Best Practices in Digital Radiography

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Reports on medical imaging use and resulting radiation exposure have increased following a series of widely publicized incidents of excessive patient exposure to low levels of radiation during medical imaging examinations or procedures. Increases in exposure initially were attributed to rising utilization of medical imaging as technology has improved the ability to diagnose and evaluate a wide variety of diseases and conditions. However, the increased attention also likely can be attributed to growing concern over risks attributed to medical radiation exposure. Concerns and actions of regulatory bodies, clinical societies, and the public continue to intensify despite a lack of evidence that exposure to low doses of ionizing radiation increases cancer risk. Further advances in technology and reimbursement changes have led to increased use of digital radiography and standardized techniques for indicating exposure.

The benefits of radiography have remained clear over the more than 100 years of diagnostic medical imaging's history. Another fact that has remained clear is the critical role radiographers play in ensuring patient radiation safety during medical imaging procedures. Radiographers must adhere to the "as low as reasonably achievable" (ALARA) principle by keeping occupational radiation dose as low as possible. Radiographers also adhere to similar principles of keeping patient exposure as low as possible without affecting image quality when performing digital radiography (dose optimization).

Digital imaging methods now are common across all indications for and forms of radiography, including fluoroscopy and mammography. As radiographers have adjusted to the widespread use of digital radiography, they have had to refine exposure technique selection and pay closer attention to radiation protection. Digital technologies offer many benefits for acquiring and post-processing images. As a result, radiographers must be particularly concerned about exposure technique and the possibility of using more radiation than necessary.

Radiographers assume extensive responsibility in 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." A 2010 update to ACR panel recommendations on radiation dose in medicine confirmed the ACR's responsibility for taking specific actions but emphasized that several of its recommendations "encourage radiology practices and departments to take a more proactive approach to radiation safety."

Radiation safety practices in support of dose optimization, as well as occupational radiation safety practices, are based on justifying clinical appropriateness of examinations and optimizing dose while maintaining image quality. The various exposure techniques that radiographers can use 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. Because digital radiography still is a relatively recent advancement, radiographers' skill levels vary depending on initial education and experience. Radiographers and their patients can benefit from a single source that offers background information, best practices, and recommendations for radiographers on optimizing digital radiography and patient radiation safety.

Scope of White Paper

The 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 about the issue to consumers 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, the 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 for 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 transition of radiographers to digital radiography. The paper also examined elements of best practices for digital image quality and dose reduction techniques in digital radiography (DR) from a radiographer perspective.

In 2018, the ASRT convened a new workgroup to update and revise the 2012 best practice recommendations. This white paper is the result of a year-long 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 during 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) technology also was used in clinical practice beginning in the 1980s. CR uses a storage phosphor plate. According to IMV Medical, a medical imaging market research firm, although nearly 50% of radiography systems installed in the United States in 2015 included CR equipment, as many as 70% of sites with fixed CR systems said they were planning to purchase new DR equipment or retrofit CR equipment with DR in the coming year. In 2017, the Centers for Medicare and Medicaid Services (CMS) reduced payments by 7% to imaging providers with claims for CR and analog (film-screen) examinations in a concerted effort to encourage more radiology providers to switch to digital technologies and therefore promote dose reduction.

Fewer imaging facilities use CR technology today with DR (direct or indirect capture or conversion) as the modality of choice. Both the direct and indirect types of DR technology measure attenuated rays and produce electronic signals that are sent to software to rapidly produce images in grayscale format on a monitor. The first flat-panel detector still is common in modern systems. These indirect DR detectors used amorphous silicon as a photodiode, measuring the light emitted from a scintillator material excited by exposure to x-rays. Some fixed DR systems (dedicated chest radiography rooms, mammography systems, etc.) included charge-coupled devices (CCDs) to generate an electronic signal from the emitted light. Direct 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. Roch et al reported in 2016 that flat-panel detectors have been shown to lower radiation dose to patients as much as 30% over CR phosphor technology. Indirect capture DR systems use either a

CCD or indirect flat-panel detectors to capture x-rays and process image data, although indirect flat-panel detectors offer superior quality to CCD detectors and are more common.

