an image must have contrast to demonstrate different structures and to be diagnostically useful. Very high contrast reduces the image to a scale of mostly black-and-white brightness or densities, which hinders visibility of the anatomic details. In digital imaging, contrast is the ratio of brightness of adjacent structures to one another, and gray scale represents the range of brightness levels.

Subject contrast is determined by different absorption of the x-ray beam by various tissues, anatomic thicknesses and tissue densities in the body and the penetrability of the beam primarily controlled by kVp. Unlike image contrast, subject contrast cannot be manipulated or recovered with postprocessing; it is directly affected by how the x-ray beam is attenuated in anatomic tissues, such as bone and soft tissue.

The ability to adjust display brightness and contrast during postprocessing can affect radiographers' attention to the primary principle of radiation protection: optimal image quality with minimal patient exposure. Radiographers must pay careful attention to all aspects of radiographic exposure technique to provide diagnostic image quality and minimize patient exposure, helping to maximize benefit over potential harm. In addition, the wider range of radiation intensities that digital image receptors can detect has allowed for a wider range of values to be processed digitally to display a diagnostic quality image. Because image receptor exposure information is not apparent from the examination or recorded for each digital examination, there is further disconnect between image capture and the resulting patient exposure. **A best practice in digital radiography is the consistent inclusion of information regarding the image receptor exposure in the image data provided throughout the image archiving process.**

In digital radiography, the computer automatically adjusts an image that is overexposed to ensure that the image is of diagnostic quality. This automatic adjustment, separation of image acquisition and display and lack of available dose information can contribute to increased patient exposure. What's more, an excessive exposure to a patient during a digital radiography examination does not affect image quality, except at extremely high levels of exposure. In fact, the decreased image noise that results from additional exposure can lead to a corresponding decrease in complaints from radiologists regarding image quality. In turn, radiographers might be inclined to adjust exposure technique to slightly increase the amount of radiation and subsequently patient radiation dose.

These factors have contributed to dose creep and a gradual increase in patient exposure. Radiographers, often faced with feedback that unwittingly reinforces slight overexposure and lacking the visual cues that density offered in film-screen imaging, often choose the path of least resistance: increased exposure technique, decreased chance of image noise and avoidance of repeats.

Many standard practices and the control of dose creep require careful review and strict adherence to sound radiation safety practices to minimize patient dose. Radiographers also need access to collected and standardized information at the institutional and national levels to help them better navigate the transition to the best practices for radiation safety in digital imaging. Avoidance of repeat exposures, careful use of shielding and beam restriction, clearly established accepted ranges for exposure indicators (EIs) and other practices will be covered in the Best Practices discussion below.

Social Marketing and Radiation Safety Initiatives

Issues such as dose creep have not gone unnoticed. National and global attention have focused on medical radiation, and several initiatives have begun educating radiographers, physicists, radiologists, referring physicians and the general public. One such initiative, the Image Gently campaign sponsored by the Alliance for Radiation Safety in Pediatric Imaging, began in 2008 to promote radiation protection for children who have received medical imaging procedures. With an initial focus on reducing radiation dose to children undergoing CT examinations, the campaign soon progressed to fluoroscopic and interventional procedures, nuclear medicine and other medical imaging including routine digital radiography. In 2011, the campaign released a safety checklist for performance of DR examinations on pediatric patients. More than 14,000 medical professionals have taken a pledge to minimize radiation dose to children and the campaign's pediatric CT protocol has been downloaded from its website more than 26,000 times. More recently, the American College of Radiology (ACR), ASRT, American Association of Physicists in Medicine (AAPM) and Radiological Society of North America jointly developed the Image Wisely campaign to lower the amount of radiation used in medically necessary imaging and to eliminate procedures that are unnecessary.

Much of this change was brought about by media reports linking CT scans to childhood cancer. However, once ionizing radiation from medical imaging moved into the public arena, medical professionals could no longer deal with the matter in isolation. According to the ACR, the radiology community alone had focused on patient radiation safety issues until these potential hazards were publicized. Other members of the medical community and the public now see the issue more clearly. Multiple organizations and individuals have worked together to address the problem. The Alliance for Radiation Safety in Pediatric Imaging, which was founded by four imaging organizations, continues to be a leader in radiation safety initiatives.

There also have been international efforts to improve medical radiation safety. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published a report in 2010 that described a strategic plan through 2013. UNSCEAR asked the public, authorities and scientists to be more aware of radiation dose in medicine. At a 2010 meeting, UNSCEAR called for improved data collection, analysis and dissemination of information for patients and those exposed to radiation occupationally. The International Commission on Radiation Protection has updated reports and recommendations and the International Atomic Energy Agency launched an action plan in 2002 aimed at reducing patient exposure to radiation. The plan included an informational website for patients about radiation protection.

The World Health Organization (WHO) joined with other organizations and agencies in 2010 in calling for global sets of evidence-based referral guidelines for medical imaging. The European Commission committed to developing guidelines for its member states and has aimed to compel member states to adapt their national regulations and quality assurance programs to meet more standardized and stringent requirements.

The Society for Pediatric Radiology held a 2004 white paper conference on Feb. 28, 2004, in Houston, Texas, that summarized the need to emphasize the ALARA principle in digital imaging. The white paper conference faculty recommended a team approach to dose management. Other recommendations included improved training of radiographers and standardization of nomenclature among manufacturers to assist in understanding and minimizing dose, improved dose feedback, and development of standards in digital radiography. The findings and recommendations were published in an October 2004 supplement to *Pediatric Radiology*, the December 2004 issue of *Radiologic Technology* and the February 2005 issue of the *American Journal of Roentgenology*.

In 2010, the U.S. Food and Drug Administration's (FDA) Center for Devices and Radiological Health began an initiative to decrease unnecessary exposure from medical imaging procedures. As a result the FDA has supported the development of educational materials and a safety checklist for digital radiography via the Image Gently campaign. The FDA also has recommended that manufacturers design medical imaging equipment with pediatric populations in mind. Through education, research and reports in the literature and change in practice, culture change can occur. Much work still can be done to compel the culture and practice changes needed to ensure radiation safety and minimize patient dose in digital radiography.

ACR Practice Guideline for Digital Radiography

The ACR developed a practice guideline for digital radiography in 2007. The document's intent was "to provide guidance and assistance in the understanding and clinical use of digital radiography equipment in order to deliver optimal image quality at appropriate radiation doses, and to ultimately provide excellent safety and care for patients undergoing digital radiography examinations." In general, ACR practice guidelines for any examination or process undergo literature and field review, summary of expert opinion and informal consensus that results in recommended conduct. The guidelines are not intended to be legal standards of care; providers can use them as the basis for practice and modify them according to individual circumstances and resources.

The ACR guideline on digital radiography provides information lost in the gap between film-screen and digital imaging, and some of the key points of the guidelines are included in this paper. By clearly outlining information such as personnel qualifications, grid use, prevention of dose creep and determining proper exposure factors, the guidelines laid the groundwork for facility protocols and standardization of digital exposure technique. The ACR guidelines also compare film-screen and digital technologies, helping radiographers and other medical professionals better understand the nuances they face in working with digital imaging.

Scope of White Paper

The ASRT has championed radiation protection in digital imaging for all age groups through its support of and participation in the Image Gently and Image Wisely campaigns. In addition, ASRT has a continued history of promoting these areas of professionalism through publication of educational and promotional materials for the public and the medical imaging community. The Consistency, Accuracy, Responsibility and Excellence in Medical Imaging and Radiation Therapy (CARE) bill can help provide the foundation for national uniformity of licensure laws. The ASRT supports efforts toward the passage of the CARE bill to promote minimum standards in each state that ensure only educationally prepared and clinically competent radiographers perform radiographic examinations and radiation therapy procedures. This white paper is a significant continuation of ASRT's dedicated efforts in promoting radiation protection for patients and professionalism for radiologic technologists.

This white paper combines information from trusted sources such as the ACR guidelines, textbooks, professional and government organizations and periodical literature on exposure technique and patient exposure. The information gathered aims to support preparation of radiographers for digital radiography practice and to examine digital radiography's best practices for a balance of optimal image quality and patient radiation safety.

Radiographers assume extensive responsibility in the radiation safety of patients. The ACR white paper on radiation dose in medicine places final responsibility for additional action before radiation exposure on radiographers. Further, the paper states that "technologists are responsible for limiting radiation exposure to patients by ensuring that proper procedures and techniques are followed. …"

Radiographers who perform digital radiography examinations must recognize their responsibility in understanding how to optimize digital images while minimizing radiation dose to patients. As the "experts" on exposure technique in radiology teams, radiographers should be proactive in remaining up-to-date on the basics of radiation protection and new technologies.

The best practices and recommendations included in this white paper serve as a resource for radiographers who perform digital radiography examinations. This white paper is not, however, an all-inclusive document, nor should any of these recommendations be taken as superseding institutional policy or state regulations. In addition, much like digital technology, it is meant to be a fluid, living document.

Step-by-Step Best Practices

Radiographers need to take responsibility for understanding and appropriately performing digital radiography procedures because it is their professional duty and an essential component of the radiographers' practice standards and code of ethics. Aside from preparing for digital radiography examinations through attainment of proper education and skills sets, there are a number of ways before, during and after examinations that radiographers can optimize exposure technique and minimize radiation exposure.

