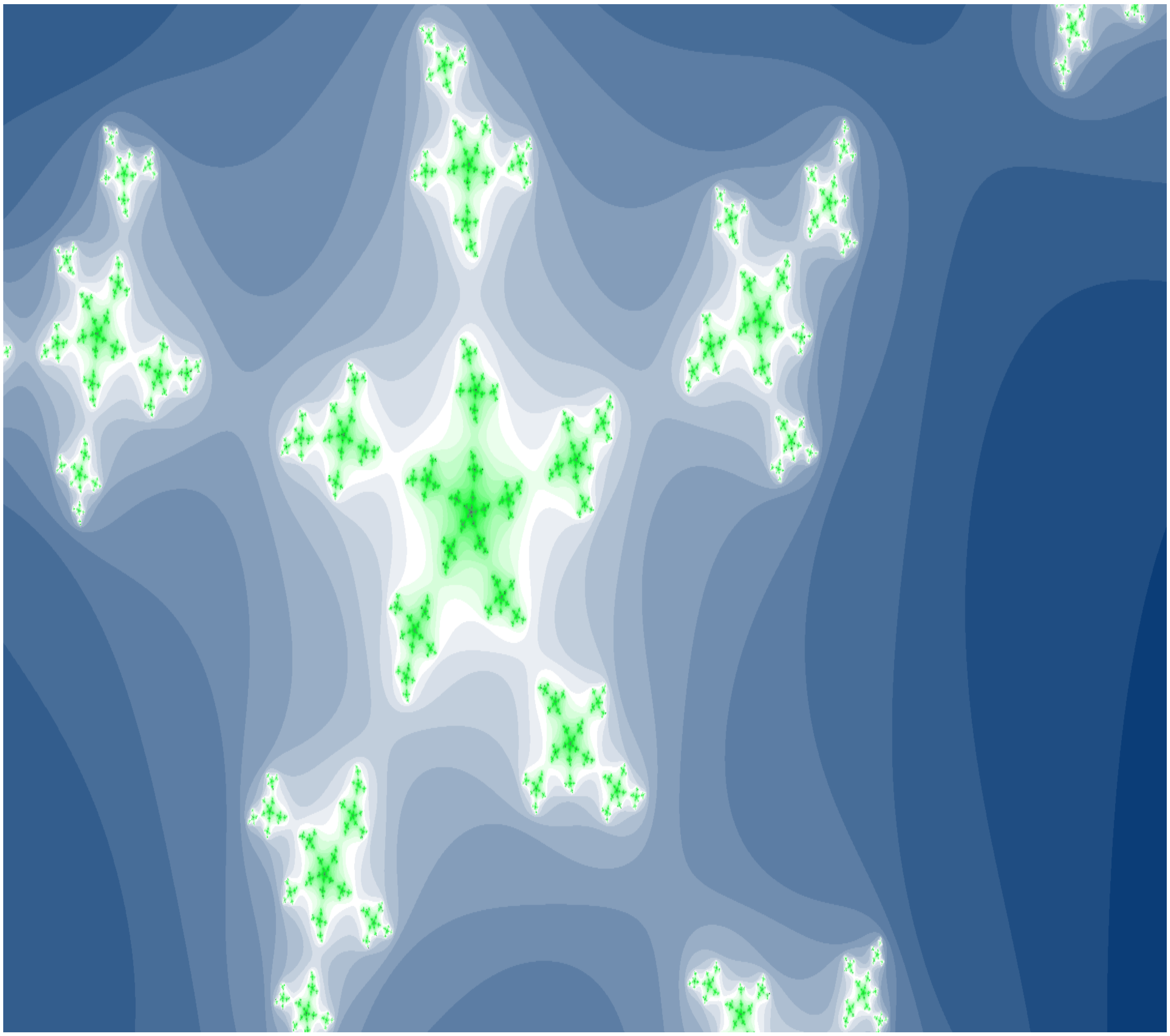
Best Practices in Digital Radiography

Vesna Balać, Ed.D., R.T.(R)(MR); Daniel N. DeMaio, M.Ed., R.T.(R)(CT); Randy Griswold, M.P.A., R.T.(R);
Robert (Bob) Grossman, M.E., R.T.(R)(CT); Lauren B. Noble, Ed.D., R.T.(R);
Craig St. George, M.S., R.T.(R)(VI); Jason Young, M.S.Ed., R.T.(R); Kathryn Faguy, M.A., ELS



Published by the American Society of Radiologic Technologists, 15000 Central Ave. SE, Albuquerque, NM 87123-3909.

American Society of Radiologic Technologists

Best Practices in Digital Radiography

Table of Contents

When Wilhelm Roentgen discovered x-rays on Nov. 8, 1895, he could not have foreseen how pervasive radiographic examinations would become or how medical imaging technology would evolve. Today, about 70% of Americans have a radiographic examination each year and digital imaging methods are common across all indications and forms of radiography, including fluoroscopy and mammography. As radiographers have adjusted to the widespread use of digital radiography (DR), they have had to refine exposure technique selection and pay closer attention to radiation protection. While digital technologies offer many benefits for acquiring and postprocessing images, radiographers must be particularly concerned about exposure technique and the possibility of using more radiation than necessary. They must continue to adhere to the principle of ALARA, as low as reasonably achievable, by keeping occupational radiation dose as low as possible as well as adhering to similar principles of keeping patient exposure as low as possible without affecting image quality (dose optimization) when performing digital radiography.

Radiographers assume extensive responsibility for the radiation safety of patients. The American College of Radiology (ACR) White Paper on Radiation Dose in Medicine places the 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" and it encourages “radiology practices and departments to take a more proactive approach to radiation safety.”

Radiation safety practices that focus on minimizing patient and occupational dose are based on justifying clinical appropriateness of examinations and optimizing dose while maintaining image quality. The various methods that radiographers can use to minimize patient and occupational exposure continue to evolve. Radiographers must be familiar with the most current dose-reduction techniques and must operate equipment optimally in accordance with safety and image quality policies and procedures. Radiographers and their patients can benefit from a single-source, best practices document that offers background information and recommendations for radiographers that focus on proper use of digital radiography equipment and radiation safety.

Scope of the White Paper

The American Society of Radiologic Technologists (ASRT) has long championed radiation protection in digital imaging for all age groups, as evidenced by the organization’s support of and participation in the Image Gently and Image Wisely campaigns. ASRT helped found and actively participates in these and similar initiatives that aim to reduce radiation exposure from medical imaging and improve education for the public and health professionals. In support of this area of professionalism, the ASRT publishes educational and promotional materials for the public and the medical imaging community. In 2012, ASRT released its first white paper on best practices in digital radiography as a significant and dedicated effort to promote radiation protection for patients and professionalism among radiologic technologists.

The 2012 white paper combined information from trusted sources such as ACR guidelines, textbooks, professional and government organizations, and periodical literature on exposure to support transitioning radiographers to digital imaging. The paper also examined elements of best practices for digital image quality and dose-reduction techniques in digital radiography from a radiographer perspective.

In 2018, and again in 2024, the ASRT convened new committees to update and revise previous best practice recommendations. This white paper is the result of a yearlong effort to ensure timely and helpful guidance for practicing radiographers. 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. Much like the constantly advancing technology used in digital radiography, this white paper is meant to be a fluid, living document.

Digital Radiography Background

The first form of digital imaging, digital subtraction angiography, was introduced in 1977 and put to clinical use in 1980. Computed radiography (CR), which uses a photostimulable phosphor plate, was adopted in clinical practice beginning in the 1980s. Fewer imaging facilities use CR technology today, with DR (direct or indirect capture or conversion) as the technology of choice. Roch et al reported in 2018 that flat-panel detectors have been shown to lower radiation dose to patients as much as 30% compared with CR phosphor technology. Both the direct and indirect types of DR technology measure attenuated rays and produce electrical signals that are sent to software to rapidly produce images in grayscale format on a monitor. The first flat-panel detector used indirect conversion and is still common in modern systems. Indirect capture DR uses a scintillating material that receives the x-ray photon energy and converts it to visible light. Amorphous silicon, which acts as a photodiode, measures the light emitted from a scintillator. The light energy is converted to an analog electrical signal that is ultimately digitized and processed using computer algorithms. Some fixed DR systems (e.g., dedicated chest radiography rooms, mammography systems) included charge-coupled devices (CCDs) to generate an electrical signal from the emitted light. Direct conversion DR systems commonly use amorphous selenium as a photoconductive material, directly converting the energy of x-ray photons into electrical signal without the need for light as an intermediary. (See Appendix C)

An advantage of DR is the ease of incorporating images and order entry into existing radiology information systems (RIS) and the medical imaging management and processing system (MIMPS), formerly known as PACS. In many ways, this has positively affected radiology department workflow, eliminating many manual steps and improving patient care and operational efficiency. For example, digital radiography is incorporated into RIS, electronic health records (EHR), and the MIMPS, where the process from order entry to report generation involves little to no human interaction. The RIS and modality worklist system help to facilitate workflow by bundling associated patient and examination information with the acquired images and sending all pertinent data to the MIMPS. The information is then available at the interpreting practitioner’s workstation. Speech recognition software can help the practitioner generate a report efficiently and then automatically archive and distribute the report to the referring practitioner through the EHR.

Properly implementing new technologies and automating processes associated with medical imaging can streamline workflow, decrease the potential for errors, and improve patient care.

Dose Optimization and Image Quality

According to National Council on Radiation Protection and Measurements (NCRP) Report No. 184, radiography and fluoroscopy represent 74% of all imaging procedures and about 10% of the collective effective dose per capita. Therefore, understanding imaging principles is necessary for optimizing patient dose and producing quality images. Digital imaging incorporates discrete acquisition, processing, and display processes that function together to produce an image of acceptable diagnostic quality. When inappropriate radiation exposure levels have been used, the system might still display a diagnostically acceptable image. While post-processing can minimize the appearance of exposure technique errors, it cannot truly compensate for these errors; therefore, this is **not** a best practice.

As a component of image quality, contrast resolution refers to the imaging system's ability to delineate subtle variations in the grayscale. Digital images are composed of pixels each containing a discrete numerical value corresponding to a particular shade of gray. Each shade of gray is representative of variations in signal intensity received by the image receptor. The bit depth of an imaging system determines the inherent grayscale or range of numerical values available to depict an image. For example, a 12-bit system yields 4,096 shades of gray, whereas a 14-bit system yields 16,384 shades of gray. The availability of more shades of gray can make it easier, for example, to detect pathologies that have attenuation characteristics similar to surrounding tissues.

Although bit depth determines a system's overall grayscale, the contrast resolution of an image is also impacted by subject contrast and display contrast. During image acquisition, subject contrast results from attenuation variations relative to tissue atomic number, density, and part thickness. Additionally, the tube potential (kVp) applied during an x-ray exposure affects the degree of differential attenuation occurring in a subject's body.

Inappropriate subject contrast, whether very low (too gray or too little contrast) or very high (too black and white or too much contrast), can make it difficult to detect objects or structures of interest in the image. Display contrast is the ratio of brightness or luminance between adjacent structures. Unlike subject contrast, display contrast can be modified by various postprocessing algorithms or functions; however, it is important to note that an insufficient degree of subject contrast cannot be recovered with postprocessing. Most importantly, the ability to adjust display brightness and contrast during postprocessing must not be a substitute for the radiographer's attention to the primary principle of radiation protection: optimal image quality with minimal patient exposure. In addition, the increased sensitivity of digital image receptors to different energies and exposure levels has allowed for a wider exposure latitude for image processing and display. Because image receptor exposure is not readily apparent in the displayed image, there is a further disconnect between image capture and the resulting patient exposure.

Except for extremely low or extremely high exposures, computer processing algorithms adjust for inappropriate exposure and display an image of diagnostic quality; however, this lack of visual feedback between exposure settings and image display can contribute to increased patient exposure. In cases of extreme underexposure, there is a decrease in the exposure reaching the image receptor. A low signal-to-noise ratio (SNR) results in images displaying a mottled or grainy appearance, often necessitating repeats. An increase in exposure will increase the signal reaching the image receptor, causing an increased SNR. This increase in SNR can lead to a corresponding decrease in complaints from interpreting practitioners regarding image quality. The feedback loop could cause radiographers to inadvertently increase exposure technique and, subsequently, patient radiation dose. These factors have contributed to a gradual increase in patient exposure, also known as dose creep. Radiographers, often faced with feedback that unwittingly reinforces slight overexposure and lacking experience with the nuances of exposure on digital image receptors, might choose the path of increased exposure technique, decreased image noise, and avoidance of repeats. This practice is ***not*** acceptable and violates the American Registry of Radiologic Technologists (ARRT) code of ethics regarding radiation protection.

As diagnostic imaging technologies continue to advance, the use of ionizing radiation for procedures in CT and interventional fluoroscopy will add to the cumulative radiation exposure levels of patients and the general population. Digital radiography also contributes to these dose levels and the control of dose creep requires 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 best practices for radiation safety in digital imaging. Avoiding repeat exposures, careful use of shielding and beam restriction, clearly established acceptance ranges for exposure indicators (EIs), and other practices are covered in the best practices discussion that follows.

Radiation Safety Guidelines, Campaigns, and Initiatives

With a widespread increase in digital imaging examinations, national and international attention has focused on medical radiation dose reduction and safety. Guidelines, as well as several campaigns and initiatives, have been implemented to educate radiographers, physicists, radiologists, referring physicians, and the public about how to minimize the risks associated with exposure to ionizing radiation. Efforts to reduce patient exposure to medical radiation begin with ensuring that examinations are justified as appropriate and that the ordered examination matches the clinical indication.

In the 1990s, the ACR recognized the need to establish national guidelines to assist physicians in making appropriate imaging decisions. The ACR created a task force charged with developing evidence-based guidelines that would enhance the quality of patient care while considering the use of limited radiology resources. Panel chairs were appointed, and guidelines were developed using scientific methodology and input from diagnostic and interventional radiologists and physicians from other medical specialties.

The resulting document, known as the ACR Appropriateness Criteria, not only provides guidance for the efficient use of radiology services but also raises awareness of radiation dose. The criteria acknowledge that potential risks, such as cancer induction, are associated with exposure to ionizing radiation and that this must be considered when ordering imaging examinations. Additionally, because the amount of exposure varies according to the diagnostic procedure, relative radiation levels (RRLs) are provided to allow for dose comparisons between examinations. The RRLs, which are listed for most examinations, are expressed as effective dose and provide a means for estimating risk among the various imaging procedures.