Dose Optimization and Image Quality

When following the dose optimization principles, radiographers should strive to minimize patient exposure during all radiography examinations. Including mammography, radiography examinations represent 74% of all radiologic examinations performed on both adults and children in the United States and contribute to about 11% of the annual per capita radiation exposure from medical imaging, according to the FDA. The appropriate use of digital image receptors requires careful and consistent attention to institutional protocol and practice standards and can result in lower patient dose. Digital radiography incorporates discrete acquisition, processing, and display processes that function together to produce an image of acceptable diagnostic quality. In situations where suboptimal radiation exposure levels have been used, the DR system still might display a diagnostically acceptable image. It is possible to make adjustments to compensate for exposure technique errors during image postprocessing and display, although this is not a best practice.

As a component of image quality, the contrast resolution of the radiographic image depends heavily on the degree to which the exposed anatomic region attenuates the x-ray beam. The contrast resolution of the radiograph represents the relative differences in receptor exposure across the image and has two primary components, subject contrast and display contrast. Subject contrast is related to the absorption of the x-ray beam by the subject's tissues and the corresponding energies imparted to the image receptor. The tube potential (kVp) applied during x-ray exposure affects the degree of differential attenuation within the anatomical area and the recorded subject contrast. Conversely, display contrast can be modified through postprocessing after image recording, by adjusting several different processing parameters.

Very low contrast (many shades of gray) makes it difficult for the reviewer to differentiate between adjacent structures and to identify anomalies or pathologies; an image must have sufficient contrast to demonstrate differentiated structures and to be diagnostically useful. Very high contrast (very few shades of gray) reduces the image to a scale of mostly black-and-white, which can also hinder visibility of anatomic details. In digital imaging, display contrast is the ratio of brightness of adjacent structures to one another, and the displayed grayscale represents the dynamic range of brightness levels.

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

The ability to adjust display brightness and contrast during postprocessing can affect radiographers' attention to the primary principle of radiation protection: optimal image quality with minimal patient exposure. Radiographers must pay careful attention to all aspects of radiographic exposure technique to provide diagnostic image quality and minimize patient exposure, helping to maximize benefit over potential harm. In addition, the 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 further disconnect between image capture and the resulting patient exposure.

In digital radiography, the computer automatically adjusts an overexposure to display an image of diagnostic quality. This automatic adjustment disconnects the processes of image acquisition and display, which can contribute to increased patient exposure because of a lack of visual feedback for dose errors. Excessive exposure to a patient during a DR examination does not affect image quality, except at extremely high levels of exposure. In fact, the increase in exposure will increase the signal reaching the image receptor, causing an increased signal-to-noise ratio (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. This practice is not acceptable and violates the code of ethics regarding radiation protection.

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.

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. Avoidance of repeat exposures, careful use of shielding and beam restriction, clearly established acceptance ranges for exposure indicators (EIs) and other practices will be covered in the Best Practices discussion below.

Radiation Safety Initiatives

Over the past decade, national and global attention has focused increasingly on medical radiation dose reduction and safety. Several 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. The Choosing Wisely campaign of the American Board of Internal Medicine Foundation gathers and promotes recommendations from various organizations on which imaging tests might be avoided to limit exposure to ionizing radiation when the examinations might not be clinically indicated at a sufficient level. Examples include lumbar spine radiographs for lower-back pain and routine daily chest radiographs for premature infants.

In 2004, the Society for Pediatric Radiology (SPR) emphasized the ALARA principle in digital imaging and the adoption of a team approach to dose management. These findings were published in *Radiologic Technology* and other journals. In 2008, the Image Gently campaign sponsored by the Alliance for Radiation Safety in Pediatric Imaging began to promote radiation protection for children who have received medical imaging procedures. With an initial focus on reducing radiation dose to children undergoing CT examinations, the campaign soon progressed to fluoroscopic and interventional procedures, nuclear medicine, dental, and other medical imaging, including routine digital radiography. In 2011, the campaign released a safety checklist for performance of DR examinations on pediatric patients, followed by an implementation manual. By mid-2018, nearly 64,000 medical professionals had taken a pledge on the Image Gently website (ImageGently.org) to minimize radiation dose to children.

In a 2016 report, the SPR emphasized continuing efforts of the Image Gently campaign and recommended expanding further reduction efforts in radiation dose. In 2010, the U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health began an initiative to decrease unnecessary exposure from medical imaging procedures. Much of the emphasis has been on pediatric patients, including new guidance in 2018 recommending medical imaging examinations be optimized to the lowest radiation dose needed.