Before the Exam Begins

Because radiographers usually are the first, and often the only, medical professional to interact with patients who are scheduled for radiology examinations, radiographers are charged with a great deal of responsibility even before examinations begin. Ensuring that patient radiation safety is maintained and exposure minimized requires regular attention to several matters before capturing the images. Some of the issues are common to the film-screen environment, but reiterated here.

Procedure Validity

As a patient advocate and the last medical professional to potentially screen for appropriateness before performing an examination, the radiographer has a responsibility to recognize and take action when an incorrect exam is ordered. In an ASRT survey of radiographers conducted for the Image Gently campaign, nearly 12 percent of respondents cited "unneeded exams ordered by doctors" as contributing to or causing excess radiation exposure when performing pediatric digital radiography. Inappropriate diagnostic imaging examinations unnecessarily add to cumulative radiation dose in patients. The radiographer might be the only person who has the opportunity to recognize that the examination is a duplicate or is questionable in terms of indication or appropriateness. Radiographers should consult with the radiologist or ordering physician or request additional information from the ordering physician that can further indicate the correct procedure to be performed when there is a suspicion of an inappropriate exam order.

On a broader scale, increased utilization of diagnostic medical imaging has added to increased patient radiation doses. A higher frequency of high-dose examinations can directly affect individual and collective dose. The issue of imaging overutilization is being addressed globally with calls for standardizing of image justification, along with social media campaigns and intervention of payers or other third parties.

Organizations such as the ACR have addressed utilization by developing guidelines to help referring physicians select the appropriate imaging procedure. An example is the ACR Appropriateness Criteria, evidence-based guidelines developed by panels of experts in imaging; the criteria cover several types of diagnostic imaging and therapeutic uses of imaging and ionizing radiation. The World Health Organization has proposed development of global guidelines for appropriate referrals to medical imaging. WHO hosted a conference in March 2010 with 36 experts from around the world; the experts recommended development of the guidelines under WHO's umbrella. The guidelines are expected to include radiation dose level for examinations, along with efficacy ratings and a grade for strength of existing evidence regarding each examination's efficacy.

Tracking of previous examinations also can help radiographers identify duplicate examinations before beginning the procedure. Reviewing health records can help spot duplicate examinations, but patients may have imaging examinations performed by any number of providers within a given time period. Many international organizations and agencies have approved or developed systems that track radiographic procedures in a fashion similar to vaccination records. Using a system-based approach that standardizes input from providers rather than patients could help facilitate identification of duplicate examinations and recording of cumulative dose. In addition to identifying duplicate examinations a radiographer must review the patient's health history with the patient. Important information can be obtained by asking routine questions of the patient to further validate the ordered examination and to determine whether the patient should have an examination that involves radiation. **It is a best practice in digital radiography for the radiographer to carefully review the examination ordered to prevent potential duplication and to ensure appropriateness as related to the patient's history. If there is a possibility that the examination might be inappropriate, the radiographer then should consult with the radiologist and/or ordering physician to ensure the appropriate examination is being obtained.**

Departmental Standards and Protocols

National or international guidelines and accreditation requirements provide the foundation upon which radiology departments can base their specific protocols for all imaging examinations, including digital radiography examinations. For example, if a radiology department does not develop exposure technique charts or make them available to radiographers, it is more difficult for radiographers to manually set milliampere-seconds (mAs) and optimal kilovoltage peak (kVp). When systems have automatic exposure control (AEC), other variables such as AEC detector cell configuration and backup time also can be standardized. Departments should establish protocols for common digital radiography examinations and conspicuously post them for radiographers' use.

Radiographers should expect to consult with radiologists and vendors to refine information provided by vendors for exposure techniques and protocols. Nuances in equipment, personal preference and learning curves for digital technology all could be factors that contribute to inconsistencies in exposure techniques. The best way for a radiographer to ensure consistency is by following department protocols that are based on established clinical research and guidelines.

Advantages of digital radiography include the ease of incorporating images and order entry into existing radiology information systems (RIS) and picture archiving and communication systems (PACS). In many ways, this has positively affected radiology department workflow, eliminating many manual steps and improving patient care and efficiency. For example, digital radiography is usually incorporated into facilities that have RIS, electronic health records (EHR) and PACS where the process from order entry to report generation involves little to no human interaction. The RIS and modality worklist system schedules a worklist for the digital radiography equipment, which bundles the information with the acquired images and sends it to the PACS. This information is available at the radiologist's workstation, and if the radiologist uses speech recognition software, the report is generated automatically for radiologist approval, then archived and distributed to referring physicians through the EHR.

The lack of human interaction is one reason that adopting a new technology and automating various ordering and hand-off processes can be less disruptive to patient care and decrease the potential for errors. Another is that the transition to a digital environment streamlines workflow. The transition from a film to a digital radiography environment can initially be very daunting when digital radiography is the first, only or final modality transitioned in a given radiology department, it is imperative to take steps to assess, prepare and establish procedures for digital image interpretation and storage. This preparation should involve technologists, who must have the proper tools and procedures in place to do their jobs correctly.

Though digital technologies simplify workflow, planning for workflow adjustments is critical. It begins with looking at current workflows for acquiring and interpreting images, along with quality assurance (QA). Radiographers and other team members must decide whether to attempt to duplicate workflow with digital technologies or improve them. They also must work together—and with vendors—to identify potential gaps in workflow or function. The team must then document the workflow and standardize protocols and procedures. Radiographers must follow the protocols and standards set by their departments and actively participate in establishing and further developing protocols that ensure consistency of diagnostic quality images and improved practices to reduce patient radiation dose. This is a critical best practice in digital radiography.

Screening for Pregnancy

As with film-screen radiography, the radiographer needs to carefully review the patient's history before beginning the digital examination to determine whether the patient is pregnant. How to verify pregnancy varies slightly according to department protocol, but typically includes asking women of childbearing age if there is any possibility they are pregnant. The radiographer can use physical signs and lead-up questions to aid in determining possible pregnancies. Tact and professional communication help put the radiographer and the patient at ease.

The exact protocol for proceeding once a patient responds that she might be pregnant is specific to the department. Departments often require written documentation before pregnancy screening can occur, and the patient's referring physician or radiologist generally decide whether pregnancy testing is necessary. The physicians also decide whether the patient should have an alternative imaging examination to avoid radiation exposure. **The screening of patients for potential pregnancy is an essential best practice for radiation safety in digital imaging.**

Image Acquisition

The foundations of radiographic exposure technique selection don't change simply because a radiographer uses a different type of image receptor. When producing images using digital technologies, radiographers still must determine the radiation exposure needed to produce a quality image for diagnostic interpretation. A quality image has sufficient density/brightness to display anatomic structures, an appropriate level of subject contrast to differentiate among the anatomic structures, the maximum amount of spatial resolution and a minimal amount of distortion. In addition, limiting the amount of quantum noise/mottle as a result of too few x-rays reaching the image receptor is a common concern in digital imaging. Many variables affect the acquisition, processing and display of a quality image and the advent of digital imaging has created new challenges for the radiographer.

Digital imaging technologies continue to evolve and vary in their construction and how the latent or invisible image is acquired. Common digital image receptors in routine radiography include computed radiography photostimulable image receptors, charge-coupled devices, and flat-panel thin-film-transistor detectors. Because the technology is rapidly changing, digital image receptors will be discussed as a category, digital imaging, and specific differences will be described where appropriate. Standardizing exposure technique and emphasizing sound practices can help ensure a radiographer follows the ALARA principle when performing digital examinations.

Standardized Exposure Technique

A digital image receptor responds to a large variance in x-ray intensities exiting the patient. As a result, the digital image receptor also has a wide dynamic range. In addition, computer processing produces "acceptable" images even when significant overexposure has occurred. Because of this, the standardization of exposure techniques used in a radiology department has become even more essential. Digital technologies are progressing rapidly, and departments cannot rely solely on vendors and professional organizations to set technical standards. Setting department policies and protocols helps the radiology department ensure consistency in diagnostic quality of digital examinations and minimizes the potential for exposure technique selection errors.

Standardizing exposure techniques, however, does not mean that radiographers use the same protocols for all patients in all situations. Exposure techniques must be adjusted for a patient's specific history and condition. Appropriate and consistent use of exposure technique charts, adequate kVp and AEC is essential to consistently producing diagnostic images while minimizing patient radiation exposures.

Kilovoltage Peak (kVp)

Image quality is dependent on a sufficient amount and energy of x-rays reaching the image receptor. As a general rule, kVp and mAs should be selected for digital radiography in the same manner as the exposure factors are selected for film-screen image receptors. However, the amount of exposure (mAs) to the digital image receptor does not directly affect the amount of density/brightness produced as a result of computer processing. Adequate penetration of the anatomic part (kVp) is needed to create the differences in x-ray energies exiting the part to produce the desired level of contrast. Given adequate penetration of the part, kVp has less of an effect on the contrast of the image because of computer processing. A quality digital image is produced following adequate penetration (kVp) along with enough mAs to produce a diagnostic image with a minimal amount of quantum noise/mottle.

The use of higher kVp values along with an appropriate decrease in mAs is a practice advocated by some imaging professionals for many adult digital exams. Increasing the kVp by 15% with a corresponding decrease in mAs reduces patient radiation exposure. Because increasing kVp decreases image contrast and increases scatter radiation reaching the image receptor, the use of a grid may be necessary. Specifying the kVp level for digital exams along with grid use are important exposure technique variables to standardize in a radiology department. **A best practice in digital imaging is to use the highest kVp within the optimal range for the position and part coupled with the lowest amount of mAs needed to provide an adequate exposure to the image receptor.**

Automatic Exposure Control

The AEC for digital radiography systems operates identically to AEC used for film-screen systems. It is critical that the AEC be properly calibrated to match the image receptor system before clinical use. AEC systems use radiation detectors called ionization chambers that are preprogrammed based on phantoms. These systems traditionally come equipped with three ionization chambers; some newer AEC systems have five detectors from which to choose. It is important that radiographers choose the appropriate detector configuration for the examination.