The ACR Appropriateness Criteria, which are reviewed annually, assist physicians in making judicious decisions regarding the use of imaging examinations based on a patient's clinical condition. Avoiding inappropriate imaging studies is important to help minimize or even eliminate radiation exposure to patients. To view this document, visit https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Beginning as a committee within the Society for Pediatric Radiology, the Alliance for Radiation Safety in Pediatric Imaging has grown in membership both nationally and internationally since 2007. The Alliance, consisting of pediatric radiologists, radiologic technologists, and medical physicists, was formed in part as a response to the increased use of computed tomography (CT) on pediatric patients. To raise awareness of pediatric radiation protection and the importance of appropriate pediatric exposure factors, the Alliance initiated its public service campaign, Image Gently.

Initially, the Image Gently campaign focused on radiation safety and dose reduction measures for pediatric CT by providing information and free educational materials for physicians, radiologic technologists, and parents. More recently, the campaign has expanded to include interventional radiology, fluoroscopy, nuclear medicine, digital radiography, dental imaging, and cardiac imaging. For more detailed information regarding this campaign and to access available resources, visit the Image Gently website at www.imagegently.org.

As more imaging centers transitioned to digital radiography during the late 2000s, concerns about radiation exposure to the adult population began to surface. To address these concerns, the ACR and the Radiological Society of North America (RSNA) formed the Joint Task Force on Adult Radiation Protection. The Joint Task Force partnered with the American Association of Physicists in Medicine (AAPM) and the ASRT to develop a public service campaign focused on reducing radiation exposure in adults. Beginning in 2010, the Image Wisely campaign launched its efforts to provide free resources to physicians, radiologic technologists, and patients. Information pertaining to CT, fluoroscopy, and nuclear medicine is available. Additionally, radiation safety resources, including information about diagnostic reference levels (DRLs) are provided.

The Image Wisely campaign continuously expands its focus to encompass a more comprehensive approach to ionizing radiation safety as well as include recommendations for other disciplines. Medical imaging safety should be part of an organization's *safety culture*. Safety culture goes beyond the actions carried out daily, but is a mindset that influences behaviors and outcomes. It emphasizes the importance of providing the necessary tools or processes to achieve desired outcomes, along with interventions for improvements. For example, a reporting system to capture dose data from examinations serves as a tool that allows for continuous monitoring to determine whether doses are trending higher than normally expected, signaling the need for an intervention. A culture of safety acknowledges that human errors are inevitable. Organizations that approach unintentional errors as learning opportunities, rather than opportunities for blame and shame, change behaviors and transform mindsets. For more detailed information regarding this campaign and to access available resources, visit the Image Wisely website at www.imagewisely.org.

A new advocacy campaign called Image IntelliGently was launched in 2024. Its mission acknowledges the role of artificial intelligence in pediatric medicine and seeks to ensure that children's care is provided in a "safe, equitable, and reliable manner." Additionally, Image IntelliGently addresses concerns regarding children's access to "clinically useful medical imaging AI" and envisions improvements in pediatric health through the implementation of AI-enabled medical imaging features. To pledge your support, become a champion for safe AI use in pediatric health care, or to learn more about this campaign, visit the IntelliGently website at https://www.acr.org/Practice-Management-Quality-Informatics/Informatics/Pediatric-Radiology-AI-Resources.

At the international level, the World Health Organization (WHO) acknowledges the benefits of using ionizing radiation for medical purposes but also recognizes the need to minimize exposure risks. As a leader in global efforts, the WHO's Global Initiative on Radiation Safety in Health Care Settings aims to promote the safe and effective use of radiation by improving radiation safety standards. To accomplish this, the initiative focuses on three main areas: risk assessment, risk management, and risk communication. As an example of risk assessment, the WHO, in collaboration with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), analyzes population dose distributions from ionizing radiation used in health care. Risk management addresses areas such as reducing radiation exposure to patients and occupational workers by cultivating a strong safety culture and strengthening cooperation between health authorities and radiation protection regulatory agencies. Risk communication involves measures to support effective dialogue between health care providers and patients relative to the benefits vs. risks of medical imaging. Additionally, the WHO emphasizes the importance of collaboration among entities such as health care providers, patient groups, regulatory agencies, professional societies, and academic institutions.

National and international strides are being made to minimize exposure from ionizing radiation. Radiographers are encouraged to keep current with information pertaining to radiation protection measures and follow protocols and guidelines established by their facilities. Since the publication of NCRP Report No. 160 in 2009, there has been a substantial reduction in medical radiation dose to the U.S. population. NCRP Report No 184 (2019), reported a significant decrease in estimated dose per patient from 2.92 mSv in 2006 to 2.16mSv in 2016.

Practice Parameters for Digital Radiography

The ACR developed a practice guideline for digital radiography in 2007; the parameters have since been amended several times with input from members of the American Association of Physicists in Medicine, the Society for Imaging Informatics in Medicine, and the Society for Pediatric Radiology. It was most recently updated in 2022. The document's intent is "to provide guidance and assistance in the understanding and clinical use of digital radiography (DR) equipment (other than mammography) to deliver necessary image quality at an appropriate radiation dose and to ultimately provide excellent safety and care for patients undergoing digital radiography examinations." In general, ACR practice parameters for any examination or process undergo literature and field review and are based on a summary of expert opinion and informal consensus that results in recommended conduct. The parameters 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 specific to DR, and some of the key points of the guidelines are included in this white paper. By clearly outlining information such as personnel qualifications, grid use, prevention of dose creep, and determining proper exposure factors, the guidelines provide a foundation for facility protocols and the standardization of digital exposure techniques. The ACR guidelines also help radiographers and other medical professionals improve their understanding of the nuances of working with digital technology.

The ACR practice parameters for digital imaging recommend that radiographers performing digital examinations be registry certified and, if required by state and local regulations, be licensed and possess training for the proper operation of routinely used systems. Training should include image acquisition technology, image processing protocols, proper technique selection, image evaluation, exposure indicator appropriateness, and patient safety procedures. Although radiographers and their supervisors might rely on applications training to supply equipment-specific skills, it is the radiographer's responsibility to have complete and up-to-date knowledge regarding digital radiography while using radiation exposure techniques and dose optimization principles designed to minimize patient radiation exposure.

The ASRT Practice Standards for Medical Imaging and Radiation Therapy state that radiographers must be educationally prepared and clinically competent to perform their responsibilities. Education and clinical preparation include the ability to perform imaging examinations safely and effectively, evaluate images for diagnostic quality, and adhere to proper radiation safety measures. Managers should support these efforts, but it is the responsibility of radiographers to take advantage of the literature, seminars, and other available educational tools to maintain clinical competence. The radiographer must retain the skills necessary to expertly perform examinations and work cooperatively with interpreting practitioners to reduce radiation exposure.

Variations in vendor-specific features require thorough and ongoing applications training for digital equipment. Radiology departments and radiographers should be proactive in seeking training from vendors, particularly during equipment installations and system upgrades. However, vendors must also ensure that their applications specialists and support personnel are up to date with changing technology. Vendors and radiology department managers must work together to determine training expectations in advance, which include preassessment and postassessment of trainees' knowledge and skills.

Best Practices

The emergence of digital radiography systems created a learning gap for radiographers and others in the early 2000s. To address the need for education on the proper use of these complex imaging systems, the ASRT published Best Practices for Digital Radiography in 2012. As DR technology has become increasingly pervasive in modern clinical practice and radiologic sciences education, periodic updates to these best practices have become necessary. To ensure that radiologic technologists who perform DR examinations continue to use the DR technology to optimize image quality while minimizing patient exposure before, during, and after examinations, radiographers must remain current with proper education and clinical competence regarding the appropriate use of DR imaging systems. This responsibility is not only a professional duty but also an essential component of radiography practice standards and code of ethics.

Before the Exam Begins

Radiographers typically are the first medical imaging professionals to interact with patients when they arrive for examinations. As such, radiographers have a great deal of responsibility to prepare for the examination and to ensure the patient is correctly identified, the correct medical imaging procedure has been ordered, the department protocols are followed, the examination is explained to the patient, and the patient is screened for pregnancy, if applicable. These actions ensure patient safety and help minimize radiation exposure.

Patient Identification

The radiographer must verify the patient's identity using HIPAA guidelines and the institution's protocol. This process must occur confidentially, and it usually involves verifying at least two identifiers, such as the patient's name and date of birth. Identifying the patient before the procedure ensures that the correct patient is examined and helps prevent instances in which the patient responds to the wrong name when called from the waiting room, which can happen when patients are anxious about their procedure.

It is the radiographer's responsibility to properly identify each patient using the department protocol and HIPAA guidelines.

Procedure Appropriateness

As a patient advocate, the radiographer plays an important role in evaluating the appropriateness of examinations ordered, paying careful attention to ensuring the examination matches the clinical indication. The radiographer has a responsibility to recognize and intervene when an ordered examination might not be justified by the patient's clinical history. In an ASRT survey of radiographers conducted for the Image Gently campaign, nearly 12% of respondents cited "unneeded exams ordered by doctors" as contributing to or causing excess radiation exposure when performing pediatric digital radiography. Inappropriate radiographic examinations unnecessarily add to cumulative radiation dose in patients, and, therefore, should be prevented. The radiographer must take advantage of the opportunity to recognize that the examination is a duplicate or is questionable in terms of indication or appropriateness. Whenever there is a suspicion of an inappropriate or duplicate order, radiographers should consult with the radiologist or ordering practitioner or request additional information from appropriate health care personnel who can clarify and confirm whether the correct examination is requested.

Organizations such as the ACR have developed clinical referral guidelines to assist referring physicians in selecting the correct medical imaging examination and continue to address the concerns of requests for inappropriate examinations. Examples of guidelines include the ACR Appropriateness Criteria and Radiology Across Borders, which was originally developed as Diagnostic Imaging Pathways under the auspices of Western Australia Health. Both are evidence-based imaging referral guidelines that have received global acceptance. The guidelines include radiation dose level for examinations, along with efficacy ratings and a grade for strength of existing evidence regarding each examination's appropriateness. The ACR reviews its criteria annually, with the most recent update in 2024. In addition, the WHO developed global guidelines for appropriate referrals to medical imaging. These guidelines are also evidence-based and cover several types of diagnostic imaging and therapeutic uses of imaging and ionizing radiation. The Radiological Society of

North America (RSNA) also supports the adherence to appropriateness criteria in medical imaging and radiation oncology and organized a global review of radiation safety initiatives at its annual meeting in 2017.

Tracking and monitoring previous examinations also can help radiographers determine procedure appropriateness by identifying potentially unnecessary duplicate examinations before beginning image acquisition. Many international organizations and agencies have approved or developed systems that track radiographic examinations using methods similar to vaccination records. Using a system-based approach that standardizes input from providers rather than patients could help improve identification of duplicate examinations and aid in the accurate recording of cumulative dose. In addition, a radiographer must review the patient's health history with the patient or an appropriate representative to help identify duplicate examinations. Radiographers can obtain important information about duplicate examinations by asking patient-centered questions. For example, the Image Gently campaign provides a wallet-sized card or letter-sized sheet for parents to use in tracking their child's examinations, which can be helpful in preventing duplicate examinations.

It is a best practice in digital radiography for the radiographer to review examination orders and health records carefully to prevent unnecessary duplication and to ensure appropriateness as related to the patient's history and clinical indication(s). If there is a possibility that the examination might be a duplicate or might not be clinically appropriate, the radiographer should consult with the radiologist and/or ordering practitioner to ensure the appropriate examination has been ordered.

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 procedures, including DR examinations. Based in part on these guidelines and parameters, radiology departments or imaging centers should develop and routinely update exposure technique charts and anatomically programmed radiography (APR) settings, and post or make them readily available to radiographers. This ensures improved accuracy and consistency when radiographic exposure factors such as milliampere-seconds (mAs) and kilovoltage peak (kVp) must be set manually. When systems have automatic exposure control (AEC), other variables such as AEC detector cell configuration and backup time also should be standardized.

Radiologic technologists should expect to consult with radiologists and vendors to refine the information for exposure techniques and protocols provided for digital radiography systems. Nuances in equipment, personal preference, and variation in the learning curves associated with implementing new digital technology can contribute to inconsistencies in exposure techniques. The best way for a radiographer to ensure consistency is to follow department protocols based on established clinical research and guidelines.

Properly implementing new technologies and automating processes associated with radiography can decrease the potential for errors and improve patient care. The transition to a digital environment can streamline workflow significantly.

Radiographers must follow the protocols and standards set by their departments and actively participate in developing and revising protocols to ensure diagnostic-quality images, efficient workflow, and minimized patient radiation exposure. This is a critical best practice in digital radiography.

Explaining the Examination

Explaining the examination to a patient before it begins is crucial for ensuring their understanding and cooperation. Radiographers should describe what the patient can expect during the procedure and the steps involved, such as positioning, holding still, and any necessary breathing instructions. In addition, explaining how the patient can help ensure quality images are obtained by following instructions can improve their cooperation. Finally, radiographers should invite their patients to ask any questions they may have about the examination and encourage them to clarify anything they do not understand.

Radiographers must explain the examination and include information related to positioning and holding still, emphasizing the importance of patient cooperation for optimal image quality, and encouraging patients to ask questions to ensure their understanding and safety.

Screening for Pregnancy

The radiographer needs to carefully review a patient's history before beginning an examination to determine whether the patient is pregnant. The method used to verify pregnancy varies slightly according to department protocol, but typically includes asking the patient whether there is any possibility they are pregnant. All patients of appropriate age are questioned about pregnancy status when the radiographer gathers the medical history from the patient. A standardized form can be used to document the pregnancy status for the medical record. The ACR and Society of Pediatric Radiology (SPR) developed sample forms that facilities can use as a basis for developing their own forms. In addition, Duke Medical Center's department of radiology and the *American Journal of Roentgenology* developed consent forms to document pregnancy prior to medical imaging examinations of body areas where there is a higher risk of fetal dose. Tact and professional communication help put the radiographer and the patient at ease when screening for pregnancy.

In 2008 the ACR identified the need to develop practice parameters when pregnant or potentially pregnant female patients would be exposed to ionizing radiation; the ACR collaborated with the SPR to revise the practice parameters in 2013, 2018, and 2023. Because there is no safe level of radiation, the parameters are meant to provide guidance for screening for pregnancy prior to medical imaging examinations that use ionizing radiation. Examinations that deliver a high dose of ionizing radiation to a pregnant uterus include fluoroscopy and interventional procedures of the pelvis. Examinations to the chest, extremities, head, and neck deliver a low dose of ionizing radiation. When imaging a pregnant female patient, it is crucial to avoid direct exposure to the pelvis whenever possible and to properly collimate the beam to limit radiation exposure.