Building on the efforts to lower radiation dose in children, the ACR, Radiological Society of North America, and the Joint Task Force on Adult Radiation Protection jointly developed the Image Wisely campaign to lower the amount of radiation used in medically necessary imaging and to eliminate unnecessary procedures. The task force, later named the Alliance of Imaging Professionals, aimed to develop and disseminate educational resources for medical professionals who provide imaging care in the United States. Finally, imaging equipment vendors and the ACR assisted CMS in plans to encourage adoption of

DR over CR among providers because of lower dose and improved efficiency from DR.

Many of these radiation safety initiatives were brought about by media reports linking CT scans to childhood cancer and other risks. Since awareness of the potential risks associated with ionizing radiation from medical imaging has moved into the public arena, medical professionals have worked together to address the problem. Both the Image Gently and Image Wisely campaigns continue to offer resources and information to imaging professionals, referring practitioners and patients.

There also have been international efforts to improve medical radiation safety. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published a report in 2010 that described a strategic plan through 2013 and published an update in August 2013. UNSCEAR asked the public, authorities, and scientists to be more aware of radiation dose in medicine. At its 2010 meeting, UNSCEAR called for improved data collection, analysis, and dissemination of information for patients and those exposed to radiation occupationally. In 2013, the committee gathered data from several international entities to form a strategic plan for 2014 through 2019. Because radiation exposure to patients undergoing medical examinations and procedures was the most significant source of manmade radiation, the committee placed greater emphasis on gathering data from United Nations member states to address medical radiation more specifically.

The International Commission on Radiation Protection published a report in 2004 on digital radiology and published a 2017 report on diagnostic reference levels in medical imaging. The International Atomic Energy Agency (IAEA) launched an action plan in 2002 aimed at reducing patient exposure to radiation. The plan included developing an informational website for patients about radiation protection. According to the IAEA, a group of 500 experts from 77 countries met at a conference in Bonn, Germany in 2012, calling for global progress in the strengthening of radiation protection support and enforcement in health care. In some countries, tracking the radiation dose history of individual patients has become a reality. Patients are assigned a permanent ID that is used to track dose. The use of cumulative tracking still is in its infancy. Researchers and policymakers continue to assess this practice, in an effort to determine the utility of patient dose tracking and to standardize tracking processes.

Practice Parameters for Digital Radiography

The ACR developed a practice guideline for digital radiography in 2007; the parameter has since been amended four 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 2017. The document's intent is "to provide guidance and assistance in the understanding and clinical use of digital radiography equipment (other than mammography) in order 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 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 technique. The ACR guidelines also help radiographers and other medical professionals to improve understanding of the nuances of working with digital technology.

The ACR practice parameter for digital imaging recommends that radiographers performing digital examinations be trained to properly operate the systems they routinely use. The training should include image acquisition technology, image processing protocols, proper selection of options for specific examinations, image evaluation, radiation dose indicators, and patient safety procedures. Although radiographers and their supervisors might rely on applications training to supply equipment-specific skills, it is the responsibility of the radiographer 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 state that radiographers should be educationally prepared and clinically competent to perform their responsibilities. Education and clinical preparation include the ability to perform digital imaging examinations safely and effectively and to review digital images to monitor appropriate radiation exposure. 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 also must ensure that their applications specialists and support personnel are continuously trained and kept current on changes to technology. Vendors and radiology department managers must work together to determine training expectations in advance, which includes preassessment and postassessment of trainees' knowledge and skills.

Best Practices

The significant innovation and complexity of DR systems created a learning curve for radiographers and others, leading to ASRT's publishing of best practices for digital radiography in 2012. DR technology is pervasive in modern clinical practice and radiologic science education today, and an update to best practices is prudent. Radiographers who perform DR examinations must recognize their responsibility in optimizing image quality and minimizing patient dose. As the radiology team "experts" on exposure technique, radiographers should be proactive in remaining current on the basics of radiation protection and new technologies. Further, understanding and appropriately performing DR examinations is the professional duty of radiographers and an essential component of radiographer practice standards and code of ethics. Aside from preparing for DR examinations through attainment of proper education and clinical competence, there are many ways before, during, and after examinations that radiographers can optimize exposure technique and minimize radiation exposure.

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 correct medical imaging procedure has been ordered. Preparing for the examination includes several details the radiographer must consider before acquiring the DR images. Among these, patient safety and minimizing radiation exposure are paramount.

Procedure Appropriateness

As a patient advocate, the radiographer plays an important role in evaluating 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. The radiographer has the opportunity to recognize that the examination is a duplicate or is questionable in terms of indication or appropriateness. Radiographers should consult with the radiologist or ordering practitioner or request additional information from appropriate health care personnel that can clarify and confirm whether the correct examination is requested whenever there is a suspicion of an inappropriate exam order.