The purpose of AEC is to control exposure time, so use of this feature is critical to patient radiation safety. AEC helps control total mAs, but the radiographer still is responsible for selecting optimum mA (if set) and kVp for an examination when using AEC, and technique charts help ensure consistent use of these factors with AEC. Although AEC use is recommended in most radiographic examinations to help reduce patient radiation exposure, there are times when it can't be used. For example, if the anatomy of interest is too small to cover at least one of the AEC's detector cells, AEC will not work and should not be used. If AEC is used when the anatomy of interest is too small, those areas of the detector not covered by the patient's anatomy receive more radiation than the area of interest, causing the AEC to terminate the exposure time prematurely and causing quantum noise in digital images. This is especially important to consider when performing pediatric radiography. Using AEC to image anatomy close to the edge of the patient's body, such as the clavicle, also can cause the time of exposure to prematurely terminate and result in insufficient exposure to the image receptor resulting in increased quantum noise. Finally, presence of large metal artifacts such as orthopedic hardware can contraindicate the use of AEC. Unless large metal objects can be moved away from the area of interest, they create unexposed areas over the AEC detectors that can affect the time of exposure and potentially overexpose the patient.

Although use of the unit's AEC is the best way to control the amount of radiation exposure regardless of the type of image receptor, doing so requires accurate positioning and systematic calibration of the AEC. Radiographers should ensure that the anatomy of interest covers most of the AEC detector(s) used, and place emphasis on proper positioning for an examination. It is important for radiographers to follow department protocols and exposure technique charts regarding use of AEC. **A best practice in digital radiography is to use AEC when indicated and to use AEC that has been calibrated to the type of image receptor to provide a consistent exposure to the image receptor.**

Anatomically Programmed Radiography and Exposure Technique Charts

Anatomically programmed radiography (APR) is a system of preprogrammed exposure technique settings that is organized by position and procedure and set through the control panel of the radiography unit. APR settings commonly provide recommendations for small, medium and large adult patient sizes and include a combination of AEC and manual exposure technique settings. It is important for the radiographer to assess the programmed exposure technique for its appropriateness to each radiographic examination.

An exposure technique chart also can be used to standardize exposure techniques according to patient size, procedure and position. Use of exposure technique charts is required in some states and as a standard of care per The Joint Commission. Departments can provide the charts with relatively simple spreadsheets that are posted and accessible to radiographers. Although exposure technique charts take time and effort to develop accurately, they prevent exposure technique errors. Routine use of the charts is can provide consistent and accurate radiation exposure to the image receptor, thereby reducing patient dose.

Providing exposure technique charts establishes department standards and eliminates much of the confusion and concern regarding appropriate use of variables such as kVp, mA, grid use and SID. The charts also allow radiologists and technologists to work together to determine an acceptable level of radiation exposure that provides diagnostic quality images within the ALARA principle. A thorough exposure technique chart includes, at a minimum, the following variables for each x-ray tube:

- Backup exposure time or mAs (if set).
- Source-to-image receptor distance (SID).
- kVp.
- Focal spot size.
- mA (if set).
- Use of a grid and the grid ratio.
- AEC detector(s).
- Acceptable exposure indicator range.

Typically, exposure technique charts are developed based on patient thickness. Although measuring patient thickness in adult imaging may not be practical in all departments, well-developed charts that are consistently used can reduce the variability in exposure techniques that occurs during digital imaging. The charts don't take the place of radiographers carefully assessing individual patient pathology, condition and unusual circumstances because exposure technique charts are designed for the average or typical patient. Exposure technique charts should be monitored and revised continuously to ensure exposure techniques are producing diagnostic images within the ALRA principle. **A best**

practice in digital radiography is to use exposure technique charts that are continuously improved and applicable to a wide range of patient sizes.

Collimation and Electronic Masking

It is essential that radiographers carefully use collimation to the appropriate anatomy of interest when performing digital examinations to minimize patient exposure and prevent errors in processing of the digital image data. By limiting the anatomy that receives radiation, a smaller area of the patient's tissue is exposed, thereby reducing patient dose and minimizing scatter radiation to the image receptor. Collimation is very important in digital radiography because digital image receptors are more sensitive to low levels of radiation, and the resulting digital image might demonstrate reduced image contrast because of excess scatter radiation striking the receptor.

Digital radiography systems have software that provides electronic masking (collimation) based on recognition of the borders of the exposed area of the image receptor; radiographers may need to adjust the electronic masking to accurately align it to the exposure field. The unexposed area of the image outside of the collimated exposure field has a bright appearance on the display monitor that affects viewing conditions. The purpose of the masking is to reduce the eye strain of the viewer caused by high brightness levels. To document appropriate collimation for an examination, the mask should be applied to the image with a small distance between the exposure field and the start of the mask overlay.

Masking, shuttering or cropping should not be used as replacements for beam restriction achieved through physical collimation of the x-ray field size. The appropriate use of masking is to act as an overlay on the areas outside of the collimated exposure field; masking never should be used to cover anatomy that is contained within the exposure field at the time of image acquisition because of legal and radiation safety concerns.

The appropriateness of including multiple exposures on one image receptor depends on the type of image receptor being used. If the image receptor is capable of acquiring more than one image prior to image processing, the decision to do so should be determined by the department protocol established in consultation with the radiologist. When multiple fields are included on one image receptor, radiographers should keep the exposure fields aligned, avoid overlapping fields and use flexible lead shielding on all areas of the receptor not being exposed by the x-ray beam, regardless of image receptor technology. The literature includes several reports stating that the use of collimation that uses a smaller field size could help lower radiation doses to patients.

A best practice in digital radiography is to collimate the x-ray beam to the anatomic area appropriate for the procedure. Electronic masking to improve image viewing conditions should be applied in a manner that demonstrates the actual exposure field edge to document appropriate collimation. Masking must not be applied over anatomy that was contained in the exposure field at the time of image acquisition.

Shielding

Lack of patient shielding can contribute to increased patient dose. Shielding is particularly important to protect anatomic areas near the exposure field, but should not interfere with obtaining diagnostic information. At a minimum, a patient's gonads should be shielded when within 5 cm of the edge of a properly collimated x-ray beam.

Radiographers should follow department guidelines for proper shielding. This is particularly critical for digital examinations because shielding can interfere with the equipment's ability to optimize display for the region of interest if the shielding material is included as part of the data used for processing the image. Shielding is a fundamental radiation safety practice that remains important when performing digital radiography. **A best practice in digital radiography is the use of lead shielding for anatomic parts that are adjacent to the x-ray field.**

Anatomic Side Markers

Radiographers should use lead anatomic side markers that are placed on the image receptor for digital radiography examinations. Electronic annotations of anatomic side on the image during postprocessing are not an acceptable substitute for lead markers captured during the exposure to the image receptor as part of the original image. Failing to use lead markers to denote the side or to identify the radiographer performing the examination can be a legal issue. The ACR also emphasizes consistent use of lead markers in its digital practice guidelines. **A best practice in digital radiography is the consistent use of lead anatomic side markers captured on the original image during the x-ray exposure.**

Grids

The fact that digital imaging technology is more sensitive to low-level radiation exposure makes the use of antiscatter grids critical to ensuring quality images. A major disadvantage of using a grid is the required increase in radiation exposure to the patient. However, using a grid decreases the amount of scatter radiation that reaches the image receptor and improves image quality. Department guidelines and exposure technique charts should assist radiographers in determining whether to use grids for specific radiographic examinations. As a general rule, grids are appropriate for anatomy that is 10 cm thick or more and for examinations using kVp settings of 70 or higher. Grid use could vary for pediatric patients, however, or based on department protocol or recommendations of the equipment vendor. In addition, it is important to consult with the vendor to match the appropriate grid design to the digital imaging system to prevent artifacts. **A best practice in digital imaging is the use of a grid with specifications recommended by the digital imaging equipment vendor, generally for body parts that exceed 10 cm.**

Positioning

Accurate positioning is critical to radiographic image quality. Positioning errors have been identified in several studies as the number one reason for having to repeat digital radiography examinations. The increase in exposure latitude in digital radiography seems to have led to an overall reduction in repeats, and the cause of most repeat imaging has shifted to positioning errors. Inaccurate positioning of the part relative to the image receptor, along with a poorly collimated exposure field, often results in poor quality digital images. Independent of the image receptor system, it is critical that all positioning be performed accurately according to national standards and department protocol with accommodation for the patient's condition to prevent the need for a repeat exposure.

Immobilization is a critical component of positioning that helps to prevent retakes, particularly in examinations of pediatric patients. The radiographer must note that some immobilization devices used in positioning patients such as sandbags, and sponges with plastic coverings can cause artifacts in digital imaging and must be kept out of the exposure field. **A best practice in digital imaging is to use immobilization devices when needed and prevent repeat exposures by appropriately positioning the patient.**

Considerations for Pediatric Patients

Pediatric patients are not just small adults; they require special attention from the radiographer. Therefore, many of the factors radiographers must consider during adult radiographic examinations should be given special consideration when performing radiography of pediatric patients. Pediatric patients have developing organs and are up to 10 times more sensitive to ionizing radiation than are adults. They also have longer life expectancies, so attention to ALARA for pediatric digital examinations is essential.