The exact protocol for proceeding once a patient responds she might be pregnant is specific to the facility and department. Departments often require written documentation before pregnancy screening can occur, and the patient's referring practitioner or radiologist generally decides whether pregnancy testing is necessary. Ordering practitioners also can decide whether the patient should have an alternative imaging examination to avoid radiation exposure.

The screening of patients for potential pregnancy and appropriate written documentation are essential best practices for radiation safety in digital imaging.

Image Acquisition

When producing digital radiographs, radiographers must predetermine the precise radiation exposure needed to produce a quality image for diagnostic interpretation. A diagnostic-quality image is one that has sufficient brightness to display anatomic structures, an appropriate level of contrast to differentiate anatomic structures, maximized spatial resolution and minimal quantum noise and distortion. To achieve this, the radiographer must select exposure factors that limit the quantum noise/mottle that can result from an insufficient amount of radiation reading the digital image receptor, in order to accurately represent the differential absorption of x-ray energy by the anatomic structures.
The selection of the appropriate exposure indicator (EI) target by the medical physicist and radiologists will determine the acceptable level of visible quantum mottle.

Many variables affect the acquisition, processing, and display of a quality image and the complexities of DR systems continue to create significant challenges for radiographers. Standardizing exposure technique and emphasizing sound practices can help ensure radiographers follow dose optimization principles when performing digital examinations.

As a general rule, long-held radiographic exposure theories and technical practices apply to the acquisition of DR images. For example, using the law of reciprocity to change to a higher mA and shorter time in an effort to reduce motion artifacts and improve temporal resolution will yield an exposure indicator similar or identical to the one obtained with the equivalent mAs technique. Another example is the exposure maintenance formula used for changes in source-to-image receptor distances, which remains applicable with DR systems.

Standardized Exposure Technique

A digital image receptor measures the variance in x-ray intensities exiting the patient. The digital image receptor also has a wide exposure latitude. In addition, computer processing produces images that appear to be acceptable on a display monitor even when significant overexposure has occurred. Because of this, the standardization of exposure techniques used during radiographic procedures has become even more essential. Digital technologies continue to advance, and departments cannot rely solely on vendors and professional organizations to set technical standards. Setting comprehensive department policies and accurate and current protocols helps the radiographer ensure consistent diagnostic image quality and minimizes the potential for errors in exposure technique selection.

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, condition, and part thickness. Appropriate and consistent use of exposure technique charts, adequate kVp, and accurate use of AEC are essential to consistently produce diagnostic images while minimizing patient radiation exposures. Technique charts also can be updated when the need to override preprogrammed techniques arises. There are numerous manufacturers and types of digital imaging equipment. Each company puts its own proprietary footprint on its equipment. Many units come with preprogrammed techniques in the form of APR. Some units allow for a change in the image receptor's response to radiation or sensitivity.

Despite all these features, selection of exposure factors by the radiographer is essential. Accurate technique selection is still the most important part of obtaining an image in digital radiography. To prevent dose creep, the technique must be based on sound theories and predicated on the appropriate mAs and kVp for the thickness of the body part and condition of the patient to produce a sufficient number of photons in the primary beam. In addition, the kilovoltage necessary to produce appropriate penetrability and differential absorption must be selected. APR programs and technique charts with valid exposure factors should be available to all radiographers.

It is best practice for a radiographer to know the proper applications of technical theories, the techniques to be used for a specific imaging system's sensitivity, and the operational functions of the digital radiography system. This includes selecting appropriate exposure factors for a patient's size, body composition, and condition.

Kilovoltage Peak (kVp)

Image quality depends on a sufficient amount and energy of x-ray photons reaching the image receptor. As a general rule, kVp and mAs should be selected carefully for digital image receptors to ensure appropriate image SNR and diagnostic image quality at the lowest possible patient radiation exposure. Correct kVp selection determines adequate penetration and the degree of differential absorption needed to create differences in the x-ray energies exiting the part. These differences in exiting x-ray energies are necessary to produce the desired level of subject contrast. Given adequate penetration of the part, kVp has less of an effect on the contrast of the displayed image because of computer processing. A quality digital image is produced following adequate penetration along with enough image receptor exposure and signal data to produce a diagnostic image with a minimal amount of quantum noise/mottle and appropriate spatial and contrast resolution.

The use of higher kVp values along with an appropriate decrease in mAs is broadly advocated to reduce patient dose. Increasing the kVp by 15% with a corresponding 50% decrease in mAs reduces patient radiation exposure while maintaining image receptor exposure. Using the 15% rule to compensate for an increase or decrease in kVp also will show a reliable consistency in the exposure indicator. Specifying the appropriate kVp level for digital examinations is an important exposure technique variable for radiology departments to standardize.

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 mAs needed to provide an adequate exposure to the image receptor.

Source-to-Image-Receptor Distance (SID)

Digital radiographs are typically acquired using one of two standard source-to-image-receptor distances (SIDs): either 100 cm (40 inches) or 180 cm (72 inches). Increasing the SID can effectively lower patient radiation dose and improve image quality. For example, an anteroposterior (AP) radiograph of the pelvis acquired at an SID of 140 cm instead of the standard 100 cm may result in a significant reduction in patient entrance skin dose (ESD) and overall effective dose (E). Empirical research has demonstrated these advantages during radiography of several anatomic areas, including the abdomen, lower extremities, lumbar spine, pelvis, and skull.

Due to the geometric properties of image acquisition, an increase in SID will also reduce geometric magnification, thereby reducing the projected part size and potentially including more anatomic information on the image. This may be of particular importance when imaging patients of larger body habitus or parts that are too large to be included on an image receptor, such as lower leg examinations.

Radiographers must take care to annotate the specific SID used to acquire an image when it has been increased from the standard. The interpreting clinician must be aware of any change in SID between similar images acquired on the same patient due to changes in magnification and displayed image part size. Also, the radiographer must remain aware that an increase in SID when using AECs may result in an increase in exposure time to maintain proper image receptor exposure. As a guide, the ACR recommends that exposure times be as short as possible for radiography to optimize temporal resolution. This is particularly true for abdomen and chest radiography because increased exposure times may introduce motion blur on the image. The radiographer must work to strike a balance between dose reduction and the potential for reduced image quality due to motion.

A best practice in digital radiography is to increase the source-to-image-receptor distance (SID) when feasible in order to decrease patient entrance skin dose (ESD), effective dose (E), and geometric magnification.

Automatic Exposure Control

It is critical that the AEC be calibrated properly to match the image receptor exposure indicator before clinical use. AEC systems use radiation detectors that are preprogrammed based on standardized phantoms. These systems traditionally come equipped with 3 sensing areas; some newer AEC systems have 5 areas from which to choose. It is important that radiographers choose the appropriate detector cell configuration for the examination.

AEC controls 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; APR and technique charts help ensure consistent use of these factors with AEC. Proper selection of kVp is critical when using AEC to avoid quantum noise/mottle that might occur because of underpenetration.

Although AEC use is recommended in most radiographic examinations to help reduce patient radiation exposure, there are times when it cannot be used. For example, when the anatomy of interest is too small, those areas of the detector cells not covered by the patient's anatomy receive more radiation than the area of interest, causing the AEC to terminate the exposure prematurely and causing increased 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 end and result in insufficient exposure to the image receptor and a consequent increase in quantum noise. Finally, the 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 detector cells 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 cell(s) used, and place emphasis on proper positioning for an examination. The plus or minus (+/-) "density" (exposure intensity) controls should not be routinely necessary to arrive at the appropriate exposure level for a digital radiograph. These controls should be used only for specific radiographic projections and special circumstances where the exposure to an anatomical region needs to be increased or decreased because of positioning limitations, pathologic considerations, or other factors. It is important for radiographers to follow department protocols and exposure technique charts regarding the use of AEC.

A best practice in digital radiography is to use AEC when indicated, with proper positioning of the area of interest over the activated AEC detector cell(s), 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 examination and set through the control panel of the radiography unit. Essentially, an APR system is an electronic technique chart. APR settings commonly provide recommendations for small, medium, and large adult patient sizes and include a combination of AEC and manual exposure technique settings. The APR settings should be programmed carefully and routinely revised to ensure the appropriate exposure is used for the anatomy demonstrated and to result in an optimized digital radiograph. Specific APR technical settings (e.g., mA, exposure time, kVp) should consider the predetermined speed class of the digital detector(s) and the subsequent sensitivity to remnant radiation, thus ensuring that the target exposure values for each projection are precisely met, and that patient dose is optimized. It is important for the radiographer to assess the programmed exposure technique for its appropriateness to each radiographic examination. As an electronic technique chart, APR provides a starting point for the selection of appropriate exposure factors. However, it is important for the radiographer to adjust these factors based on patient-specific variables such as body habitus and pathologic considerations, as well as the clinical indication for the examination, to ensure proper exposure and diagnostic efficacy.

An exposure technique chart also based on measurement of part thickness can be used to standardize exposure techniques according to patient size, examination, and position. Use of exposure technique charts is required in some states and as is 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. When coupled with careful monitoring of exposure and deviation index data, routine use of the charts can provide consistent and accurate radiation exposure to the image receptor, thereby optimizing 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 with optimized dose. A thorough exposure technique chart includes, at a minimum, the following variables for each x-ray tube:

- Acceptable exposure indicator range
- Additional filtration
- AEC detector cells
- Backup exposure time or mAs (if set)
- Filament/focal spot size
- kVp
- mA (if set)
- Source-to-image receptor distance (SID)
- Speed/sensitivity
- Use of a grid (and ratio), grid-replacement software, or no grid

Typically, exposure technique charts are developed based on part thickness. Although measuring part 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 do not 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 dose optimization principles.

A best practice in digital radiography is to use both automated and traditional exposure technique charts that are continuously improved and applicable to a wide range of patient sizes, and to adjust technical settings based on the specific patient, projection, and clinical indications for the examination.

Collimation and Electronic Masking

The ASRT, ACR, and the SPR support pre-exposure collimation of the x-ray field, which limits the beam to the area of interest and defines the irradiated anatomy. By collimating appropriately, a smaller area of the patient's tissue is exposed, thereby reducing patient dose and minimizing the production of scatter radiation, which also minimizes the amount of scatter reaching the image receptor. Collimation is very important in digital radiography because the 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.

A digital radiograph is an electronic dataset of signal values directly related to radiation exposure levels collected by the detector elements (DELs). These signal values are arranged according to their frequency of occurrence in a histogram, which is a graphical representation of all values from minimum to maximum. Computer software analyzes the histogram to determine clinically significant signal values. Proper pre-exposure collimation is crucial for accurate histogram analysis and initial image processing. Without adequate collimation, scatter radiation increases, reaching the image receptor and adding unwanted exposure. This results in a narrower histogram, as scatter radiation makes pixel values more uniform, reducing their range. Scatter radiation limits this range by adding a consistent exposure level across the image. Additionally, kilovoltage values can create a histogram of varying widths depending on the kVp chosen. In contrast, film-screen image receptors handle scatter radiation differently, as seen in the slope of the D log E curve. With film-screen image receptors, increased scatter radiation widens the curve's slope. Therefore, the traditional rules of exposure technique selection and image appearance no longer apply as they did when medical images were photographic in nature. Technologists must understand these relationships and how inadequate collimation impacts the histogram's clinical value.

The postprocessing capabilities of digital imaging include the function commonly referred to as electronic collimation, shuttering, masking, or cropping. Even though these terms might be used interchangeably, the effects of postprocessing functions on the image and patient data can vary. These effects make appropriate pre-exposure collimation for exposure field recognition imperative for preventing errors in image processing. Masking is the act of applying a black border to eliminate the white areas around a properly collimated image. This is done automatically based on the exposure field recognition in the image data captured by the image receptor. Radiographers might need to adjust the electronic masking to accurately align it to the exposure field when automatic processing fails to do so. The unexposed area of the image outside of the collimated exposure field has a bright appearance that negatively affects viewing conditions and can lead to veil glare. The purpose of masking is to reduce eye strain in the viewer that can be caused by the increased brightness levels. To document the actual pre-exposure collimation, the mask should be applied to the image with a small distance between the exposure field and the start of the mask overlay, leaving a thin white border commonly referred to as a "silver lining."

A best practice in digital radiography is to use pre-exposure collimation to limit the x-ray beam to the anatomic area of interest 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, cropping, or

shuttering must not be applied over anatomy that was contained in the exposure field at the time of image acquisition. Radiographers are obligated to provide interpreting practitioners with all information that is captured by an image receptor and should, therefore, refrain from manipulating the image in a way that hides or removes data.

Shielding

Radiographers must possess, apply, and maintain knowledge of current radiation protection and safety principles in accordance with dose optimization practices to minimize exposure to the patient, self, and others. Significant advances in digital radiographic equipment have resulted in reduced patient dose during radiographic procedures, including those that image the abdomen and/or pelvis. Current recommendations support the elimination of fetal and/or gonadal shielding during abdominopelvic radiography.

Radiologic technologists should follow department guidelines for all radiation protection practices, including patient shielding. Improper use of a shield can interfere with the equipment's ability to identify and optimally display the values of interest if the shielding material is included as part of the data used for processing the image. Placing a lead apron over the AEC detector cells when using automatic exposure control (AEC) may result in an inadvertent increase in patient dose. Therefore, the shield should not be placed within the collimated field during digital radiography. Patient gonadal and/or fetal shielding remains an appropriate practice in clinical scenarios where the shield does not obscure pertinent anatomy, lead to a repeat radiograph, or interfere with equipment operation. Appropriate patient shielding remains an important component of efforts to minimize patient dose and increase patient comfort and confidence in our expertise.

A best practice in digital radiography is the use of lead shielding to reduce unnecessary radiation exposure to the anatomic parts of the patient that lie outside of the x-ray field. Occupational shielding and providing appropriate shielding to others in the procedure room during the exposure should continue as best practice.

Anatomic Side Markers

Radiologic technologists should use uniquely identifiable anatomic lead markers that are recorded radiographically during the exposure to indicate laterality. Although electronic annotations may be added to the final image during postprocessing to indicate laterality, they are not an acceptable substitute for lead markers captured during the exposure to the image receptor as part of the original image data. This is because any new data that is added to the original image file during postprocessing is treated as an additional layer, which may get altered or lost during data transmission. Therefore, because electronic annotations can be changed or erased, the use of lead markers captured during the exposure is a best practice as they are a permanent part of the image data. Furthermore, failing to use uniquely identifiable lead markers to denote the anatomic side or to identify the radiographer performing the examination can lead to a legal issue. The ACR also emphasizes the consistent use of lead markers in its digital practice guidelines and recommends that each facility establish a policy concerning the storage of annotation on the images according to digital imaging and communications in medicine (DICOM) standards.