A greater frequency of high-exposure examinations can affect individual and collective dose. Organizations such as the ACR continue to address the concerns of requests for inappropriate examinations. The ACR developed guidelines to assist referring physicians in selecting the correct imaging examination. Examples of guidelines include the ACR Appropriateness Criteria and the Western Australian Diagnostic Imaging Pathways. Both are evidence-based imaging referral guidelines that have received global acceptance. The ACR reviews their criteria annually, with the most recent update in 2018. The World Health Organization developed global guidelines for appropriate referrals to medical imaging. The guidelines are evidence-based and cover several types of diagnostic imaging and therapeutic uses of imaging and ionizing radiation. 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. A global review of radiation safety initiatives occurred at the annual RSNA meeting in 2017.

Tracking and monitoring previous examinations also can help radiographers identify potentially unnecessary duplicate examinations before beginning image acquisition. Careful review of health records can help radiographers identify duplicate examinations, but patients might have imaging examinations performed by several providers within a given time period. The Image Gently campaign provides a wallet-sized card or letter-sized sheet for parents to use in tracking their child's examinations.

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 to identifying duplicate examinations, a radiographer must review the patient's health history with the patient or an appropriate representative. Radiographers can obtain important information about appropriateness of radiographic examinations by asking patient-centered questions.

It is a best practice in digital radiography for the radiographer to review examination orders 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 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 centers should develop and routinely update exposure technique charts and automatically 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 peak kilovoltage (kVp) must be set manually. When systems have automatic exposure control (AEC), other variables such as AEC detector cell configuration and backup time also can be standardized. Departments should establish protocols for common digital radiography examinations and conspicuously post them for radiographers' use.

Radiologic technologists should expect to consult with radiologists and vendors to refine the information for exposure techniques and protocols provided by 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 that are based on established clinical research and guidelines.

An advantage of DR is the ease of incorporating images and order entry into existing radiology information systems (RIS) and picture archival and communications systems (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 PACS, where the process from order entry to report generation involves little to no human interaction. The RIS and modality worklist system helps to facilitate workflow by bundling associated patient and examination information with the acquired images and sending all pertinent data to the PACS. The information then is 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 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.

Screening for Pregnancy

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

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 Society of Pediatric Radiology to revise the practice parameters in 2013 and 2018. 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 and to properly collimate the beam to limit radiation exposure.

All patients of appropriate age are questioned about pregnancy status when the radiographer interviews the patient. A standardized form can be used to document the pregnancy status for the medical record. The ACR and SPR developed sample forms facilities can use as a basis for developing their own forms. Duke Medical Center 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.

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 decide 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 distortion. In addition, the radiographer must select exposure factors that limit the quantum noise/mottle that can result from an insufficient amount of x-ray energy reaching the digital image receptor. 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 a radiographer follows 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 will yield an exposure index (EI) 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 large variance in x-ray intensities exiting the patient. As a result, the digital image receptor also has a wide exposure latitude. In addition, computer processing produces "acceptable" images even when significant overexposure has occurred. Because of this, the standardization of exposure techniques used during radiography 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 and condition. Appropriate and consistent use of exposure technique charts, adequate kVp, and accurate use of AEC is essential to consistently producing diagnostic images while minimizing patient radiation exposures. Technique charts also can be updated when the need to override pre-programmed techniques arises. There are numerous manufacturers and types of digital imaging equipment. Each company puts their own proprietary footprint on their 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 for the thickness 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 must be selected. APR programs and technique charts with valid exposure factors should be available to all radiographers.

> *It is a 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 and condition.*

Kilovoltage Peak (kVp)

Image quality is dependent on a sufficient amount and energy of x-rays reaching the image receptor. As a general rule, kVp and mAs should be selected carefully for digital radiography to ensure diagnostic image quality at the lowest possible patient radiation exposure. Adequate penetration of the anatomic part (kVp) is 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 image because of computer processing. A quality digital image is produced following adequate penetration (kVp), along with enough exposure to produce a diagnostic image with a minimal amount of quantum noise/mottle and appropriate spatial/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 decrease in mAs reduces patient radiation exposure. Using the 15% rule to compensate for an increase or decrease in kVp will also show a reliable consistency in the exposure index. Specifying the appropriate kVp level for digital exams is an important exposure technique variable to standardize in a radiology department.