Beam Attenuation and Tissue

Tissue thickness, body habitus and tissue composition result in differences in x-ray beam attenuation. This is the basis on which digital and all radiologic imaging creates radiographs. For example, muscle tissue is more dense than fat tissue, and requires an increase in technique so that the beam can adequately penetrate the muscle tissue, regardless of the patient's size. Reconfiguring techniques applied to adult tissues for use on children does not work; the dimensions of children's anatomies vary much more than those of adults. This makes it difficult to estimate exposure technique because patient thickness depends not only on a child's age, but also on the child's individual characteristics.

In addition to the variation in growth along the age continuum and from one child to another, children's body parts grow at different rates. For example, the femur of an infant is one-fifth the size of an adult femur, and represents the extreme in development from birth to adulthood. On the other hand, an infant's skull grows more slowly, only tripling in size by adulthood. Grids typically are not used when anatomy is less than 10 cm, so radiographers must carefully consider whether to use grids based on the patient's actual size and tissue composition. Because the tissue composition is different in pediatric patients, a grid should not be considered for body parts less than 12 cm in thickness.

Exposure Technique

In pediatric radiography, APR and exposure technique charts must be adjusted for patients who may vary from premature infants to obese adults. Radiographers must carefully select optimal kVp to penetrate the pediatric patient's anatomy under study. Selection of appropriate kVp is more critical with exams of infants and children because their bodies typically display less subject contrast. Infants and young children have bones with less calcification than adult bones, which requires lower kVp compared to that required in adult exams. As a result, radiographers can reduce kVp, but still adequately penetrate the bone with the x-ray beam for a diagnostic-quality image.

Adult AEC settings cannot be used for pediatric patients. Radiographers who use AEC settings for imaging pediatric patients should follow the Imaging Gently digital safety checklist, which emphasizes that radiographers must be diligent in ensuring that the appropriate kVp, backup time, image receptor and detector (or detectors) have been selected. Radiographers may need to use of manual technique selection in pediatric radiography where the part is smaller than the ionization chamber.

Collimation/Shielding

Appropriate collimation and minimizing the anatomy exposed to radiation can reduce radiation dose to pediatric patients. As with adult examinations, proper alignment is critical to ensure essential anatomy is included in the image. Studies have found that poor collimation of lumbar spines led to unnecessary radiation exposure for children. Proper shielding also can help reduce dose. Lap shields and half-shields can help protect children's gonads. Specially shaped shields can be helpful for male gonads or female breasts. It is important, however, with some digital radiography systems that shields not interfere with the software's ability to identify the exposure field. Protocols may be established that allow for the use of a shield on one projection when multiple projections in the same area of the gonads are required. Radiographers should follow department protocols regarding collimation and shielding for pediatric examinations.

Positioning and Immobilization

Because pediatric patients have more trouble complying during positioning and image capture, the anatomy might not be centered accurately or consistently within collimation boundaries compared with adult positioning. In some digital imaging systems, improper centering affects how the digital system software forms the image. Immobilization devices may help ensure that the pediatric patient can be imaged without need for repeat. However, care needs to be taken when using some standard immobilization aids that can create artifacts on digital image receptors. A variety of toys, books and other distraction tools also can be used to help comfort or focus pediatric patients to support their compliance with the positioning requirements of the procedure.

A best practice in pediatric digital radiography is to take appropriate actions to use ALARA principles, radiation protection, and size-appropriate exposure techniques. Proper positioning and immobilization also are necessary to decrease repeat exposures.

Image Critique

Radiographers must ensure that they thoroughly critique their radiographs to review each image for the following:

- Correct patient and examination information.
- Brightness/contrast.
- Exposure indicator.
- Processing errors.
- Required anatomy.
- Positioning accuracy.
- Artifacts.

In short, the radiographer's review is important to ensure that the images contain the information the radiologist needs to interpret the image for pathology and clinical reporting.

Image Appearance

The visual cues of underexposure and overexposure errors are more difficult to recognize or are missing in digital radiography as a result of what happens to the image data during imaging processing. A common misconception is that the digital system "fixes" exposure errors, when in fact it does not. During the analysis of the image data, the potential exists for the digital system to make adjustments to the image data so that the image has an acceptable brightness level in the presence of underexposure and overexposure. The exposure error remains regardless of what occurs during imaging processing. Underexposure appears on the digital image as quantum noise/mottle that is clearly visible in the thicker portions of the anatomy contained in the image. Overexposure results in a loss of image contrast throughout the image because of the increase in radiation striking the image receptor. In the event of significant overexposure, the result is the radiologist's inability to see all anatomical structures normally visible in the image because of saturation. The saturation can be seen regardless of image brightness and contrast settings. It is up to the radiographer and radiologist to determine whether an underexposed or overexposed image is of diagnostic quality.

Exposure Indicator

Digital systems lack the visual cues that lead to the recognition of exposure errors when working with film-screen imaging systems. As a result, the radiographer needs to monitor the exposure indicator (EI) associated with the digital imaging system. Monitoring the EI for each image helps to track and eliminate trends that can lead to dose creep. Radiographers should assess EIs as part of image critique, keeping in mind the variability among vendors and the limitations of the EI.

Exposure indicators have been developed by most equipment manufacturers. The purpose of the EI is to allow the radiographer to assess the level of exposure the receptor has received and thereby determine if the correct exposure technique for the image was used. At the present time, the name of the EI varies widely among manufacturers. In addition to the variations in name between manufacturers, the relationship between a change in the level of exposure and the corresponding change in EI is anything but uniform between manufacturers. The lack of a standardized name and l response relationship between dose and exposure indicator creates confusion for radiographers who work with equipment from multiple manufacturers, or of different ages from the same manufacturer. It is critical to note that EI's are not measures of radiation dose to the patient and reiterate that EI records the level of exposure to the image receptor.

The vendor community has responded, and by a joint effort of the International Electrotechnical Commission, the Medical Imaging and Technology Alliance (MITA) and the American Association of Physicists in Medicine (AAPM), manufacturers are implementing an international standard for EIs called IEC 62494-1. The IEC standard provides common EI values for use with all types of digital image receptors. The standard EI values do not provide an actual patient dose, but instead provide an estimated value of the incident radiation exposure to the detector for each acquired image.

In 2009, the AAPM published AAPM Report 116: An Exposure Indicator for Digital Radiography. The report contains multiple recommendations regarding the standardization of an exposure indicator. The recommendations of greatest significance to the radiographer are the use of consistent terminology between manufacturers; a uniform response relationship between receptor exposure and exposure indicator; identification of target exposure values for examinations and a clinically relevant exposure level indicator. Another of the many recommendations contained in the report is that each technologist workstation include a prominent display of the DI following each image.

The deviation index (DI) is an important term to recognize and understand. The deviation index is based upon the established target exposure index values for the examination. The purpose of the deviation index is to provide the radiographer with feedback related to the level of exposure used to create the image and to aid in determining whether corrective action is required.

As a best practice in digital radiography, radiographers must become familiar with the specific EI standards for their equipment, and with the newer standardized EI and DI as they become

available in new and upgraded equipment used for digital radiography.

Exposure Indicator Limitations

It is important to remember that currently the EI is an indication of incident exposure at the image receptor and not the radiation dose to the patient. A radiographer must understand the exposure technique factors that lead to the EI value. During the processing of the image data, a portion of the sequence involves the identification of exposure field borders. Errors during exposure field recognition can cause inaccurate standard deviation readings, and causes of exposure field recognition errors vary among vendors.

Other limitations are the varying methods that manufacturers use to determine relevant image regions to analyze when generating EI values. Further, the wide exposure range afforded by digital imaging and issues such as poor collimation, patient positioning or a patient's unusual body habitus can cause EIs to be higher or lower than expected. Completing an examination with an acceptable EI should not automatically be accepted as verification of proper technique. **A best practice in digital radiography is the effective use of the EI to determine whether adequate exposure has reached the image receptor. The EI provides valuable information about exposure to the image receptor, and when evaluated along with image quality, assists the radiographer in determining whether the digital image meets departmental standards. Because the EI has limitations, the radiographer must carefully assess whether a repeat exam is necessary.**

Artifact Analysis

Artifacts are unwanted densities in the image that are not part of the patient's anatomy and may negatively affect the diagnostic quality of the image. The classification of artifacts with film-screen imaging are based upon how and when the artifact is recorded on the image. Radiographers are accustomed to identifying artifacts in film-screen radiographs, along with their causes. Artifacts are classified according to cause: exposure, processing and handling/storage. Artifacts on digital images also can be classified into exposure, processing and handling/storage. Regardless of the acquisition method, radiographers should determine the cause of any artifact on a digital image and report it according to departmental policy.

Storage Phosphor Artifacts

Storage phosphor based image receptors used in CR may be cassette-based or cassette-less. Because of the manner in which the image data is captured and subsequently processed, storage phosphor based receptors present artifacts that are unique to their design. The phosphor plate may be the source of the artifact. Dust, stains, cracks and scratches are some of the causes of artifacts in the image. Identifying plate artifacts is a straightforward process because the artifact only occurs with one particular plate. Removing the damaged plate or cleaning the dirty plate corrects the problem. Cleaning of the phosphor plate should be done in accordance with the manufacturer's directions.