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.

Antiscatter Grids

The sensitivity of digital image receptors to scatter radiation makes the use of antiscatter grids critical to ensuring quality images because of the grid's ability to absorb scatter before it reaches the image receptor. However, a major disadvantage of using a grid is the required increase in radiation exposure to the patient. Therefore, the choice to use an antiscatter grid for a specific radiographic examination requires careful consideration following departmental guidelines. As a general rule, grids are appropriate for anatomy with a thickness of 12 cm or more in adult patients. If a grid is used, it is best practice to use one with the lowest grid ratio. The ACR recommends that the decision to use an antiscatter grid when imaging pediatric patients be based on the patient's size and the collimated exposure field size.

Although displayed image contrast increases with the use of grids because of scatter removal, exposure to the image receptor decreases because of some unintended absorption of the primary radiation. The need to maintain image receptor exposure, therefore, always has been regarded as a disadvantage of grid use because of the subsequent increase in patient exposure. Historically, maintaining image receptor exposure has been achieved by increasing the mAs according to the grid conversion factor relative to the grid ratio. While the concept of maintaining image receptor exposure with an increase in mAs when a grid is added to a radiographic procedure is valid, radiographers are responsible for ensuring that the technical conversion factors used are appropriate for the digital systems they are using to acquire their images. To accomplish this, radiographers should consult with vendors and must carefully monitor the EI during grid-based radiographic procedures to avoid overestimating the amount of mAs necessary to maintain image receptor exposure.

Great advancements have taken place with grid-replacement software, also known as grid substitution software. Grid-replacement software may be used as an alternative to a physical grid for scatter removal. The process begins with the use of advanced algorithms that can predict scatter location through the use of machine learning models to estimate the scatter radiation. The algorithms then analyze the dataset to identify scatter radiation by distinguishing between scatter photons and remnant radiation, based on the variations in the intensity between the two. Scatter radiation is then subtracted from the original dataset while remnant radiation is retained. As a result, the final processed image has reduced scatter and improved image contrast. The advantage of this technology, which removes the scatter through image processing, is the significant dose reduction compared with traditional physical antiscatter grids.

In addition, when a physical grid is used, grid suppression software is available to reduce or remove visible grid lines, which can occur due to grid presence, as well as the grid or x-ray tube misalignment. The grid suppression software is capable of analyzing the image to identify the grid lines by recognizing the regular pattern of lines that correspond to the physical grid. The software then applies specific algorithms to remove these lines from the image by interpolating the pixel values around the grid lines to merge them with the surrounding image data. After the grid lines are removed, the software may further process the image to adjust the image contrast and brightness, and to maintain diagnostic accuracy. The result is an image that retains the benefits of scatter reduction provided by the physical grid but without the visual distraction of grid lines.

What remains important is the proper use of grids. Angling against the grid lines will still result in a significant decrease in the amount of x-ray energy reaching the image receptor, commonly referred to as grid cutoff. The radiographer must remain aware that grid cutoff can occur if the grid is not used properly. Off-center, off-level, upside-down placement, and focal range errors still result in grid cutoff. Also, a change in grid ratio will result in a change in the EI in many cases unless properly compensated for by an adjustment in mAs. A thorough exposure technique chart includes when a grid should or should not be used, and when grid-replacement postprocessing software is implemented.

A best practice in digital imaging is the use of a grid with the lowest grid ratio and specifications recommended by the digital imaging equipment vendor, generally for body parts that exceed 12 cm in adults. In addition, department protocols and technique charts should include information about grids being used and, if applicable, considering the use of grid-replacement software.

Positioning

Accurate positioning is critical to radiographic image quality. The increase in exposure latitude in digital radiography has led to an overall reduction in repeats due to the use of incorrect exposure techniques, 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. Studies such as that by Fintelmann et al indicate that using CR and DR has led to more images being rejected for positioning reasons. Similarly, a recent systematic review that focused on the repetition rate for routine radiographs using digital image receptors reported that in the majority of studies that were analyzed, positioning errors emerged as the primary cause of repeated examinations. The repeat rate for positioning errors ranges from 51% to 85%, compared with the standard 8% repeat rate that was associated with analog imaging.

Research indicates that technology does not affect the radiographer's skills in accurately positioning the patient. For example, the technical capabilities of digital radiography equipment provide the unique opportunity to crop or mask the image at the workstation to compensate for a poorly collimated exposure field. However, masking or cropping is not a substitute for proper collimation. Therefore, radiographers still must use proper collimation and correctly position the anatomy of interest relative to the digital image receptor.

Immobilization is a critical component of positioning that helps to prevent repeat images and provides higher-quality images for diagnosis, particularly in examinations of pediatric, geriatric, and trauma 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. 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 repeat exposure.

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. Many of the factors radiographers must consider during adult radiographic examinations should be given special consideration when performing radiography examinations of pediatric patients. Pediatric patients have developing organs and are up to 10 times more sensitive to ionizing radiation than adults. Pediatric patients have longer life expectancies than adult patients, which means they have more years in which late radiation effects may occur. Because of this increased sensitivity and longer life expectancy, attention to dose optimization 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 x-ray imaging creates radiographs. For example, muscle tissue is denser 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 adult dimensions. This makes it difficult to estimate exposure technique because patient thickness depends on a child's age and 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. Radiographers must carefully consider whether to use grids based on the patient’s actual size and tissue composition. The smaller thickness of pediatric anatomy allows for most radiography to be done without a grid. Air-containing anatomical structures greater than 12 cm can be imaged without a grid. An example is a chest radiograph of a child who weighs 75 pounds.

Exposure Technique and Filtration

In pediatric radiography, APR settings must be adjusted for imaging patients who can vary from premature infants to obese older pediatric patients. Radiographers must carefully select optimal kVp to penetrate the pediatric patient’s anatomy under study. Selection of appropriate kVp is more critical with examinations of infants and children because their bodies typically display less subject contrast. The bones of infants and young children are less calcified than adult bones and require lower kVp for appropriate attenuation compared with adults. As a result, radiographers can reduce kVp but still adequately penetrate the bone with the x-ray beam to obtain a diagnostic-quality image. The spatial resolution demands are higher in pediatric imaging owing to smaller body parts being imaged, so the small focal spot size is recommended.

The AEC should be used only if the pediatric patient's anatomy of interest can completely cover the active AEC detector cells. Radiographers who use AEC settings for imaging pediatric patients should follow the Image Gently digital safety checklist, which emphasizes that radiographers must be diligent in ensuring the appropriate kVp, backup time, image receptor, and AEC detector cells have been selected. Radiographers may need to use manual technique selection in pediatric radiography when the part is smaller than the AEC detector cell. When using manual technique selection, radiographers should measure the part's thickness with calipers to select the appropriate technique factors for each patient from proven APR settings.

Radiographers play a vital role in selecting appropriate filtration materials based on the specific requirements of each radiographic examination. They must consider factors such as the type of examination, patient size, and desired image quality to ensure an optimal balance between diagnostic efficacy and radiation exposure. Although copper filtration may be beneficial to other examinations, current research supports increasing the thickness of copper filtration as a dose reduction and image quality optimization strategy for routine chest imaging using digital flat-panel detectors. Use of additional filtration, such as 0.1-mm copper or more, is recommended to reduce entrance skin exposure at the patient surface for pediatric patients.

Collimation and Shielding

Appropriate collimation and minimizing the anatomy exposed to radiation can reduce radiation dose to pediatric patients. As with adult examinations, proper part alignment is critical to ensure essential anatomy is included in the image. Demonstration of the "silver lining," the edge between the collimation and the electronic mask, ensures that all exposed area of the patient has been included in the image. According to Bomer et al, failure to include the entire exposed field due to excessive masking may prevent the interpreting practitioner from evaluating the entire image and may allow for excess exposure to go unnoticed.

In accordance with recently updated guidelines, routine shielding of the gonads during abdominopelvic radiography of the pediatric patient is not recommended. Depending on the anatomic area of interest, placing a lap- or half-shield over radiosensitive tissues (e.g., gonads, breasts) during pediatric digital radiography remains appropriate, as long as the shield does not interfere with equipment operation and/or the diagnostic efficacy of the procedure. For example, placing a lap shield over the pediatric patient's gonads during extremity radiography carries no risk and may help to increase the comfort and confidence of the patient and his or her caregiver. 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 than adults typically do, the anatomy of interest might not be centered accurately or consistently within collimation boundaries. In some digital imaging systems, improper centering affects how the digital system software forms the image. Immobilization devices can help ensure the pediatric patient does not move during the exposure, which would result in a repeat radiograph. 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, such as a parent holding a smartphone playing the child's favorite cartoon, 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 dose optimization principles, radiation protection, and size-appropriate exposure techniques. Proper collimation, positioning, and immobilization also are necessary to decrease repeat exposures.

Image Critique

Radiologic technologists must thoroughly critique every image before sending it on for interpretation. The radiographer is responsible for critically assessing each image for the following:

- Correct patient and examination information
- Exposure indicators
- Required anatomy
- Positioning accuracy
- Artifact analysis
    - Image acquisition artifacts
    - DR detector artifacts
    - Image processing artifacts (errors)
- Exposure errors
    - Underexposure
    - Underpenetration
    - Overexposure
- Markers
- Collimation
- Image quality factors
    - Visibility
    - Spatial resolution/recognizability

Correct Patient and Examination Information

Checking that radiographic images include the correct patient and examination information is crucial for ensuring patient safety, legal and ethical compliance, and efficient workflow. Incorrect information can lead to misdiagnosis or inappropriate treatment, which can have serious consequences for patient outcomes. Furthermore, accurate patient information ensures that the radiographic images are correctly interpreted in the context of the patient's medical history and the condition that led to the examination. Proper patient identification helps in maintaining accurate medical records, which is essential for legal and ethical reasons. Finally, correct information reduces the likelihood of interpretive errors and the need for repeat examinations, saving time and resources for both patients and health care providers.

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 for image quality with radiation safety in mind, as well as medical-legal implications.

Ensuring that the radiographic image contains accurate patient and examination information is a best practice in digital radiography. This helps prevent patient safety issues and ensures legal and ethical compliance.

Exposure Indicators

Because of the separation of image acquisition and display, digital systems lack the visual cues apparent in analog systems that lead to the recognition of exposure errors. As a result, the radiographer needs to monitor the exposure indicator 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 image receptor has received and thereby determine whether the correct exposure technique for the image was used. It is critical to note that EIs are not measures of radiation dose to the patient and that the EI records the level of exposure to the image receptor. At the present time, the name of the EI varies widely among manufacturers. In addition to the variations in name among manufacturers, the relationship between a change in the level of exposure and the corresponding change in EI is not uniform between manufacturers. The lack of a standardized name and EI response relationship between image receptor exposure and exposure indicator has created confusion for radiographers who work with equipment from multiple manufacturers, or of different versions from the same manufacturer.

The vendor community has responded, and by a joint effort of the International Electrotechnical Commission, the Medical Imaging and Technology Alliance (MITA), and 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 deviation index (DI) is an important term to recognize and understand. The deviation index is based on the established target EI values for the examination. The deviation index provides the radiographer with feedback related to the level of exposure used to create the image and aids 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

Each manufacturer has developed its own target ranges for incident exposure at the image receptor as measured by their respective EIs. 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. A radiographer must understand the exposure technique factors that lead to the EI value. During the image data processing, a portion of the sequence involves identifying exposure field borders. Errors during exposure field recognition can cause inaccurate EI and DI calculations; 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 variability, or a patient's unusual body habitus can cause EIs to be higher or lower than expected. Completing an examination with an acceptable EI does not necessarily verify proper exposure technique.

To address concerns regarding the wide variety of exposure measurement values, manufacturers and physicists devised a deviation index system that was introduced in 2012. The system was based on recommendations by the AAPM. This system has been developed to indicate when an exposure number falls within the appropriate range by indicating those that are too high, too low, or in range. The numbers vary from unit to unit and are based on the applications used by a specific manufacturer. The standardized systems use zero as the indicator for a correct exposure for an image. Positive numbers indicate overexposure and negative numbers indicate underexposure. As an example, a DI of 0 is a correct exposure; a –1 indicates the exposure is about 21% too low, and a +1 indicates the exposure is about 26% too high. A 3 indicates 100% overexposure and a −3 indicates 50% underexposure.

It is the responsibility of the radiographer to use the EI and DI information to optimize exposure factors from projection-to-projection and from patient-to-patient. To determine the optimal mAs for a repeat or subsequent exposure for the same part and projection, the following formula may be used: Optimal mAs= $(mAs)(4/5)^{DI}$. For example, if 5mAs was used for an AP Chest exposure, and it resulted in a DI value of +2, using 3.2 mAs on a similar part/projection would result in an optimal DI value of 0.

The table below illustrates this system. The AAPM proposed −0.5 to +0.5 as a target range. Images should be repeated if the DI is less than −3.

Example Deviation Index (DI) Table

Deviation Index	% of Target
3	~100% too high
2	~58% too high
1	~26% too high
0	Correct
-1	~21% too low
-2	~37% too low
-3	~50% too low

Note: Optimal mAs= $(mAs)(4/5)^{DI}$

Some units show these values in numerical terms, and others use a color system such as green, yellow, and red. For example, the DI might be represented by a red, green, or yellow color bar to indicate percentage of overexposure, percentage of underexposure, or appropriate exposure range. It is important for the radiographer to understand the exposure relationship to EI numbers and not simply a color indicator.

A best practice in digital radiography is the effective use of the EI/DI to determine whether adequate exposure has reached the image receptor. Because the EI/DI has limitations, the radiographer must carefully assess whether a repeat examination is necessary.

Required Anatomy

Ensuring that all required anatomy is included in radiographic images is a crucial aspect of image critique for several reasons. Complete anatomical coverage allows radiologists to accurately diagnose pathologies as missing anatomy can lead to misdiagnosis or the need for repeat imaging, which increases patient exposure. In addition, including all necessary anatomy ensures compliance with legal and professional standards. Lastly, making sure that only the required anatomy is included for each projection is important for correct digital processing and exposure indicator calculation.