A best practice in digital imaging is to use the highest kVp within the optimal range for the position and part coupled with the lowest amount of mAs needed to provide an adequate exposure to the image receptor.

Automatic Exposure Control

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

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

Although use of the unit's AEC is the best way to control the amount of radiation exposure regardless of the type of image receptor, doing so requires accurate positioning and systematic calibration of the AEC. Radiographers should ensure that the anatomy of interest covers most of the AEC detector(s) used, and place emphasis on proper positioning for an examination. The plus or minus (+/-) "density" (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 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(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. 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 to ensure proper exposure.

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 a standard of care per The Joint Commission. Departments can provide the charts with relatively simple spreadsheets that are posted and accessible to radiographers. Although exposure technique charts take time and effort to develop accurately, they prevent exposure technique errors. Routine use of the charts can provide consistent and accurate radiation exposure to the image receptor, thereby reducing patient dose.

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

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

Typically, exposure technique charts are developed based on patient thickness. Although measuring patient thickness in adult imaging may not be practical in all departments, well-developed charts that are consistently used can reduce the variability in exposure techniques that occurs during digital imaging. The charts 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 upon the specific patient and projection.

Collimation and Electronic Masking

The ASRT, ACR and the Society for Pediatric Radiology support pre-exposure collimation of the x-ray field, which limits the beam to the area of interest, and defines the field of view. 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.

Histogram analysis and the initial image processing depend on proper pre-exposure collimation. Inappropriate collimation will cause the histogram to widen because of a higher amount of exposure data recorded than is expected for the indicated radiographic examination. Widening of the histogram will cause anatomic values of interest (VOI) to scale inappropriately, as the digital system processes the image data. Most likely, histogram widening will cause the image to appear grayer, with decreased visibility of details in the displayed image. With digital imaging and the ability to perform postprocessing functions, terms such as electronic collimation, shuttering, masking and cropping are commonly referenced. 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 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 affects viewing conditions. 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."

Inappropriate masking occurs when it is used to cover up or hide anatomical information that would not have been included on the image had it been properly collimated. For example, if a hand x-ray is ordered and the image includes the forearm, masking the forearm so only the hand is displayed is inappropriate. Masking for this reason is not acceptable because information that has been captured by the image detector will be intentionally and permanently covered up or hidden from view. Both radiation safety and legal concerns can arise from inappropriate masking.

Cropping or shuttering refers to removing or eliminating information by electronically changing the field of view. Using the example from the preceding paragraph, if the forearm is cropped, data is removed from the image, which again is inappropriate use of postprocessing. Additionally, when a DR system processes cropped image data, the new data set will include only the information that is available in the cropped field of view. Because cropping removes information, the exposure indicator might be changed when compared with the entire data set available at image acquisition. Removing information also can change the way the image displays on the viewing monitor. Not only can the dynamic range be altered, but the resulting image might appear magnified upon viewing because the data to be displayed fills to fit the size of the display monitor.

Masking, shuttering or cropping should not be used as replacements for appropriate pre-exposure collimation of the x-ray field of view. All captured image data is a part of the patient's permanent medical record and should therefore be presented to the interpreting practitioner to determine whether the exposed anatomy obtained on any image is significant or of diagnostic value.

> *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 on an image detector 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 radiation protection and safety principles in accordance with dose optimization practices to minimize exposure to the patient, self and others. Lack of patient shielding can contribute to increased patient dose. Shielding is particularly important to protect anatomic areas near the exposure field but should not interfere with obtaining diagnostic information. Radiation exposure to tissues adjacent to the collimated field can be significantly reduced by properly positioned lead equivalent shielding. At a minimum, a patient's gonads should be shielded when within 5 cm of the edge of a properly collimated x-ray beam.

Radiologic technologists should follow department guidelines for radiation protection. Shielding is critical for digital examinations. Improper use of a shield can interfere with the equipment's ability to identify and optimally display the region of interest if the shielding material is included as part of the data used for processing the image. Shielding is a fundamental radiation safety practice that remains important when performing digital radiography.

A best practice in digital radiography is the use of lead shielding to reduce unnecessary radiation exposure to the anatomic parts that are adjacent to the x-ray field, the patient, the radiographer, and others.