When artifacts occur routinely across multiple examinations, they most likely are caused by problems that occur during the reading of the plate. A description of the components of the plate reader is beyond the scope of this paper. However, a few key components that often are involved with artifacts that occur at the time of plate processing are the light guide, mirror optics, laser system and plate transport mechanism. Determining the source of a plate reader artifact can be challenging. The artifact needs to be described in terms of its brightness, size, shape and location on the image.

Another source of image artifacts that occur across multiple examinations involves the electronic and software components associated with the image creation. Identifying the specific source of this type of artifact is particularly difficult because of the frequency of their occurrence and the complexity of the electronic circuitry. The appearance of these types of artifacts also should be described in terms of their brightness, size, shape and location on the image.

Finally, some CR image artifacts are caused by problems with the hardcopy printer; these closely resemble film-screen artifacts. Fog, pressure marks and static electricity can appear on printed images. Image distortion, abnormal shading and uneven distribution of line scans can occur when the printer's film conveyor system malfunctions. Radiographers also can cause artifacts on the printed CR image if they place single-emulsion film upside down in the printer.

Direct Digital Receptor Artifacts

The flat panel TFT and CCD-based receptors are highly integrated and use complex electronic systems. The flat-panel TFT receptors may be cassette-based or cassette-less. At the time of this writing, the CCD-based receptor is cassette-less. The appearance of artifacts on these systems is described in terms of their brightness, size, shape and location on the image. The appearance of an artifact with direct digital systems can be the loss of an individual pixel within the image or the loss of rows or columns of pixels. In addition, system calibration issues can affect the entire image, resulting in an image that does not have the proper brightness and gray scale. Correction of the artifacts associated with direct digital systems may occur by using a built-in calibration software or may require contacting service personnel to repair the equipment.

Image Processing Software Artifacts

Digital systems have elaborate software that is used to process the image data to produce a specific image appearance. The radiographer's selection of the processing menu (specific to the body part and examination) is a critical step during the imaging process that helps minimize the likelihood of image processing artifacts. Each examination menu has associated computer analysis codes that are specific to the examination and designed to determine the image appearance.

On some systems, the processing menu also determines how the EI is calculated for that examination. It is because of this specificity that the radiographer needs to select the appropriate processing menu to avoid processing artifacts and miscalculation of EIs. The selection of the processing menu affects the display qualities of the image, and in some systems menu selection can affect the spatial resolution of the image. The common display qualities of the image that menu selection can control are brightness, contrast, edge enhancement and equalization. The specifics of how each of these display characteristics is manipulated are beyond the scope of this paper. In the circumstance that a selected processing menu does not produce the desired image appearance, the radiographer needs to determine whether how the exam was performed caused the poor quality image or whether the menu needs correction. The menu should only be corrected by someone with a thorough understanding of image processing as it applies to the specific piece of equipment. It is important to note that when used inappropriately, edge enhancement and equalization can degrade the diagnostic quality of the image submitted to PACS and therefore potentially affect the final image interpretation.

A best practice in digital radiography is to recognize image artifacts and prevent future artifacts from occurring by properly maintaining or acquiring service for the digital radiography equipment. In addition, a best practice in digital radiography is selection of the correct processing menu for an examination to ensure image quality.

Medical-legal Considerations

The radiographer must review the image from a medical-legal standpoint, taking into consideration such indications as ensuring that lead markers were used and are visible on the digital image, and that patient name and date of exam are imbedded in the image. All departments should have documented policies and procedures regarding digital imaging. Radiographers should adhere to these policies and should document sound reasons for deviations from these policies and procedures for a given examination. Radiographers must review the image not only for adequate exposure technique and image quality with radiation safety in mind, but also for medical-legal implications.

Following Examination Completion

It is helpful for radiographers to remember that image acquisition, processing and display are separate stages in digital imaging. As a result, images can be evaluated and optimized throughout each stage. As a best practice, however, radiographers should resist the urge to modify image features after images have been processed and displayed. There are steps radiographers should take after the examination is completed, though, to ensure that data associated with the image (dose and demographics) are recorded and that the final image is prepared for diagnostic interpretation.

Postprocessing

Digital imaging offers postprocessing capabilities that are not possible with film-screen radiography. Regardless, radiographers should perform postprocessing of digital images only if necessary. Any electronic masking that the radiographer performs on the image should take place only outside of the actual exposure field, and not be confused with collimation during the image acquisition stage.

The digital image has original, raw data that should be kept intact. Postprocessing can change the original raw data and the set point that establishes the levels of gray scale assigned to the pixels. A change in the raw data can cause loss of information and thereby affect the viewing capabilities in the PACS system where it will be accessed by the radiologist or referring physician for diagnosis. Therefore, radiographers should adjust window level or width settings only if absolutely necessary. As described in the previous section on image processing software artifacts, if radiographers find that the processing menu chosen does not provide adequate image quality, they should identify the cause of the poor image quality and determine appropriate corrective action. The processing menus are designed to provide optimum image quality relative to the anatomical part exposed to x-rays. If the processing menu consistently provides inadequate image quality, the radiographer should report the problem for adjustment.

Recording of Exposure and Dose Data

All EI and exposure technique information (such as mAs and kVp) should be included with the digital image. All exposure information should be displayed for the radiographer upon image review, and should be retained as part of digital imaging and communications in medicine (DICOM) information imbedded in the DICOM header. In digital radiography systems where the x-ray control panel is not connected to the image receptor electronically, such as with many cassette-based systems, the radiographer should record the technical factor information in the electronic data associated with the image.

It is best practice that all radiation exposure information be recorded without radiographer intervention to eliminate errors or incomplete records, and international standards have been issued to ensure this occurs. The standards may not apply, however, to all types and brands of equipment, particularly cassette-based systems. Radiology departments should work closely with vendors and PACS administrators to determine how EIs and technique factors can be recorded according to departmental policy and attached to and transmitted with the image. Currently, radiographers can add missing information only in technologist notes.

Inclusion of exposure information on every final digital radiograph will help enable radiographers to take note of and use the information for refinement of exposure technique selection. Inclusion of data related to technical factors on every final exam's DICOM header should ensure that the radiology department can maintain quality and adherence to the ALARA concept. It is essential that EI values and exposure technique factors be recorded and tracked along with dose information. **It is a best practice in digital radiography to electronically record exposure technique, EI and dose data with the radiographic image to allow for assessment and refinement of technique selection practices.**

Quality Assurance

The need for sound quality control (QC) practices as part of a quality management program is important in digital imaging. Radiographers are the operators of complex imaging equipment and therefore are the individuals who may first recognize equipment malfunction. In addition, as with film-screen radiography, human error can occur with digital imaging, and these errors must be acknowledged and corrected to prevent trends that could jeopardize patient radiation safety. Even more important, problems that occur in digital acquisition or processing equipment tend to be systematic problems, which can affect the quality of every image and the radiation exposure of every patient until the problems are identified and corrected. Acceptance testing, regular calibration and proactive and consistent QC can prevent these systematic errors; repeat analyses can contribute to overall department quality improvement.

Equipment Acceptance Testing and Calibration

Digital equipment is calibrated at the manufacturer's site, but conditions change when the equipment is installed on site. A sound QC program begins with thorough and organized acceptance testing immediately following equipment installation and before clinical use. The facility's medical physicist should be actively involved in the acceptance testing, following the most current AAPM task force recommendations for establishing standards of performance for digital equipment. Initial testing and equipment calibration often is followed by a period of observation while the device undergoes routine use. Initial acceptance testing and calibration also helps the physicist establish a baseline performance for the equipment and subsequent QC testing, which should occur systematically to reestablish a baseline.

Systematic Quality Control

Generators and x-ray tubes generally remain the same when converting to digital systems, but other parts of digital systems are new to radiographers and require updated QC policies and procedures. Departments transitioning to digital may have to revise their QC procedures to accommodate digital imaging. Regular performance testing and calibration of equipment should be done in accordance with equipment manufacturer specifications, industry standards and any applicable state and federal regulations. ACR guidelines recommend that a medical physicist assist in establishing the systematic QC program, monitor results and assist with corrective actions. In addition, radiographers must become familiar with the performance operation of the equipment in an effort to identify potential equipment malfunction and report their concerns to the appropriate individuals.

The guidelines also recommend that an on-site radiographer be responsible for conducting routine QC noninvasive activities. Radiographers should perform daily and periodic checks of equipment that do not require physicist involvement. For example, the radiographer should inspect the digital system daily for possible physical defects, perform weekly phantom testing for image quality and artifacts, and inspect and clean image receptors routinely. It may not be possible to perform every QC test daily, but periodic testing can identify potential equipment malfunction. Examples follow below, but each department may vary, depending on the established quality assurance program, along with institutional, state and federal regulations or accrediting standards.

Image Receptors

QC procedures on image receptors may vary depending on the type of digital imaging equipment and manufacturer. It is important for the radiographer to follow the manufacturer's recommendations and recognize performance malfunctions. At a minimum, radiographers should perform routine equipment self-tests and calibration procedures where appropriate or image a QC phantom to assess equipment performance on a regular basis. In addition, CR imaging plates should be visually inspected for damage or artifacts and cleaned appropriately. Radiographers also should perform secondary erasure of plates daily at the start of their shifts to prevent exposure artifacts.