Digital processing systems store histogram models with shape characteristics of the selected anatomic region and projection, and map regions or values of interest to guide image processing. This is why selecting the appropriate anatomic region, projection, and exposure technique, along with correct pre-exposure collimation that includes only the required anatomy is crucial to allow the system to accurately generate EI values and analyze the histogram correctly. Therefore, issues such as poor collimation and inclusion of anatomic structures that are not required for the specified projection can result in incorrect EI values and lead to a histogram analysis error.

As a best practice, radiographers should ensure that all required anatomy is included in radiographic images. Missing or unnecessary anatomy can lead to misdiagnosis, increased patient exposure, incorrect exposure indicator values, and histogram analysis errors.

Positioning Accuracy

Image critique also includes evaluating positioning accuracy, which ensures that the area of interest is clearly visible and accurately represented. This is crucial for making an accurate diagnosis. Furthermore, the stored histograms are not only based on appropriate collimation and correctly selected anatomic region, projection, and exposure technique; positioning accuracy and anatomy orientation also play a significant role in how the system processes and displays the digital image. Proper initial positioning ensures that computer processing can be completed without compromising the diagnostic integrity of the image. When the shape of the acquired histogram does not match the shape of the stored histogram because of incorrect positioning, histogram analysis errors may occur and lead to a poor-quality image. Radiographers should determine the cause of image degradation and repeat the image as needed according to departmental policy.

Evaluating positioning accuracy is a best practice in digital radiography as it ensures that digital processing systems can correctly analyze and display the image, preventing histogram analysis errors and maintaining diagnostic integrity.

Artifact Analysis

Artifacts are unwanted elements of the image that do not correlate to the patient's anatomy and can negatively affect the diagnostic quality of the image. Classifying artifacts according to their cause may aid in identifying and preventing their clinical appearance. Artifacts can be classified as those relative to the digital image receptor, image acquisition, and image processing. The appearance of artifacts might be described in terms of their brightness, size, shape, and location on the image. Radiographers should strive to prevent image artifacts; however, if they do occur, radiographers should determine the cause, report if needed, and repeat the image as needed according to departmental policy.

Image Acquisition Artifacts

The improved contrast resolution of DR receptors makes the appearance of image artifacts more problematic. The best defense for preventing artifacts is to properly prepare the patient for the imaging examinations. It is essential for the radiographer to ensure the removal of any clothing or items that can potentially appear as an artifact in the exposure field. This includes items such as clothing with printing, buttons, pins, and hairclips.

The selection of appropriate technical factors is critical for minimizing patient exposure and the appearance of exposure-related artifacts. Extreme overexposure results in saturation of the detector. This is evidenced by decreased brightness or luminance in the anatomic structures, making visualization difficult. Extreme underexposure results in quantum mottle/noise due to an insufficient number of photons to create the image. This, too, can hinder the ability to see detail in anatomic structures. Underpenetration occurs when the x-ray beam does not have enough energy to pass through the tissues adequately and appears as a lack of visible detail. Having standardized exposure charts can help radiographers avoid these types of artifacts.

Additionally, the advent of built-in AEC detector technology may lend itself to the probability of exposure artifacts if not used properly. This type of imaging detector incorporates multiple regions of interest (ROI) or sensors, similar to that of traditional AEC devices. Each ROI detects photons and terminates the exposure once the preset threshold value is reached. However, as with traditional AEC devices, if an ROI does not correspond to the structure of interest, under- or overexposure may occur.

A less frequently seen artifact, but still a possibility with some image receptors, is a backscatter artifact. This artifact can occur when photons transmitted through the image receptor scatter backwards, creating an image of the detector electronics or the cassette. Preventing this artifact can be accomplished by using appropriate x-ray beam collimation. Additionally, using lead shielding behind the image receptor can help prevent backscatter artifacts.

DR Detector Artifacts

Flat-panel detectors consist of sophisticated sensors and highly integrated electronic components. They can be wired, wireless, cassette-based, or cassette-less. At the time of this writing, most flat-panel detectors consist of a glass plate on which the thin-film transistor array is attached. Mishandling or dropping the detector may result in artifacts due to glass and electronic breakage. Detector failure also can result in the appearance of artifacts such as the loss of an individual DEL the loss of rows or columns of DELs or the loss of an entire image segment. These can appear on the image as narrow bands or a large, rounded area where no signal/image is visible. It is also important to protect the image receptor from fluids/liquids that can damage the readout electronics of the detector, resulting in an image with repeated linear artifacts. Detector calibration issues can create image artifacts in the form of radiopaque vertical striping or radiolucent irregular lines. Eliminating these artifacts may occur through software corrections supported by review of flat-field images. In addition, it might be necessary to contact service personnel to repair or replace permanently damaged equipment. Detector lag is another potential cause of artifacts. A shadow of the previous exposure remains on the subsequent image as a result of taking images in rapid succession. This is particularly problematic when the image of a lead marker remains.

Image Processing Artifacts

Image data is processed with elaborate software algorithms, resulting in a specific image appearance. In some cases, the software fails to recognize exposure field edges. When this occurs, the algorithm may process all the data recorded on the image receptor, resulting in poor image quality. In this situation, it may be appropriate for radiographers to adjust the electronic shutter to the exposure field and reprocess the image. This eliminates the image processing artifact and avoids repeating exposure. Poor image processing also can be prevented by using appropriate collimation of the x-ray beam. Large areas of direct exposure, or raw radiation, to the image receptor can affect the values of interest included in processing the image.

The radiographer's selection of the processing menu (specific to the body part and examination) is also crucial in helping to minimize the likelihood of image processing artifacts. The common image qualities that menu selection affects are brightness, contrast, edge enhancement, and equalization. Additionally, the processing menu may determine how the EI is calculated for each image. If a processing menu is erroneously selected, the radiographer may reprocess the image using the correct menu. Note that a processing menu should never be selected based on radiographer preference regarding image appearance or for EI reasons. The processing menu data is part of the DICOM information and, therefore, part of the patient's medical record and should match the image that was acquired.

Lastly, when certain image processing algorithms such as edge enhancement are used inappropriately, the diagnostic quality of the image may be degraded. For example, in arthroplasty, excessive edge enhancement can create an artifact between the metal and bone that can negatively affect visualization of this interface.

A best practice in digital radiography is to prevent artifacts by 1) protecting the image detector from damage caused by mishandling and fluids, 2) using appropriate examination menus, and 3) preparing the patient for the examination and selecting proper exposure factors. Radiographers and their institutions also must recognize the causes of image artifacts and prevent future artifacts by properly maintaining or acquiring service for digital radiography equipment and replacing equipment as needed.

Exposure Errors

The visual cues of exposure errors are more difficult to recognize or are missing in digital radiography because of what happens to the image data during imaging processing. A common misconception is that the digital system corrects exposure errors, when in fact it does not. During the analysis of the image data, the potential exists for the digital system to adjust the image data, so the image has an acceptable appearance in the presence of underexposure, overexposure, and underpenetration. The exposure error remains regardless of what occurs during imaging processing.

Underexposure

Underexposure appears on the digital image as quantum noise/mottle visible in the thicker portions of the anatomy in the image. It can be recognized as a grainy appearance, consisting of tiny freckle-like spots of dark and light tones scattered throughout the affected area. Because quantum noise is a result of insufficient exposure to the image receptor, it can easily be corrected by increasing mAs or kVp depending on the clinical situation.

Overexposure

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 overexposure, there is an overall grayed-out appearance to the image. The anatomy still is visible, but the image's appearance is less than optimal. Severe overexposure can result in saturation that is displayed as a very dark area and can result in a reduction in the ability to see all anatomical structures. When the appearance of an image is less than optimal, it is up to the radiographer and interpreting practitioner to determine whether the image is of diagnostic quality.

Underpenetration

Underpenetration results in an inability to display small details. An underpenetrated bone would appear as a uniform white area, while a technique that used a higher kVp, capable of penetrating the bone, would result in a radiograph in which fine details such as the bony trabeculae would be visible. No amount of image processing can compensate for underpenetrated areas.

In digital radiography, exposure errors are harder to recognize because of image processing, which can make images appear acceptable despite exposure errors. It is important that radiographers can recognize these exposure errors during image critique and correct them as needed.

Markers

During image critique, the radiographer must review the image from a medical-legal standpoint, considering such indications as ensuring that uniquely identifiable pre-exposure radiopaque (lead) anatomical markers were used and are visible in the digital image. Furthermore, radiographers must make sure that the correct lead anatomical marker was used and that it does not obscure any structures of interest as visualized in the displayed image.

Radiographers should always use and verify the visibility of pre-exposure radiopaque anatomical markers in digital images to ensure accurate identification without obscuring any structures of interest.

Collimation

Radiographers should evaluate image collimation to ensure that all required structures of interest are included in the image. There should be evidence of pre-exposure border in the image that defines the irradiated field. This border documents that all necessary information for a radiographic image has been recorded. Electronic collimation or electronic masking of irradiated anatomy should not be used as a substitute for proper pre-exposure collimation. Doing so creates the potential to inappropriately eliminate information that might be important to the procedure’s outcome. Radiographers should take care to avoid eliminating exposed anatomy or other image-related information with electronic collimation.

As a best practice, radiographers must ensure proper pre-exposure collimation to include all necessary structures in the image and avoid using electronic collimation as a substitute.

Image Quality Factors

Image quality factors have an impact on image visibility and accuracy or recognizability, and, therefore, should be evaluated during image critique. Visibility factors include image receptor (IR) exposure and image contrast, while accuracy includes spatial resolution or sharpness, size distortion or magnification, and shape distortion.

IR Exposure

With visual cues of IR exposure errors being more difficult to recognize, appropriate exposure to the image receptor is vital. This is best evaluated using the EI values. Therefore, verification of proper EI value is essential to ensuring that the image receptor receives the appropriate exposure. It is also important to note that image brightness is a monitor control function that allows the radiographer to change the lightness and darkness of the image on a display monitor, but does not reflect IR exposure, and, therefore, should not be used to assess IR exposure.

Each manufacturer has developed its own target ranges for incident exposure at the image receptor as measured by their respective EIs. 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. A radiographer must understand the impact exposure technique factors have on the EI value. Insufficient IR exposure will lead to quantum noise, while excessive exposure may lead to saturation. In either of these extreme cases, visibility of anatomical structures may be affected.

It is a best practice in digital radiography to use EI values to evaluate image receptor exposure, which is crucial for accurate imaging because it impacts the visibility of anatomical structures. Radiographers must understand how exposure technique factors affect EI values and prevent quantum noise or saturation, ensuring the image meets departmental standards.

Image Contrast

Verifying that the final image displays proper image contrast is an essential step in image critique, as appropriate contrast affects the visibility of anatomical structures and aids in accurate diagnosis. Image contrast refers to the difference between the ranges of adjacent IR exposures represented as gray tones in an image. Because contrast consists of IR exposures, any change in overall IR exposure may affect image contrast. Therefore, proper selection of technical factors is important to ensure digital radiographs display proper contrast. For example, higher kVp settings may reduce image contrast, while lower kVp settings can increase it, despite digital systems using algorithms to display optimal image contrast.

It is best practice to evaluate image contrast to ensure that the correct processing algorithm that provides the appropriate level of grayscale for the anatomy of interest is applied. Ensuring proper image contrast is crucial for accurate diagnosis because it affects the visibility of anatomical structures.

Spatial Resolution/Sharpness

Spatial resolution is the sharpness with which an object's structural edges are represented in a radiographic image. It is affected by the focal spot size, beam geometry, motion, and digital processing, as well as image receptor and display monitor characteristics. When evaluating the spatial resolution during image critique, the radiographer should make sure that the maximum sharpness is displayed and that the image does not demonstrate any motion.

Evaluation of spatial resolution during image critique is a best practice, requiring radiographers to ensure maximum sharpness and absence of motion in radiographic images.

Size Distortion/Magnification

Size distortion or magnification is the difference between the size of a structure being imaged and the actual size of that structure. It can be created during the examination, as well as by applying the digital zoom during display. During image critique, radiographers should make sure that their images represent the actual size of the anatomical structures and that the magnification is kept to a minimum, except when magnification techniques are employed for selected examinations.

As a best practice, radiographers must evaluate whether digital radiographs demonstrate minimal magnification to ensure accurate anatomical representation of the structures of interest.

Shape Distortion

Shape distortion is the difference between the shape of the anatomical structures of interest in the displayed image and the actual shape of that structure. Just like size distortion, shape distortion should be minimized. Therefore, radiographers should ensure that the displayed image represents the correct shape of the structures being imaged.

It is a best practice to evaluate shape distortion to ensure that the discrepancy between the displayed and actual shape of anatomical structures has been minimized.

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 refrain from modifying image features after images have been processed and displayed. There are steps radiographers should take after the examination is completed, however, to ensure that data associated with the image (such as dose and demographic information) are recorded and that the final image is prepared for diagnostic interpretation.

Postprocessing

Digital imaging offers postprocessing capabilities to enhance image appearance and the radiographer should understand these postprocessing features. 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 to improve the viewing conditions for the digital radiograph. Electronic masking does not restrict the beam and reduce radiation exposure to the patient. Therefore, it should not be used in place of appropriate pre-exposure beam collimation during the image acquisition stage.

The expected processed data of the digital image should be kept intact. Some postprocessing features permanently change the grayscale values assigned to each pixel. A change in these values can cause loss of information and thereby affect the viewing capabilities in the MIMPS where it will be accessed by the interpreting or referring practitioner for diagnosis. For example, the postprocessing software feature called the region of interest (ROI) image adjustment tool allows the technologist to define a smaller area of the image, with the software using that smaller area to reprocess all the image pixel values as well as the exposure indicator (EI) for the entire image. Any adjustments to the window level or width will limit the data available to the interpreting or referring practitioner, and, therefore, should not be saved. If the radiographer determines that the approved default image processing does not provide adequate image quality, he or she should identify the cause of the poor image quality and determine appropriate corrective action rather than corrupt the expected pixel values through the use of the ROI tool or make changes to the window width or level. The processing algorithms are designed to provide optimum image quality relative to the anatomical part that is exposed to x-rays. If the processing algorithm consistently provides inadequate image quality, the radiographer should report the problem for investigation.

A best practice in digital radiography is to preserve the expected pixel values created by the approved processing methods. If changes to the window width or level are made or if the use of the ROI tool is required to provide alternate displayed image brightness and contrast, these modified images should only be provided as an additional copy for review and not as the only data set.

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 the DICOM information embedded in the DICOM header. It is recommended that the EI and DI values be displayed as well. A modern digital radiographic system also may be equipped with a dose area product (DAP) meter, designed to calculate the x-ray dose to the exposed air within the acquired field. DAP information, reported in units of gray-cm^2, also should be included as part of the DICOM information for the image.