Display Monitor

Display monitor performance has taken on added importance because digital images only are viewed electronically for quality review and diagnostic interpretation. Though most QC activities for monitors are not the responsibility of radiographers, it is helpful to understand the basics of monitor performance. Radiologists' display monitors used for interpretation (primary) should be tested and monitored according to specifications set forth by the manufacturers and the ACR Quality Control Manual, along with applicable state and federal regulations. Devices degrade at different rates, but generally should be tested at least monthly, and more frequently as they become older. There are more stringent guidelines in place for diagnostic monitors than for secondary display monitors, which are found at the radiographer workstations. It is important that monitors throughout a work area be consistent in terms of spatial resolution, luminance (the amount of light emitted) and contrast resolution.

Radiographers should physically inspect their digital workstation monitors daily. Physicists use Society for Motion Picture and Television Engineers (SMPTE) or AAPM test patterns as minimum QC checks for display monitors as well. A QC test pattern should be imaged and displayed to test normal operation and stored to compare results over time.

Repeat Analysis

A repeat analysis should be a component of any quality assurance program in radiology. The monitoring of repeats allows for the assessment of overall image quality, modification of examination protocols, the need for in-service education, and tracking of patient radiation exposures. Radiographers need to accurately identify and document the reason for a repeat image. Analysis of the department's repeat rate provides valuable information for process improvement and the overall performance of the radiology department, and helps minimize patient radiation exposure.

It is a best practice in digital radiography to implement a comprehensive quality assurance program that involves aspects of quality control and continuous quality improvement, including repeat analyses that are specific to the digital imaging system.

Workplace Culture

When departments convert to digital environments, the effects are felt beyond the demands of learning to operate new equipment. Digital imaging affects workflow within and outside of the radiology department. Although numerous personnel must adjust, the implementation of digital radiography affects radiographers more than any other staff members. The electronic transmission of images from radiographer to radiologist and other workflow issues have significantly reduced the amount of direct contact between the radiographer and the radiologist, thereby affecting their working relationship. Radiographers have less opportunity to discuss image quality or other issues with the radiologist. Only teamwork and open efforts at communication can ensure a smooth transition and an ongoing culture of quality, safety and efficiency. It is up to radiographers to personally emphasize a culture of safety and professionalism and to pursue open discussions regarding digital radiography to learn from and support radiologists and other technologists.

Safety and Professionalism

Digital radiography is expected to improve workflow and patient throughput. As a result, radiographers often are expected to work faster or manage more patients. It is critical that radiographers continue to adhere to protocols and retain their responsibilities for patients even in this fast-paced environment. The potential for harm in performing radiologic examinations is high. A culture of safety and professionalism emphasizes patient safety and advocacy, and recognizes the radiographer's critical role as the professional who delivers radiation to patients. The American Registry of Radiologic Technologists (ARRT) Code of Ethics and ASRT Practice Standards for Medical Imaging and Radiation Therapy both emphasize professionalism and radiographers' participation in and adherence to patient safety activities. The ASRT Practice Standards also emphasize innovation and lifelong learning.

It is essential that radiographers continue to learn in an industry with technological advancements as the norm. Radiographers should learn from one another as well as from vendors, supervisors, physicians and formal education or continuing education programs. Most of all, a culture of safety and professionalism recognizes improvement and modification of systems and operations over punishment of individuals. Successful safety cultures are proactive, working to prevent error events. Prevention of errors requires transparent reporting without fear of reprisal and with the intent of continuous improvement. Thus, a strong teamwork environment is imperative.

Promote Collaboration and Radiation Safety in the Workplace

The culture of safety and improvement must take place within a fluid workforce. This can be positive if members approach it professionally and as a team. For example, ARRT data show that by 2015, the age of radiologic technologists in the workplace will "balance," and workers from the baby boom, generation X and generation Y demographics will each make up about one-third of the workforce. In a 2011 ASRT workplace survey of hospital-based radiologic technologists, 11 percent of registered radiologic technologists said they had left the radiologic sciences field. Of those 11 percent, nearly 26 percent said they left because they retired.

Most recent graduates have been educated using digital radiography, and can contribute to the understanding of practicing radiographers regarding the technology and workflow. To do so, however, experienced radiographers must be open to the recent graduates' input. On the other hand, recent graduates must appreciate and respect the backgrounds and practical knowledge of experienced technologists.

Donnelly et al implemented a comprehensive approach to patient safety in a radiology department that included teamwork with other hospital departments, addressing staffing, opening communication and feedback mechanisms, teamwork, nonpunitive error responses and support from supervisors and hospital management for patient safety. The number of days between serious safety events increased nearly fourfold. Emphasizing teamwork and implementing formal safety programs can shift the culture toward one focused on overall patient safety instead of simply reporting errors or concerns about exposure alone.

A best practice in digital radiography is the development of a collaborative and supportive work team in which team members learn from one another and practice radiography safely and ethically.

Applications Training and Support

The ACR guideline for digital imaging recommends that radiographers performing digital examinations be trained to properly operate the systems they routinely use. The training should include image acquisition technology, image processing protocols, proper selection of protocol options for specific examinations, image review, EIs and radiation safety during procedures. Though it is appropriate for radiographers and their supervisors to rely on applications training to supply equipment-specific training in these skills, it is the responsibility of the radiographer to have base knowledge regarding digital radiography while using radiation exposure techniques and ALARA principles designed to minimize patient radiation exposure.

The ASRT practice standards state that radiographers should be educationally prepared and clinically competent to perform their jobs. Education and clinical preparation include being prepared to perform digital examinations should their departments use the technology. Managers should support these efforts, but it is the responsibility of radiographers to take advantage of the literature, seminars and other educational tools available to them to become clinically competent. The radiographer must retain all skills necessary for performing examinations and work cooperatively with radiologists to reduce radiation exposure.

The variation in vendor-specific features necessitates thorough and ongoing applications training for digital equipment. Radiology departments and radiographers should be proactive in seeking help from vendors, particularly during equipment installations and upgrades to provide appropriate training, however, vendors also must ensure that their applications specialists and support personnel are continuously trained and updated on changes to technology. Vendors and radiology department managers must work together to determine training expectations in advance, which includes preassessment and postassessment of trainees' skills and time expectations. Once applications trainers arrive on site, managers must support radiographers' attendance at training, and trainees must remain engaged throughout training completion. It also is essential that all members of the digital imaging team, including service engineers, have training and updated competencies in radiation protection.

Review of Best Practices

The following best practices for digital radiography have been identified in this paper. This is not an all-inclusive list but one that highlights the actions most pertinent to digital radiography, radiation safety and ethical practice.

It is best practice to:

- Select the appropriate exposure technique factors for the patient's size and condition, based on a planned exposure system, designed in collaboration with radiologists, to determine adequate image quality for diagnosis.
- Consistently include information regarding the image receptor exposure in the image data provided throughout the image archiving process.
- Carefully review the examination ordered to pre-

vent potential duplication and to ensure appropriateness as related to the patient's history. If there is a possibility that the examination might be inappropriate, the radiographer then should consult with the radiologist and/or ordering physician to ensure the appropriate examination is being obtained.
- Follow the protocols and standards set by the department and actively participate in establishing and further developing protocols that ensure consistency of diagnostic-quality images and improved practices to reduce patient radiation dose. This is a critical best practice in digital radiography.
- Screen patients for potential pregnancy.
- Use the highest kVp within the optimal range for the position and part coupled with the lowest amount of mAs as needed to provide an adequate exposure to the image receptor.
- Use automatic exposure control (AEC) when indicated and use AEC that has been calibrated to the type of image receptor to provide a consistent exposure to the image receptor.
- Use exposure technique charts that are continuously improved and applicable to a wide range of patient ages and sizes.
- Collimate the x-ray beam to the anatomic area appropriate for the procedure.
- Apply electronic masking in a manner that demonstrates the actual exposure field edge to document appropriate collimation.
- Electronic masking must not be applied over anatomy that was contained in the exposure field at the time of image acquisition.
- Use lead shielding for anatomic parts that are adjacent to the x-ray field.
- Consistently use lead anatomic side markers captured on the original image during the x-ray exposure.
- Use a grid with specifications recommended by the digital imaging equipment vendor, generally for body parts that exceed 10 cm.
- Use immobilization devices when needed and prevent repeat exposures by appropriately positioning the patient.
- Take appropriate actions to follow ALARA principles, radiation protection, proper positioning, immobilization and size-appropriate exposure techniques in pediatric digital radiography.
- Become familiar with the specific exposure indicator standards for equipment and with the standardized EI as it becomes available in new and upgraded equipment used for digital radiography.
- Effectively use the EI and deviation index to determine whether adequate exposure has reached the image receptor.
- Evaluate EI values, along with image quality to determine whether the digital image meets departmental standards.
- Recognize that because the EI has limitations and other variables can affect the value, carefully assess whether a repeat examination is necessary.
- Recognize image artifacts and prevent future artifacts from occurring by properly maintaining or acquiring service for the digital radiography equipment.
- Select the correct processing menu for an examination to ensure image quality.
- Electronically record exposure techniques, EI and dose data with the radiographic image to allow for assessment and refinement of technique selection practices.
- Implement a comprehensive quality assurance program that involves aspects of quality control and continuous quality improvement, including repeat analyses that are specific to the digital imaging system.
- Develop a collaborative and supportive work team in which team members learn from one another and practice radiography safely and ethically.

Recommendations

This committee makes several recommendations for the future of digital radiography based on best practices to help ensure continued quality and improved patient safety:

- Industry societies and vendors must continue to work together to improve standardization of exposure indicator values. This includes consistency in exposure indicators and standard deviation indexes.

- Equipment manufacturers provide radiographers access to EI and DI information clearly displayed on each image when viewed and retained as part of the PACS DICOM headers to ensure accurate exposures and data recording.
- At the institutional level, all radiology departments should develop and post exposure technique charts with radiologist and radiologic technologist involvement; the charts must identify acceptable exposure indicator ranges.
- Members of the radiology team must collaborate to promote patient radiation safety. This includes medical physicists, radiologists, radiologic technologists and radiographers just graduating from programs who have a more formal education involving digital imaging skills.
- Radiographers, equipment manufacturers and physicists should investigate and perform research into grid construction as appropriate for digital imaging.
- Radiographers, equipment manufacturers and physicists should investigate and perform research to further investigate kVp effects on patient dose and the use of 15 percent increases (the 15 percent rule) in digital radiography image receptor systems.
- Ensure that managers, radiologic technologists and applications trainers collaborate to prepare for applications training and base knowledge before training begins on digital equipment.
- Institutions that care for children must develop radiologic and digital imaging equipment protocols for pediatric radiography.

Bibliography

1. The Alliance for Radiation Safety in Pediatric Imaging. Image Gently website. www.pedrad.org/associations/5364/ig/?page=365. Accessed April 2, 2012.
2. The Alliance for Radiation Safety in Pediatric Imaging. Implementation manual. Image Gently digital radiography safety checklist. ImageGently.org. www.pedrad.org/associations/5364/files/Attachment%20C.FINAL%20Implementation%20Manual.pdf. Accessed December 28, 2011.
3. American Association of Physicists in Medicine. Acceptance testing and quality control of photostimulable storage phosphor imaging systems. Report of AAPM Task Group 10. www.aapm.org/pubs/reports/RPT_116.pdf. Published October 2010. Accessed January 27, 2012.
4. American Association of Physicists in Medicine. An exposure indicator for digital radiography. Report of Task Group 116. www.aapm.org/pubs/reports/RPT_116.pdf. Published July 2009. Accessed January 27, 2012.
5. American College of Radiology. ACR Appropriateness Criteria. www.acr.org/SecondaryMainMenuCategories/quality_safety/app_criteria.aspx. Accessed March 30, 2012.
6. American College of Radiology. Dose Index Registry. https://nrdr.acr.org/Portal/DIR/Main/page.aspx. Accessed April 16, 2012.
7. American College of Radiology. Practice guidelines and technical standards. www.acr.org/SecondaryMainMenuCategories/quality_safety/guidelines.aspx. Accessed March 29, 2012.
8. American College of Radiology. Practice guideline for digital radiography. www.acr.org/SecondaryMainMenuCategories/quality_safety/guidelines/dx/digital_radiography.aspx. Published 2007. Accessed December 28, 2011.
9. American Registry of Radiologic Technologists. ARRT Standards of Ethics. www.arrt.org/pdfs/Governing-Documents/Standards-of-Ethics.pdf. Published September 1, 2011. Accessed March 29, 2012.
10. American Society of Radiologic Technologists. Background information on state and federal licensure laws. www.asrt.org/content/GovernmentRelations/LegislativeGuidebook/LicensureBackgroundInfo.aspx. Accessed April 20, 2012.
11. American Society of Radiologic Technologists. Computed radiography/direct radiography survey. Albuquerque, NM: American Society of Radiologic Technologists; 2010.
12. American Society of Radiologic Technologists. The Practice Standards for Medical Imaging and Radiation Therapy. www.asrt.org/media/pdf/practicestds/GR11_Rad_PS.pdf. Effective June 19, 2011. Accessed March 29, 2012.
13. American Society of Radiologic Technologists. Radiologic Sciences Workplace Survey 2011. www.asrt.org/Media/pdf/Research/RSWorkplaceSurvey2011.pdf
14. Amis ES, Butler PF, Applegate KE, et al. American College of Radiology white paper on radiation dose in medicine. *J Am Coll Radiol.* 2007;4(5):272-284.
15. Bowden L, Faulkner R, Clancy C, et al. Doses under automatic exposure control (AEC) for direct digital radiographic (DDR) x-ray systems. *Radiat Prot Dosimetry.* 2011;147(1-2):210-214.
16. Busch HP, Faulkner K. Image quality and dose management in digital radiography: a new paradigm for optimization.

Radiat Prot Dosimetry. 2005;117(1-3):143-147.

17. Bushong S. *Radiologic Science for Technologists: Physics, Biology and Protection.* 9th ed. St Louis, MO: Elsevier/Mosby; 2008: 422; 459-465.
18. Carroll QB. *Radiography in the Digital Age.* Springfield, IL:Charles C Thomas Publisher Ltd;2011.
19. Carter C, Viele B. *Digital Radiography and PACS.* St Louis, MO: Elsevier/Mosby; 2008:80-108.
20. Castañon PG, España Lopez ML, Fernandez Bedoya V, Bermudez Luna R, Rodriguez Martin G. A dose index as a tool to estimate paediatric patient doses in digital projection radiography [epub ahead of print]. *Radiat Prot Dosimetry.* 2011;Jul 20.
21. Charnock P, Connolly PA, Hughes D, Moores BM. Evaluation and testing of computed radiography systems. *Radiat Prot Dosimetry.* 2005;114(1-3):201-207.
22. Chotas HG, Dobbins JT III, Ravin CE. Principles of digital radiography with large-area, electronically readable detectors: a review of the basics. *Radiology.* 1999;210(3):595-599.
23. Compagnone G, Pagan L, Baleni MC, Calzolaio FL, Barozzi L, Bergamini C. Patient dose in digital projection radiography. *Radiat Prot Dosimetry.* 2008;129(1-3):135-137.
24. Donnelly LF, Dickerson JM, Goodfriend MA, Muething SE. Improving patient safety: Effects of a safety program on performance and culture in a department of radiology. AJR Am J Roentgenol. 2009;193(1):165-171.
25. Fauber TL. Exposure variability and image quality in computed radiography. Radiol Technol. 2009;80(3):209-215.
26. Frank ED, Long B, *Smith BJ. Merrill's Atlas of Radiographic Positioning & Procedures Volume 1.* 12th ed. St Louis, MO: Elsevier/Mosby; 2012:36-40.
27. Gogos KA, Yakoumakis EN, Tsalafoutas IA, Makri TK. Radiation dose considerations in common pediatric x-ray examinations. Pediatr Radiol. 2003;33(4):236-240.
28. Harvey D. Technology update: direct digital radiography. Radiology Today website. www.radiologytoday.net/archive/rt1011p26.shtml. Published October 2011. Accessed March 28, 2012.
29. Hawk N, Elmore A. Effects of AEC chamber selection on patient dose and image quality. *Radiol Technol.* 2009;80(5):411-419.
30. Image Gently. www.pedrad.org/associations/5364/ig/. Accessed April 2, 2012.
31. Image Wisely. About us. www.imagewisely.org/About-Us. Accessed June 2, 2012.
32. Johnson CD, Miranda R, Osborn HH, et al. Designing a safer radiology department. AJR Am J Roentgenol. 2012;198(2): 398-404.
33. Langer SG, Ramthun S, Bender C. Introduction to digital medical image management: departmental concerns. *AJR Am J Roentgenol.* 2012;198(4):746-753.
34. Körner M, Weber CH, Wirth S, Pfeifer KJ, Reiser MF, Treitl M. Advances in digital radiography: physical d and system overview. *Radiographics.* 2007;27(3):675-686.
35. Kostova-Lefterova D, Taseva D, Ingilizova K, Hristova-Popova J, Vassileva J. Potential for optimization of paediatric chest x-ray examination. *Radiat Prot Dosimetry.* 2011;147(1-2):168-170.
36. Krupinski EA, Williams MB, Andriole K, et al. Digital radiography image quality: image processing and display. *J Am Coll Radiol.* 2007;4(6):389-400.
37. Matthews K, Brennan PC. Optimisation of x-ray examinations: General principles and an Irish perspective. *Radiography.* 2009;15:262-268.
38. Mazzocchi S, Belli G, Busoni S, et al. AEC set-up optimization with computed radiography imaging. *Radiat Prot Dosimetry.* 2005; 117(1, 3):169-173.
39. Mettler FA, Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: Frequency, radiation dose, and comparison with other radiation sources—1950-2007. *Radiology.* 2009;253(2):520-531.
40. Moores BM, Regulla D. A review of the scientific basis for radiation protection of the patient. *Radiat Prot Dosimetry.* 2011;147(1-2):22-29.
41. Nitrosi A, Borasi G, Nicoli F, et al. A filmless radiology department in a full digital regional hospital: quantitative evaluation of the increased quality and efficiency. *J Digit Imaging.* 2007;20(2):140-148.
42. Papp J. *Quality Management in the Imaging Sciences.* 4th ed. St Louis, MO:Mosby; 2011: 137-138.
43. Platt JM, Sturdwich RM. The application of anatomical side markers during abdominal and IVU examinations: An investigation of practice prior to and postinstallation of computed radiography (CR). Radiography. 2009;15:292-299.
44. Pongnapang N. Practical guidelines for radiographers to improve computed radiography image quality [epub]. Biomed Imaging Interv J. 2005;1(2). www.ncbi.nlm.nih.gov/pmc/articles/PMC3097595/pdf/biij-01-e12.pdf. Accessed March 23, 2012.
45. Powers K. New generation of students equals new generation of leaders. Presented at: ASRT Educational Symposium; June 16, 2011. Albuquerque, NM.
46. Rehani MM, Vano E. Medical radiation protection in the next decade. *Radiat Prot Dosimetry.* 2011; 147(1-2):52-53.
47. Rehani MM, Frush DP. Patient exposure tracking: The IAEA Smart Card project. *Radiat Prot Dosimetry.* 2011;147(1):314-316.