All radiation exposure information should 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 such as CR cassette-based systems. Radiology departments should work closely with vendors and MIMPS personnel to determine how unaltered 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.

Including exposure information on every final digital radiograph allows radiographers to take note of and use the information to refine exposure technique selection in subsequent exposures. Including data related to technical factors on every final examination's DICOM header should ensure that the radiology department can maintain quality and adherence to dose optimization concepts. It is essential that EI and DI 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, DI, 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 might first recognize equipment malfunction. In addition, the electronic nature of modern digital imaging recognizes that human error can occur with digital imaging, and these errors must be acknowledged and corrected to prevent trends that could jeopardize patient radiation safety and image quality. 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. The role of the radiographer is very important in recognizing image quality issues and communicating those concerns to trained service personnel. The communication link between the radiographer and biomedical service personnel is more important than ever, as image creation is predominantly controlled by system electronics and sophisticated software algorithms. Acceptance testing and regular quality control inspections can help identify systematic errors. Quality control measures should include radiographers, as they are integral to the initial detection of system errors and can be proactive on corrective measures. Additionally, 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 by the manufacturer and these published specifications serve as a baseline performance benchmark. Upon completion of the installation and turnover of equipment for first clinical use, these benchmarks should be recorded and subsequent inspections graded against these standards. Additionally, most systems have integrated self-diagnostics that enable accurate assessment of detector issues and are of great benefit to qualified service engineers. 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. When appropriate, an institution's biomedical personnel may be involved with this testing. Initial testing and equipment calibration often are followed by a period of observation while the device undergoes routine use. Initial acceptance testing and calibration also help the physicist establish a baseline performance for the equipment and subsequent QC testing, which should occur systematically to re-establish a baseline. The department should have established QC measures in place with specified timelines for these measures and performed by the appropriate staff.

Systematic Quality Control

Generators and x-ray tubes generally remain the same when implementing use of digital radiography, but other parts of digital systems might be new to radiographers and require updated QC policies and procedures. 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 to identify potential equipment malfunction and report their concerns to the appropriate individuals. Unusual equipment sounds and operation often are first sensed by the radiographer and should be noted for service personnel.

ACR guidelines also recommend that an onsite radiographer be responsible for conducting routine QC noninvasive activities. Radiographers should perform routine 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 monthly phantom testing for image quality and artifacts, and inspect and clean image receptors routinely. Additionally, viewing monitors should be assessed weekly using established software test patterns that are universally accepted. Periodic testing can identify potential equipment malfunctions and image quality issues. Examples follow below, but each department can 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 can 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 regularly. Most manufacturers recommend that these phantom images be taken during acceptance testing of the equipment monthly or more often when problems are suspected.

Display Monitor

Display monitor performance has taken on added importance because digital images are only 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. Display monitors used for interpretation (primary) should be tested and monitored according to specifications set forth by the manufacturers and the ACR-AAPM Technical Standard for Electronic Practice of Medical Imaging, 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 class 1 monitors, which are used for diagnostic interpretation, than for secondary (class 2) display monitors, which are part of 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. A QC test pattern — either the Society for Motion Picture and Television Engineers (SMPTE) pattern or the AAPM TG18-QC pattern —should be used to characterize the display monitor performance at a regular frequency.

Repeat Analysis

Careful analysis of repeats 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. Appendix D lists the information required for an effective repeat analysis program according to the AAPM Task Group 151. 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

Digital technology continues to have a significant effect on workflow in clinical practice and in the radiology department. The change to and appropriate use of digital image receptors affects radiographers more than any other staff members. For example, the electronic transmission of images from radiographer to radiologist and other workflow adjustments 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 interpreting practitioners, creating more opportunity to collaborate with management and fellow technologists regarding image quality and analysis. Only teamwork and open efforts at communication can ensure a smooth transition and an ongoing culture of quality, safety, and efficiency.

In this environment of continuously advancing technology, it is the responsibility of the radiographer to develop and maintain a comprehensive knowledge and understanding of digital radiography and its associated best practices. The radiographer must combine knowledge and understanding with the critical-thinking skills necessary to evaluate the quality of images submitted for interpretation and to perform the appropriate quality assurance procedures with the equipment they use. 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 interpreting practitioners, as well as fellow technologists.

Safety and Professionalism

The overall efficiency of digital radiography improves workflow and increases patient throughput. As a result, radiographers can be expected to work faster or manage more patients. It is critical that radiographers continue to adhere to protocols and uphold their responsibilities for patients even in this fast-paced environment. The potential for harm in performing digital radiography can be high, especially as acquiring images becomes faster and easier. A culture of safety and professionalism emphasizes patient safety and advocacy while recognizing the radiographer's critical role as the professional who delivers radiation to patients.

The ARRT Code of Ethics and ASRT Practice Standards for Medical Imaging and Radiation Therapy both emphasize professionalism, with radiographers continually striving to improve knowledge and skills, and participating in and adhering to patient safety activities. The ASRT Practice Standards also emphasize innovation, research, best practice, and a commitment to lifelong learning. The ARRT Continuing Qualifications Requirements (CQR) requires that radiographers who earned their credential after 2010 engage in a process that assesses current skills and provides opportunities to improve knowledge, so that the credentialed radiographer can continue to provide the highest level of quality care to patients.

It is essential that radiographers continue to learn and improve personal professional practice in an industry where technology advances on a regular basis. As members of the health care team, radiographers participate in quality improvement processes and continually assess their professional performance. Radiographers should learn from one another as well as from vendors, supervisors, physicians, and formal education or continuing education programs to maintain clinical relevance and competence. Most of all, a culture of safety and professionalism recognizes improvement and modification of systems and operations rather than punishment of individuals who make errors. 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.

A best practice in digital radiography is to learn and consistently adhere to the latest, empirically supported best practices to ensure patient safety.

Promote Collaboration and Radiation Safety in the Workplace

The culture of safety and improvement must take place within a fluid workforce. Radiographers must approach this culture professionally and as a team, learning from and supporting each other. Recent graduates have learned the fundamental physical principles of digital radiography, which can contribute to a deeper understanding of the advancing technology in practicing radiographers, and lead to additional improvements in workflow and outcomes. To do so, however, experienced radiographers must be open to recent graduates' input. On the other hand, recent graduates must appreciate and respect the backgrounds and practical knowledge of more experienced technologists, as many of the core principles of radiographic technique, exposure, and image quality learned and applied during analog imaging still apply to digital radiography.

A team approach to implementing best practices in digital radiography is a key to ensuring a culture of safety. Donnelly et al reported in 2009 on implementing a comprehensive approach to patient safety in a radiology department that included teamwork with other hospital departments, addressing staffing, opening communication and feedback mechanisms, 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**.** In 2015, Larson et al concluded that the establishment and maintenance of a safe patient environment depends on individual skill and an organizational culture that fosters a cooperative environment where team members adhere to standards, quickly learn from problems, and are willing to accept and apply feedback.

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.

Developing Technologies

Radiology is a technology-driven medical specialty that plays a crucial role in patient care. Throughout radiology's history, technological innovation to improve patient care outcomes has been a hallmark characteristic. The development of digital detector technology is evidence of this important trait and the result of collaboration between clinical research centers and the commercial community.

Flat-panel detector (FPD) technology has brought about the concept of electronic image data sets. Newer FPD features will take advantage of the quick response of data acquisition and the quantification of electronic data points as they are being acquired in real time. The electronic data set is a frequency-based, analog set of signal values that is converted to a pure, digital signal through analog-to-digital conversion. The speed and processing power of modern computers will enable further increases in data acquisition rates and with that, no doubt, improved clinical value to practitioners. A current example of this is the technology of digital tomosynthesis (DT). This technology provides more views of patient anatomy as part of a pulsed x-ray acquisition, which enhances the diagnostic yield of DT. Additionally, artificial intelligence (AI) and machine learning (ML) algorithms are integrated into system designs at all levels.

Vendors have now incorporated post-patient radiation exposure detection into the design of a detector. The detector will terminate the exposure when a preset signal value has been acquired. Consistent high image quality will be expected in more radiography settings, including mobile radiography. In addition, machine learning algorithms now are being used to improve image noise levels at lower exposure (mAs) levels. This enables the operator to select various acceptable noise levels based on a large library of images related to signal values. The radiographer will need to understand the proper application of this noise reduction technology on a case-by-case basis.

With improved FPD sensitivity and faster computer processing speeds, x-ray images now can be acquired with pulsed exposures at rates up to 15 frames per second and with controlled patient motion, *during the acquisition*. Referred to as dynamic digital radiography (DDR), this technology is showing particular promise with pulmonology and orthopedic applications. Temporal resolution is the ability of an imaging system to accurately reflect changes over time. Temporal resolution is measured in milliseconds. As acquisition speed increases, temporal resolution improves enabling image acquisition of moving anatomy without any motion blur. Excellent temporal resolution continues to be one of radiography's greatest strengths. Radiographers must understand the importance of temporal resolution and specific patient instructions to ensure correct patient motion during DDR exposures.

In addition to DDR, new FPD technology is being developed to acquire data at multiple x-ray photon energies. This has been used in the past with dual-energy subtraction radiography that required two separate exposures in quick succession, at two distinctly different kVp values. Each image data set represents different degrees of differential absorption based on the kVp chosen. The data sets are compared through processing and selected anatomy can be removed (subtracted) from the displayed image. Because this older technology required two separate exposures, patient motion could occur, negatively impacting image reconstruction and subtraction quality. A new type of FPD has energy-discriminant filtration built into the detector design, which permits a single exposure for dual-energy subtraction imaging. The radiographer should expect greater use of this type of technology in the future.

As a best practice, the radiographer is responsible for continued learning about new clinical applications of digital detector technologies and understanding how these developments will add new clinical responsibilities as dynamic imaging data files are collected and processed to improve patient care outcomes.

Artificial Intelligence and Digital Radiography

Another ASRT white paper, The Artificial Intelligence Era: The Role of Radiologic Technologists and Radiation Therapists, released in 2020 by the Corporate Roundtable (formerly known as HCIAC) Subcommittee on Artificial Intelligence, offers a comprehensive overview of AI, defining it as the "science and engineering of making intelligent machines." Machine learning, a crucial subset of AI, is described as the use of algorithms that adapt and refine their performance by engaging with specific tasks and improving over time through exposure to data. However, the potential of these technologies extends far beyond this basic framework, presenting a paradigm shift in medical imaging and radiation therapy.

Historically, the first and second industrial revolutions of the late 18th and early 19th centuries triggered significant economic transformations, allowing humanity to overcome physical limitations in strength and production capacity. Innovations such as factory-based production, steam engines, and the spinning jenny revolutionized manufacturing processes. The third industrial revolution ushered in computer systems and automation, leading us to today's fourth industrial revolution, characterized by the integration of cyber-physical systems. This new era is marked by a fusion of technologies, including AI, robotics, the Internet of Things (IoT), 3D printing, genetic engineering, and quantum computing. These advances allow us to address not only physical constraints but also limitations in human memory and cognitive function.

Imagine a scenario analogous to neurological telepathy, where the synaptic connections of all individuals are interconnected, enabling a shared understanding of thoughts and ideas. Similarly, AI's neural networks harness computational power and interconnectivity to analyze vast datasets, identify patterns, and generate predictions. This capability reflects the essence of machine learning algorithms, enabling machines to perform tasks that were once thought to require human cognitive functions.

In the context of digital radiography, a joint statement from the International Society of Radiographers and Radiological Technologists and the European Federation of Radiographer Societies underscores the vital role of radiographers and radiologic technologists as experts in medical imaging and radiation therapy. These professionals must actively participate in the planning, development, implementation, and validation of AI applications tailored to address pressing clinical challenges. Effective integration of AI into medical safety and clinical imaging can only be realized through comprehensive education of current and future professionals, along with their proactive engagement in AI advancements.

The application of AI and ML in medical imaging has expanded significantly beyond image interpretation and analysis. These technologies now encompass data acquisition, model architecture, loss functions, and image optimization algorithms. Convolutional neural networks (CNNs) play a pivotal role in image recognition and computer vision tasks, enabling the identification of patterns indicative of lesions within patient anatomy. This enhanced capability aids radiologists in diagnosing various health conditions with greater accuracy. Nevertheless, the effectiveness of these advancements relies on high-quality radiological equipment operated by qualified technologists, as the integrity of the images is essential for meaningful clinical outcomes.

Manufacturers are equipping radiologic technologists with innovative tools designed to streamline workflows in radiography departments. Automation of routine tasks not only reduces operational costs but also allows professionals to prioritize patient-centered care. Innovations such as automated equipment positioning, patient dose verification, and technical factor selection assistance improve image consistency, optimize radiation exposure, and potentially even enhance infection control practices. In modalities like CT and MR imaging, in which patient positioning is critical, AI and ML algorithms analyze extensive datasets of medical images to enhance tumor segmentation and diagnostic precision.

Technological advancements are rapidly transforming the image acquisition and reconstruction pipeline. These innovations improve the quality of lower-resolution scans, reduce noise and artifacts, and enhance image contrast, resulting in shorter scan times, reduced radiation exposure, and even the potential elimination of contrast media in specific studies. Similar advancements are being seen in positron emission scanning technology, with acquisition times reduced by a factor of four compared with traditional systems. This rapid improvement is particularly beneficial for pediatric patients and individuals who have difficulty remaining still during examinations. The new software processes image data and enhances it before sending it to MIMPS.

Importantly, the introduction of physiological proxies — commonly referred to as digital twins — into medical imaging and radiation therapy presents a significant opportunity for radiological professionals. These tools enable practitioners to better assess and understand radiation exposure parameters before executing therapeutic plans on living patients. By integrating this concept with the enhanced workflow features of imaging and therapeutic equipment, practitioners can re-evaluate technical factor settings based on intelligence derived from dose-related data.

As we embrace these advancements, ethical considerations and liability issues in medical imaging related to AI must also be addressed. The integration of AI technologies raises questions about accountability when errors occur, especially in clinical decision-making processes. It is crucial to establish clear guidelines regarding the responsibilities of radiologic technologists and radiologists in relation to AI-assisted diagnoses and treatment plans. Additionally, ensuring patient data privacy and security remains paramount, particularly as AI systems often rely on large datasets that may include sensitive health information.

Moreover, ongoing education and training in ethical practices are vital as AI technologies evolve. Radiologic professionals must be equipped not only with technical skills but also with an understanding of the ethical implications of their work in an AI-enhanced environment. This includes the ability to critically assess AI-generated recommendations, advocate for patient safety, and make informed decisions based on a combination of technological insights and clinical judgment.

In conclusion, incorporating AI and machine learning into digital imaging practices promises to enhance job satisfaction through the augmentation of skills and the creation of new roles for technologists. By lightening workloads and improving quality control, these technologies ultimately aim to advance patient care. As the field evolves, a commitment to ethical standards, accountability, and continuous education will be essential to navigate the complexities of AI in medical imaging, ensuring that technological advancements serve to enhance both patient outcomes and the professional integrity of those in the field.

Conclusion

Digital radiography remains a vital tool in diagnosing injury and disease, helping to improve patient outcomes. Technological advances in our profession are ongoing and it is a primary responsibility of the radiographer to remain current regarding the best practices in digital radiography. The best practices and supporting information described in this white paper can serve as valuable resources for radiographers in their efforts to optimize their technical approach to producing diagnostic-quality digital radiographs while minimizing patient radiation exposure and maximizing safety.

Review of Best Practices

The following best practices for digital radiography have been identified in this white 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:

- Properly identify each patient using the department protocol and HIPAA guidelines.
- Review examination orders and health records carefully to prevent unnecessary duplication and to ensure appropriateness as related to the patient’s history and clinical indication(s). If there is a possibility that the examination might be a duplicate or might not be clinically appropriate, the radiographer should consult with the radiologist and/or ordering practitioner to ensure the appropriate examination has been ordered.
- Follow the protocols and standards set by the department and actively participate in developing and revising protocols to ensure diagnostic-quality images, efficient workflow, and minimized patient radiation exposure. This is a critical best practice in digital radiography.
- Explain the examination and include information related to positioning and holding still, emphasizing the importance of patient cooperation for optimal image quality, and encourage patients to ask questions to ensure their understanding and safety.
- Screen patients for potential pregnancy and perform appropriate documentation.
- Know the proper applications of technical theories, the techniques to be used for a specific imaging system's sensitivity, and the operational functions of the digital radiography system. This includes selecting appropriate exposure factors for a patient's size and condition.
- 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.
- Increase the source-to-image-receptor distance (SID) when feasible in order to decrease patient entrance skin dose (ESD), effective dose (E), and image magnification.
- Use AEC when indicated, with proper positioning of the area of interest over the activated AEC detector(s), and use AEC that has been calibrated to the type of image receptor to provide a consistent exposure to the image receptor.
- Use both automated and traditional exposure technique charts that are continuously improved and applicable to a wide range of patient sizes, and adjust technical settings based on the specific patient, projection, and clinical indication for the examination.
- Use pre-exposure collimation to limit the x-ray beam to the anatomic area of interest appropriate for the procedure.
- Apply electronic masking to improve image viewing conditions in a manner that demonstrates the actual exposure field edge to document appropriate collimation. Masking, cropping, or shuttering must not be applied over anatomy that was contained in the exposure field at the time of image acquisition.
- Provide interpreting practitioners with all information that is captured on an image detector and refrain from manipulating the image in a way that hides or removes data.

- Use lead shielding to reduce unnecessary radiation exposure to anatomic parts of the patient that are outside of the x-ray field. Provide appropriate shielding to others in the procedure room during the exposure and use occupational shielding.
- Consistently use lead anatomic side markers captured on the original image during the x-ray exposure, without obscuring any structures of interest.
- Use a grid with specifications recommended by the digital imaging equipment vendor, generally for body parts that exceed 12 cm in adults.
- Establish department protocols and technique charts based on techniques that fall within acceptable exposure ranges for the types of digital detectors and grids being used and, if applicable, consider the use of grid suppression and grid-replacement software.
- Use immobilization devices when needed and prevent repeat exposures by appropriately positioning the patient.
- Take appropriate actions to use dose optimization principles, radiation protection, and size-appropriate exposure techniques in pediatric digital radiography. Proper collimation, positioning, and immobilization also are necessary to decrease repeat exposures.
- Become familiar with the specific EI standards for equipment, and with the newer standardized EI and DI as they become available in new and upgraded equipment used for digital radiography.
- Effectively use the EI/DI to determine whether adequate exposure has reached the image receptor.
- Because the EI/DI has limitations, carefully assess whether a repeat examination is necessary.
- Ensure that all required anatomy is included in radiographic images.
- Evaluate positioning accuracy to ensure that digital processing systems can correctly analyze and display the image.
- Prevent artifacts by protecting the image receptor from damage caused by mishandling and fluids.
- Prevent artifacts by using appropriate examination menus.
- Prevent artifacts by preparing the patient for the examination and selecting proper exposure factors.
- Recognize the causes of image artifacts, prevent future artifacts by properly maintaining or acquiring services for the digital radiography equipment, and replace equipment as needed.
- Recognize exposure errors during image critique and correct them as needed.
- Ensure proper pre-exposure collimation to include all necessary structures in the image and avoid using electronic collimation as a substitute.
- Understand how exposure technique factors affect EI values and prevent quantum noise or saturation, ensuring the image meets departmental standards.
- Evaluate image contrast to ensure that the correct processing algorithm that provides the appropriate optimal contrast for the anatomy of interest is applied.
- Evaluate spatial resolution during image critique to ensure maximum sharpness and absence of motion in radiographic images.

- Evaluate whether digital radiographs demonstrate minimal magnification to ensure accurate anatomical representation of the structures of interest.
- Evaluate shape distortion to ensure that the discrepancy between the displayed and actual shape of anatomical structures has been minimized.
- Preserve the expected pixel values created by the approved processing methods. (If changes to the window width or level are made or if the use of the ROI tool is required to provide alternate image brightness and contrast, these modified images should only be provided as an additional copy for review and not as the only data set.)
- 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.
- Learn and consistently adhere to the latest, empirically supported best practices to ensure patient safety.
- Develop a collaborative and supportive work team in which team members learn from one another and practice radiography safely and ethically.
- Continue learning about new clinical applications of digital detector technologies and understand how these developments will add new clinical responsibilities.
- Critically assess AI-generated recommendations, advocate for patient safety, and make informed decisions based on a combination of technological insights and clinical judgment.

References

AAPM Task Group No. 116. Recommended exposure indicator for digital radiography. Accessed July 2018. https://www.aapm.org/announcements/TG116_v7.pdf

ACR-AAPM-SIIM-SPR practice parameter for digital radiography. ACR website. Revised 2022. Accessed May 2, 2024. https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Rad-Digital.pdf

ACR–AAPM–SIIM Technical standard for electronic practice of medical imaging. ACR website. Revised 2022. Accessed May 2, 2024. https://www.acr.org/-/media/ACR/Files/Practice-Parameters/elec-practice-medimag.pdf?la=en

ACR-SPR practice parameter for imaging pregnant or potentially pregnant adolescents and women with ionizing radiation. ACR website. Revised 2018. Accessed December 27, 2018. https://www.acr.org/-/media/acr/files/practice-parameters/pregnant-pts.pdf

Alexander S. Image acquisition and quality in digital radiography. *Radiol Technol.* 2016;88(1):53-68.

Alliance for Radiation Safety in Pediatric Imaging. Image Gently digital radiography safety checklist: safety steps to do and verify for your pediatric patient. Accessed June 25, 2024. https://www.imagegently.org/Portals/6/Procedures/Attachment%20C.FINAL%20Implementation%20Manual.pdf

American College of Radiology. Accessed February 14, 2025. https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria

American Registry of Radiologic Technologists Code of Ethics. Accessed November 11, 2024. https://www.arrt.org/docs/default-source/governing-documents/code-of-ethics.pdf?sfvrsn=71f304fc_14

American Registry of Radiologic Technologists. What are continuing qualifications requirements? Accessed October 2, 2018. https://www.arrt.org/CQR

American Society of Radiologic Technologists. Practice Standards for Medical Imaging and Radiation Therapy: Radiography Practice Standards. Effective June 25, 2017. Accessed October 2, 2018. https://www.asrt.org/docs/default-source/practice-standards-published/ps_rad.pdf?sfvrsn=13e176d0_18

American Society of Radiologic Technologists. Practice Standards for Medical Imaging and Radiation Therapy: Advisory Opinion Statement, Use of Post-Exposure Shuttering, Cropping and Electronic Masking in Radiography. Effective June 24,

2018. Accessed October 2, 2018. https://www.asrt.org/docs/default-source/practice-standards-published/ps_aos_postexposureshutteringinradiography.pdf?sfvrsn=5b2351d0_11

Amis ES, Butler PF, Applegate KE, et al. American College of Radiology white paper on radiation dose in medicine. *J Am Coll Radiol*. 2007;4:272-284. doi:10.1016/j.jacr.2007.03.002

Amis ES, Butler. American College of Radiology white paper on radiation dose in medicine: three years later. *J Am Coll Radiol* 2010;7:865-870. doi:10.1016/j.jacr.2010.04.006

Andriole KP, Ruckdeschel TG, Flynn MJ, et al. AACr—AAPM—SIIM practice guideline for digital radiography. *J Digit Imaging*. 2013;26:26-37. doi:10.1007/s10278-012-9523-1

Ardoni F, Choridah L, Susanto E, Irsal M. Radiation dose and image quality with exposure factor variation using a virtual grid in digital radiography. *Int J Sci Res Sci Technol*. 2023;10:323-331. doi:10.32628/IJSRST52310649

Artificial intelligence and the radiographer/radiological technologist profession: a joint statement of the International Society of Radiographers and Radiological Technologists and the European Federation of Radiographer Societies. *Radiography*. 2020;26:93-95. doi:10.1016/j.radi.2020.03.007

Balac V, Grossman R, Griswold R, Bowman D. Optimizing contrast resolution in digital chest radiography by varying copper filtration and kVp. *Radiol Technol*. 2023;95(2):94-104.

Bomer J, Wiersma-Deijl L, Holsscher HC. Electronic collimation and radiation protection in paediatric digital radiography revival of the silver lining. *Insights Imaging.* 2013;4(5):723- 727. doi:10.1007/s13244-013-0281-5

Bryan W, DeMaio D, George C, et al. Update on the elimination of fetal and gonadal shielding during abdominopelvic radiography. *Radiol Technol*. 2022;94(2):143-150.

Built-in AEC Assistance. Accessed March 12, 2024. https://mcu.canon/downloads_canon_com/cmcu/pdfs/Built-in-AEC-Assistance-brochure_DRB-047-Rev-A.pdf

Bushong SC. *Radiologic Science for Technologists: Physics, Biology, and Protection*, 12th ed. Elsevier; 2020.

Carlton RR, Adler AM, Balac V. *Principles of Radiographic Imaging: An Art and a Science*, 6th ed. Cengage; 2019.

Carroll QB. *Radiography in the Digital Age*, 4th ed. Charles C Thomas Publishers Ltd; 2023.

Casey B. Medicare to cut analog x-ray payments starting in 2017. AuntMinnie. Published February 8, 2016. Accessed June 5, 2018. https://www.auntminnie.com/index.aspx?sec=sup&sub=xra&pag=dis&ItemID=113334

Daldrup-Link HE, Sammet C, Barsness KA, et al. White paper on P4 concepts for pediatric imaging. *J Am Coll Radiol*. 2016;13(5):590-597. doi:10.1016/j.jacr.2015.10.028

Don S. New digital radiography exposure indicators and the ACR Dose Index Registry for Digital Radiography. Accessed July 20, 2018. https://www.pedrad.org/Portals/5/Events/2015/Don,%20Steve%20-%20Image%20Gently.pdf

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. doi:10.2214/AJR.08.2086

Ehrlich R, Coakes D. *Patient Care in Radiography*. 9th ed. St. Louis, MO: Elsevier/Mosby; 2016.

England A, Evans P, Harding L., Taylor EM, Charnock P, Williams G. Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. *Radiol Technol.* 2015;86(3):246-256.

Fauber TL. Gonadal shielding in radiography: a best practice? *Radiol Technol.* 2016;88(2):127-134.

FDA releases new guidance on children's x-ray exams. Imaging Technology News. Published January 26, 2018. Accessed June 18, 2018. https://www.itnonline.com/article/fda-releases-new-guidance-childrens-x-ray-exams

Fintelmann F, Pulli B, Abedi-Tari F, et al. Repeat rates in digital chest radiography and strategies for improvement. *J Thorac Imaging*. 2012;27(3):148-151. doi:10.1097/RTI.0b013e3182455f36

Flaherty S, Mortele KJ, Young GJ. Utilization trends in diagnostic imaging for a commercially insured population: a study of Massachusetts residents from 2009 to 2013. *J Am Coll Radiol*. 2018;15:834-841. doi:10.1016/j.jacr.2018.02.030

Giansanti D, Di Basilio F. The artificial intelligence in digital radiology: part 1: the challenges, acceptance and consensus. *Healthcare (Basel)*. 2022 Mar 10;10(3):509. doi:10.3390/healthcare10030509

Harper KD, Li S, Jennings R, Amer KM, Haydel C, Ali S. The relative effects of manual versus automatic exposure control on radiation dose to vital organs in total hip arthroplasty. *J Am Acad Orthopaedic Surg.* 2018;26(1):27-34. doi:10.5435/JAAOS-D-16-00713

Image Gently and digital radiography – quality improvement. Image Gently website. Accessed June 15, 2018. https://www.imagegently.org/Procedures/Digital-Radiography/Quality-Improvement

IBM. Convolutional neural networks. https://www.ibm.com/topics/convolutional-neural-networks

Image Wisely. Radiation safety in adult medical imaging. About us. Accessed June 15, 2018. https://www.imagewisely.org/About-Us

International action plan for the radiological protection of patients. International Atomic Energy Agency. Accessed June 18, 2018. http://www-ns.iaea.org/downloads/rw/radiation-safety/PatientProtActionPlangov2002-36gc46-12.pdf

Jeon S. Detector exposure indicator in GE x-ray systems. Published 2014. Accessed July 15, 2018. http://www3.gehealthcare.ru/~/media/documents/russia/products/radiography/brochure/fixed/gehc_radiography-discovery-xr656_detector-exposure-indicator.pdf?Parent=%7BB5EB9550-6D39-4C3A-BB3B-C84C1F67A8B2%7D

Jones A, Ansell C, Jerrom C, Honey ID. Optimization of image quality and patient dose in radiographs of paediatric extremities using direct digital radiography. *British J Radiol*. 2015;88(1050):20140660. doi:10.1259/bjr.20140660

Jones AK, Heintz P, Geiser W, et al. Ongoing quality control in digital radiography: report of AAPM Imaging Physics Committee Task Group 151. *Medical Physics*. 2015;42:6658-6670. doi:10.1118/1.4932623

Joyce M, McEntee M, Brennan PC, O'Leary D. Reducing dose for digital cranial radiography: the increased source to the image-receptor distance approach. *J Med Imaging Radiat Sci*. 2013;44(4):180-187. doi:10.1016/j.jmir.2013.07.002

Karami V, Zabihzadeh M, Shams N, Gilavand A. Optimization of radiological protection in pediatric patients undergoing common conventional radiological procedures: effectiveness of increasing the film to focus distance (FFD). *Int J Pediatr.* 2017;5(4):4771-4782.