48. Research and markets: The global digital radiography market to grow at a CAGR of 3.3 percent over the period 2010-2014 according to new analysis [press release]. Business Wire website. www.businesswire.com/news/home/20110920007118/en/Research-Markets-Global-Digital-Radiography-Market-Grow. Published September 20, 2011. Accessed March 28, 2012.
49. Schauer DA, Linton OW. National Council on Radiation Protection and Measurements report shows substantial medical exposure increase. *Radiology.* 2009;253(2):293-298.
50. Seeram E. *Digital Radiography: An Introduction.* Clifton Park, NY: Delmar, Cengage Learning; 2011.
51. Seibert JA. Technical issues. Presented at: CR/DR Summit; February 2010; St Louis, MO. http://rfs.acr.org/imagegently/2009/09_04.html. Accessed April 12, 2012.
52. Seibert JA, Morin RL. The standardized exposure index for digital radiography: an opportunity for optimization of radiation dose to the pediatric population. Pediatr Radiol. 2011;41(5):573-581.
53. Slovis TL. Where we were, what has changed, what needs doing: a decade of progress. *Pediatr Radiol.* 2011;41(suppl 2):S456-S460.
54. Soboleski D, Theriault C, Acker A, Dagone V, Manson D. Unnecessary irradiation to non-thoracic structures during pediatric chest radiography. *Pediatr Radiol.* 2006;36:22-25.
55. Tsalafoutas IA, Blastaris GA, Moutsatsos AS, Chios PS, Efstathopoulos EP. Correlation of image quality with exposure index and processing protocol in a computed radiography system. *Radiat Prot Dosimetry.* 2008;130(2):162-171.
56. U.S. Food and Drug Administration. Public workshop – device improvements for pediatric x-ray imaging, July 16, 2012. www.fda.gov/MedicalDevices/NewsEvents/WorkshopsConferences/ucm301989.htm. Updated June 6, 2012. Accessed June 6, 2012.
57. Vano E. Global view on radiation protection in medicine. *Radiat Prot Dosimetry.* 2011;147(1-2):3-7.
58. Waaler D, Hofmann B. Image rejects/retakes—radiographic challenges. Radiat Prot Dosimetry. 2010;139(1-3):375-379.
59. Walsh C, Gorman D, Byrne P, Larkin A, Dowling A, Malone JF. Quality assurance of computed and digital radiography systems. *Radiat Prot Dosimetry.* 2008;129(1-3):271-275.
60. Weiss MF. The profit center: part 13 – radiology as factory work? AuntMinnie.com.
61. www.auntminnie.com/index.aspx?d=1&Sec=sup&Sub=imc&Pag=dis&ItemId=90213. Published April 13, 2010. Accessed July 13, 2010.
62. Willis CE, SLovis TL. The ALARA concept in pediatric CR and DR: dose reduction in pediatric radiographic exams—a white paper conference executive summary. *Pediatr Radiol.* 2004;34 (suppl 3):S162-S164.
63. Willis CE. Strategies for dose reduction in ordinary radiographic examinations using CR and DR. *Pediatr Radiol.* 2004;34(suppl 3):S196-S200.
64. World Health Organization. Medical imaging specialists call for global referral guidelines. WHO website. www.who.int/ionizing_radiation/medical_exposure/referral_guidelines.pdf. Published March 2010. Accessed April 3, 2012.
65. Zetterberg LG, Espeland A. Lumbar spine radiography – poor collimation practices after implementation of digital technology. *Br J Radiol.* 2011;84(1002):566-569.

Appendix A

Glossary

Bit depth. The number of bits, or binary digits, per pixel. They encode the signal intensity (gray scale) of each pixel for the digital image.

Collective dose. A measure of the total amount of effective dose multiplied by the size of the exposed population. Usually measured in units of person-rem or person-sieverts, or man-rem or man-sievert.

Computed radiography (CR). The imaging system, most often cassette-based, that requires the cassette to be manually inserted into a plate reader. CR uses photostimulable phosphor technology to capture images that are then scanned by a laser to release the energy absorbed, which is then to produce digital data that are converted to an image.

Contrast resolution: also known as gray-scale resolution. This is a digital system's ability to display objects at different signal (x-ray) intensities so that they can be easily distinguished.

DICOM. Digital Imaging and Communications in Medicine. DICOM is a standard developed to interconnect medical digital imaging devices. The standard is sponsored by the ACR and NEMA and aims to have both a standard image file format and a standard communications protocol.

Digital radiography. Any form of radiography in which the acquisition and display of the image are electronic in nature; the imaging system may be cassette-based or cassette-less This may include CR or DR as defined in this glossary.

Direct digital radiography (DR). The imaging system may be cassette-based or cassette-less. DR may use a flat- panel with thin-film transistor or a charge-coupled device. The image reading process occurs immediately after the termination of the exposure and does not require the radiographer to initiate the reading process.

Effective dose. Effective dose is the quantity that relates more closely to stochastic radiation risk. The effective dose totals the absorbed dose to tissues and the weighting factors that apply to particular tissues or organs being irradiated.

Exposure indicator (EI). A quantitative method, expressed as an EI value, to estimate the incident radiation exposure required to acquire a diagnostic-quality radiograph. The EI is called by many other names, depending on the vendor.

Grayscale. The different shades of gray that a computer system can store and display in relation to the number of bits the system uses to digitize images.

Luminance. The measure that describes the amount of light that passes through or is emitted from a surface. In DR, this is the display monitor.

Pixel. A picture element, or the smallest component of a digital image and piece of information that a digital monitor can display. Pixels are represented by numerical codes.

Spatial Resolution. Spatial resolution is the ability to differentiate between small and adjacent objects. It is measured in line pairs per millimeter (lp/mm).

Standard deviation index (DI). An index that provides feedback based on signal-to-noise ratio and the target index value for each digital examination. The purpose of the index is to help radiographers know if the technique they used for a specific examination was appropriate for optimal display of the anatomy of interest.

Appendix B

Exposure Indicators

Exposure indicators (EIs) vary among manufacturers, and even have different names, symbols and units. This chart shows a list of select manufacturers and details regarding their EIs as of 2011.

Appendix C

Manufacturer	EI Name	EI Symbol	Units	Exposure Dependence	Detector Calibration Conditions
Agfa	Log of median of histogram	1gM	Bels	1gM + 0.3 = 2X	400 speed class, 75 kVp + 1.5 mm Cu; 1gN = 1.96 @ 2.5 µGy
Alara CR	Exposure indicator value	EIV	Mbels	EIV + 300 = 2X	1 mR @ RQA5, 70 kV, +21 mm A1 => EIV=2000
Canon	Reached exposure value	REX	Unitless	for brightess=c1, contrast=c2, REX α X (mR)[1]	brightness = 16, contrast = 10, 1 mR = 106[1]
Canon	EXP	EXP	Unitless	EXP = X	80 kVp, 26 mm A1, HVL=8.2 mm A1, DFEI=1.5
Carestream (formerly Kodak)	Exposure index	EI	Mbels	EI + 300=2X	80 kVp. 1. 0 mm A1 + 0.5 mm Cu; EI=2000 @ 1mR
Fujifilm	S value	S	Unitless	200/S X (mR)	80 kVp, 3 mm A1 "total filtration" S=200 @ 1 mR
GE	Uncompensated detector exposure	UDExp	µGy air kerma	UDExp α X (µ Gy)	80 kVp, standard filtration, no grid
GE	Compensated detector exposure	CDExp	µGy air kerma	CDExp α X (µ Gy)	kVp, grid, and additional filter compensation
GE	Detector exposure index	DEI	Unitless	DEI≈ratio of actual exposure to expected exposure scaled by technique, system parameters. Expected exposure can be edited by user.	Not available.
Konica	Sensitivity number	S	Unitless	for QR=k, 200/S α X(mR)	For QR=200, 80 kVp, S=200 @ 1 mR
Philips	Exposure index	EI	Unitless	1000/X (µ Gy)	RQA5, 70 kV + 0.6 mm Cu, HVL=7.1 mm A1
Siemens	Exposure index	EI	µ Gy air kerma	X(µ Gy)=EI/100	RQA5, 70 kV+0.6 mm Cu, HVL=6.8 mm A1

Task Force Members

- Tracy Herrmann, M.Ed, R.T.(R), University of Cincinnati, Blue Ash College, Professor and Radiologic Technology Program Director
- Terri L. Fauber, Ed.D., R.T.(R)(M), Virginia Commonwealth University, Radiography Program Director
- Julie Gill, Ph.D., R.T.(R)(QM), University of Cincinnati, Blue Ash College, Chairperson and Associate Professor, Allied Health
- Colleen Hoffman, R.T.(R)(M)(CT), Atlantic Medical Imaging, PACS Administrator
- Denise Orth, M.S., R.T.(R)(M), Fort Hays State University, Assistant Professor/Clinical Coordinator
- Paulette Peterson, M.Ed, R.T.(R)(M)(QM), Monroe Community College, Associate Professor/Clinical Coordinator
- Randy Prouty, B.S., R.T.(R), Regional West Medical Center, Diagnostic Supervisor
- Andrew Woodward, M.A., R.T.(R)(CT)(QM), The University of North Carolina at Chapel Hill, Assistant Professor