Kawamura T, Naito S, Okano K. Improvement in image quality and workflow of x-ray examinations using a new image processing method, 'virtual grid technology.' *Fujifilm Research & Development*. 2015;60:21-27.

Kuwahara C, Aoki T, Oda N, et al. Optimal beam quality for chest flat panel detector system: realistic phantom study. *Eur Radiol*. 2019;29(9):4538-4543. doi:10.1007/s00330-019-5998-1

Larson DB. Kruskal JB, Krecke KN, Donnelly LF. Key concepts of patient safety in radiology. *Radiographics.* 2015;35(6):1677-1693. doi:10.1148/rg.2015140277

Leong DL, Butler M-L. Understanding exposure and deviation indices. American Association of Physicists in Medicine, 2011. Accessed July 10, 2018. www.aapm.org/meetings/amos2/pdf/59-17262-70888-306.pdf

Manaf RA, Juni H. A systematic review on repetition rate of routine digital radiography. *International Journal of Current Research*. 2017;9(2):46325-46330.

Martensen KM. *Radiographic Image Analysis*, 3rd ed. St. Louis, MO: Saunders/Elsevier; 2011.

Mettler FA Jr, Mahesh M, Chatfield MB, et al. Report No. 184 – Medical radiation exposure of patients in the United States (2019). National Council on Radiation Protection and Measurements. Published 2019. Accessed July 23, 2020. https://ncrponline.org/shop/reports/report-no-184-medical-radiation-exposure-of-patients-in-the-united-states-2019/

Miller DL, Martin CJ, Rehani MM. The mandate and work of ICRP Committee 3 on radiological protection in medicine [published online ahead of print]. *Ann ICRP*. May 1, 2018. doi:10.1177/0146645318756249

National Council on Radiation Protection and Measurements (NCRP). (2009). Ionizing radiation exposure of the population of the United States. NCRP Report No. 160. In National Council on Radiation Protection and Measurements.

National Council on Radiation Protection and Measurements (NCRP). (2019). Medical radiation exposure of patients in the United States. NCRP Report No. 184. In National Council on Radiation Protection and Measurements.

National Research Council of the National Academies. *Health Risks From Exposure to Low Levels of Ionizing Radiation. BEIR VII Phase 2*. Washington, DC: National Academies Press; 2006.

Noble LB, Culp MP. Computed radiography photostimulable phosphor plate receptors: effect on grid conversion factors. *Radiol Technol.* 2017; 89(2):121-126.

Paudyal R, Shah AD, Akin O, et al. Artificial intelligence in CT and MR imaging for oncological applications. *Cancers (Basel).* 2023 Apr 30;15(9):2573. doi:10.3390/cancers15092573

Pesce M. Understanding radiology exposure indicators. Carestream. Published September 6, 2016. Accessed July 25, 2018. https://www.carestream.com/blog/2016/09/06/understanding-radiology-exposure-indicators/

Radiology Across Borders. Accessed February 2025. https://www.radiologyacrossborders.org/

Radiological Society of North America. AI-based applications boost image quality. Published May 2019. https://www.rsna.org/news/2019/may/ai-based-applications-boost-image-quality

Rehani MM. Patient radiation exposure and dose tracking: a perspective [published online ahead of print]. *J Med Imaging (Belllingham)*. 2017;4(3):031206. doi:10.1117/1.JMI.4.3.031206

Rickwood P. Radiation safety experts call for global action to improve patient and health worker protection. International Atomic energy Agency. Published December 11, 2012. Accessed June 18, 2018. https://www.iaea.org/newscenter/news/radiation-safety-experts-call-global-action-improve-patient-and-health-worker-protection

Roch P, Célier D, Dessaud C, Etard C. Using diagnostic reference levels to evaluate the improvement of patient dose optimisation and the influence of recent technologies in radiography and computed radiography. *Eur J Radiol.* 2018;98:68-74. doi:10.1016/j.ejrad.2017.11.002

Seibert JA. Standardized exposure index for digital radiography – technical issues. International Congress of Medical Physics. Published 2013. Accessed July 20, 2018. http://iupesm.ifmbe.org/wp-content/uploads/2014/08/05Seibert_ExposureIndex.pdf

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. doi:10.1007/s00247-010-1954-6

Steffensen C, Trypis G, Mander GTW, Munn Z. Optimisation of radiographic acquisition parameters for direct digital radiography: a systematic review. *Radiography (Lond)*. 2021;*27*(2), 663-672. doi:10.1016/j.radi.2020.08.012

Take the Image Gently pledge. Image Gently website. Accessed June 15, 2018. https://www.imagegently.org/

Tang H, Tong D, Dong Bao X, Dillenseger J-L. A new stationary gridline artifact suppression method based on the 2D discrete wavelet transform. *Med Phys*. 2015;42:1721-1729. doi:10.1118/1.4914861

The Artificial Intelligence Era: The Role of Radiologic Technologists and Radiation Therapists. American Society of Radiologic Technologists. Published 2020. asrt.org/docs/default-source/research/whitepapers/the-artificial-intelligence-era-the-role-of-radiologic-technologists-and-radiation-therapists.pdf?sfvrsn=7a3b3fd0_4

The Joint Commission. Sentinel Event Alert. Issue 47. Issued August 24, 2011. Accessed December 18, 2018. https://www.jointcommission.org/assets/1/18/SEA_47add.pdf

Tugwell J, Everton C, Kingma A, et al. Increasing source to image distance for AP pelvis imaging—impact on radiation dose and image quality. *Radiography*. 2014;20(4):351-355.

United Nations. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Sixty-ninth session (9-13 May 2022). Accessed October 2, 2024. https://www.un-ilibrary.org/content/books/9789213584859/read

U.S. Food and Drug Administration. White paper: initiative to reduce unnecessary radiation exposure from medical imaging. Updated February 5, 2018. Accessed June 3, 2018. https://www.fda.gov/Radiation-EmittingProducts/RadiationSafety/RadiationDoseReduction/ucm199994.htm.

U.S. Food and Drug Administration. We want you to know about x-rays: get the picture on protection. Reviewed April 12, 2021. Accessed October 2, 2024. https://www.fda.gov/radiation-emitting-products/resources-you-radiation-emitting-products/we-want-you-know-about-x-rays-get-picture-protection

Walz-Flannigan AI, Brossoit KJ, Magnuson DJ, Schueler BA. Pictorial review of digital radiography artifacts. *Radiographics*. 2018;38:833-846. doi:10.1148/rg.2018170038

Walz-Flannigan A, Magnuson D, Erickson D, Schueler B. Artifacts in digital radiography. *AJR Am J Roentgenol.* 2012;198:156-161. doi:10.2214/AJR.11.7237

Zabihzadeh M, Karami V. Letter to editor. Poor collimation in digital radiology: a growing concern. *Internet Journal of Medical Update-EJOURNAL.* 2016;11.2:29-30. Accessed October 2, 2018. https://www.ajol.info/index.php/ijmu/article/view/139769

Appendices

Appendix A: Glossary of Terms

Anatomically programmed radiography (APR). A system of preprogrammed exposure technique settings organized by position and procedure and set through the digital radiography unit's control panel.

Bit depth. 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.

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

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 used to produce digital data that are converted to an image.

CCD. Charge-coupled device.

CMOS. Complementary metal-oxide semiconductor.

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

CNR. Contrast-to-noise ratio.

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 whether the technique they used for a specific examination was appropriate for optimal display of the anatomy of interest.

Differential absorption. The result of differences in transmission of the primary beam as it passes through the patient.

Digital Imaging and Communications in Medicine (DICOM). 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 (DR). 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.

Dose optimization. A fundamental principle of radiation protection that involves the link between radiation dose and image quality. Radiographers must use procedures to ensure diagnostically acceptable images at the lowest achievable dose to patients.

ESE. Entrance skin exposure.

Exposure indicator (EI). A quantitative method, expressed as an EI value, to estimate the incident radiation exposure received by the digital image receptor during image acquisition. The EI is called by many other names, depending on the vendor.

Grid-replacement software (also known as grid substitution software). Uses algorithms to remove scatter radiation and enhance image contrast without use of a physical antiscatter grid.

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.

Remnant radiation (also known as exit radiation). The portion of the x-ray beam that passes through the patient and reaches the image receptor, carrying different intensities that reflect the varying absorption characteristics of the tissues it has passed through.

ROI. Region of interest.

Sensitivity. A qualitative term that measures the ability of a digital image receptor to detect and respond to x-rays photons during image acquisition.

SNR. Signal-to-noise ratio.

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

Temporal resolution. The ability of an imaging system to accurately reflect changes over time.

Appendix B: Exposure Indicator Table

Note: All vendors use Deviation Index values in addition to exposure reference numbers. All vendors comply with International Electrotechnical Commission (IEC) standard IEC 62494-1) regarding numerical expression as a component of the displayed DICOM data on images.

VENDOR	INDICATOR NAME	ABBREVIATION	DETECTOR EXPOSURE RELATIONSHIP
Agfa	Exposure Index	EI	Direct
Canon	Exposure Index	EI	Direct
Carestream	Exposure Index (IEC Standard)	EI or IEC/EI (customer preference)	Direct
Fuji		S or EI (customer preference)	S is Inverse (S=2000/Exposure in µGy) EI is Direct
GE Healthcare	Detector Exposure Index	DEI	Direct
Philips	Exposure Index	EI	Direct
Siemens	Exposure Index	EXI	Direct

Appendix C: Digital Radiography Systems Review — The Path to a Digital Image

The image signal formation from the remnant beam exiting the patient to the image displayed on the monitor for each of the following digital radiography systems (CR and DR) can differ. This chart lists the names of and active materials for components of the various digital systems.

Function	**CR with PSP**	**DR with CCD Indirect Conversion**	**DR Flat Panel Indirect Conversion**	**DR Flat Panel Direct Conversion**
	Remnant x-ray beam exits patient	*Remnant x-ray beam exits patient*	*Remnant x-ray beam exits patient*	*Remnant x-ray beam exits patient*
Converts x-rays to light	1. PSP—europium-doped barium fluorohalide crystals 2. Red helium neon laser	Scintillator—cesium iodide or gadolinium oxysulfide	Scintillator—cesium iodide or gadolinium oxysulfide	X
Converts light into an electrical signal	PMT (may also be CCD)	CCD (may also be CMOS)	Photodiode—amorphous silicon	X
Converts x-rays to an electrical signal	X	X	X	Photoconductor—amorphous selenium
Stores electric charge and independently transfers charge readout	X	X	TFT	TFT
Converts electrical signal to numerical data	ADC	ADC	ADC	ADC
	Image displayed on monitor	*Image displayed on monitor*	*Image displayed on monitor*	*Image displayed on monitor*

Abbreviations: ADC, analog-to-digital converter; CCD, charge-coupled device; CMOS, complementary metal-oxide semiconductor; CR, computed radiography; DR, digital radiography; PMT, photomultiplier tube; PSP, photostimulable phosphor; TFT, thin-film transistor.

Appendix D: Rejected Image Analysis

Table I. Data stored for rejected image analysis.

Field	Function	Required/optional
Acquisition station/digitizer	Can identify specific stations with problems	Required
Accession number	Links study to technologist through RIS	Required
Exam date and time	Allows temporal sorting of data	Required
Body part	Allows sorting of data by body part	Required
View	Allows sorting of data by view	Required
Exposure indicators (EI)[a]	Allows exposure analysis/troubleshooting	Required
Reject category	Allows reject analysis	Required
Technologist ID	Alternative method of linking technologist and study	Required[b]
Reject comments	Further clarifies reason for rejection–free field	Optional
Technologist name	Allows sorting of data by technologist name	Optional
Technique factors	Troubleshooting	Optional
Thumbnail image	QC of reason for rejection	Optional

[a]The target EI and DI should also be included, if available.
[b]Optional if separate user names are provided for each technologist who uses the system.

Reprinted from Jones AK, Heintz P, Geiser W, et al. Ongoing quality control in digital radiography: report of AAPM Imaging Physics Committee Task Group 151. Medical Physics. 2015;42:6658-6670.

Appendix E: Best Practices in Digital Radiography Revision Committee (2024)

Vesna Balać, Ed.D., R.T.(R)(MR), Indiana University Northwest, Radiologic Sciences Programs Department Chair, Radiography Program Director, Assistant Professor, Assistant Dean

Daniel N. DeMaio, M.Ed., R.T.(R)(CT), University of Hartford, Director, Radiologic Technology Program

Randy Griswold, M.P.A., R.T.(R), Northeast WI Technical College, Instructor, Biomedical Engineering

Robert (Bob) Grossman, M.E., R.T.(R)(CT), Yale New Haven Health Systems and Middlesex Health Systems, CT technologist, Radiographer, and Educator

Lauren Noble, Ed.D., R.T.(R), University of North Carolina at Chapel Hill, Clinical Associate Professor, Division of Radiologic Science

Jason Young, M.S.Ed., R.T.(R), Southwest Baptist University, Mercy College of Health Professions, Radiography Program Director

Appendix F: Best Practices in Digital Radiography Workgroup Members (2018)

Tracy Herrmann, Ph.D., R.T.(R), University of Cincinnati, Blue Ash College, Interim Associate Dean/Professor of Allied Health

Daniel N. DeMaio, M.Ed., R.T.(R)(CT), University of Hartford, Chair, Department of Health Sciences and Nursing

Lauren Noble, Ed.D., R.T.(R), University of North Carolina at Chapel Hill, Clinical Assistant Professor, Division of Radiologic Science

Denise Orth, M.S., R.T.(R)(M), Fort Hays State University, Associate Professor/Clinical Coordinator

Paulette A. Peterson, M.Ed., R.T.(R)(M)(QM), Monroe Community College, Professor, Health Professions/Program Director, Radiologic Technology

Jason Young, B.S., R.T.(R), Mercy Health Carthage, Manager/Director

Appendix G: Task Force on CR/DR Members (2012)

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