Anatomic Side Markers

Radiologic technologists should use uniquely identifiable anatomic lead markers that are recorded radiographically during the exposure. Electronic annotations of anatomic side markers on the image during postprocessing are not an acceptable substitute for lead markers captured during the exposure to the image receptor as part of the original image. Electronic annotations can be changed or erased, whereas the use of lead markers captured during the exposure are permanently part of the image data. Failing to use uniquely identifiable lead markers to denote the side or to identify the radiographer performing the examination can be a legal issue. The ACR also emphasizes consistent use of lead markers in its digital practice guidelines.

A best practice in digital radiography is the consistent use of lead anatomic side markers captured on the original image during the x-ray exposure.

Grids

The sensitivity of digital imaging technology to low-level radiation exposure makes the use of antiscatter grids critical to ensuring quality images. Use of a grid helps to improve image quality by decreasing the effects of scatter radiation. A major disadvantage of using a grid is the required increase in radiation exposure to the patient. However, using a grid decreases the amount of scatter radiation that reaches the image receptor and improves image quality. Department guidelines and exposure technique charts should assist radiographers in determining whether to use grids for specific radiographic examinations. As a general rule, grids are appropriate for anatomy at a thickness of 10 cm or above and for examinations using 70 kVp or higher. Angling against the grid lines also will result in a significant decrease in the amount of x-ray energy reaching the digital 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. Also, a change in grid ratio will result in a change in the EI in many cases unless properly compensated by an adjustment in mAs. The ACR and the Society for Pediatric Radiology advise against grid use for pediatric patients when the part size is less than 12 cm.

A best practice in digital imaging is the use of a grid with specifications recommended by the digital imaging equipment vendor, generally for body parts that exceed 10 cm in adults.

Although image contrast increases with use of grids due to scatter removal, exposure to the image receptor decreases. The need to maintain receptor exposure, therefore, has always been regarded as a disadvantage of grid use because of the subsequent increase in patient exposure. Historically, maintaining 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 receptor exposure with an increase in mAs when a grid is added to a radiographic procedure is valid, the technical conversion factors used might be inappropriate for digital systems. 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 receptor exposure.

Additionally, great advancements have taken place with processing software. Processing algorithms that remove data associated with scatter radiation allow radiographs traditionally acquired with a grid to be acquired without one. Such algorithms yield desired levels of image contrast while keeping patient exposure to a minimum. What has not changed, however, is the proper use of grids. Off-center, off-level and focal range violations still result in grid cut-off errors.

A best practice is to 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, taking into account the use of noise suppression (virtual grid) 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 from 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 Fintelmann et al indicate that using CR and DR has led to more images being rejected for positioning reasons. The repeat rate ranges from 51% to 85%, compared with the standard of 8% repeat rate that was associated with analog imaging.

The research indicates that technology does not affect the radiographer's skills in accurately positioning the patient. Conversely, the technical capabilities of digital radiography provide the opportunity to crop or mask the image at the workstation to compensate for poor patient positioning. A factor to consider when positioning patients for digital radiography is the placement of the anatomy relative to the image receptor.

Immobilization is a critical component of positioning that helps to prevent repeat images, particularly in examinations of pediatric patients. The radiographer must note that some immobilization devices used in positioning patients, such as sandbags and sponges with plastic coverings, can cause artifacts in digital imaging and must be kept out of the exposure field. Independent of the image receptor system, it is critical that all positioning be performed accurately according to national standards and department protocol with accommodation for the patient's condition to prevent the need for a repeat exposure.

A best practice in digital imaging is to use immobilization devices when needed and prevent repeat exposures by appropriately positioning the patient.

Considerations for Pediatric Patients

Pediatric patients are not just small adults; they require special attention from the radiographer. Therefore, many of the factors radiographers must consider during adult radiographic examinations should be given special consideration when performing radiography of pediatric patients. Pediatric patients have developing organs and are up to 10 times more sensitive to ionizing radiation than are adults, according to ACR practice parameters for digital radiography. They also have longer life expectancies, so 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. Because the tissue composition is different in pediatric patients, a grid should not be considered for body parts less than 12 cm in thickness.

Exposure Technique

In pediatric radiography, APR settings must be adjusted for imaging patients who can vary from premature infants to obese adults. Radiographers must carefully select optimal kVp to penetrate the pediatric patient's anatomy under study. Selection of appropriate kVp is more critical with 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, a require lower kVp compared for appropriate attenuation. As a result, radiographers can reduce kVp, but still adequately penetrate the bone with the x-ray beam for a diagnostic-quality image.

Adult AEC settings cannot be used for pediatric patients. Radiographers who use AEC settings for imaging pediatric patients should follow the Image Gently digital safety checklist, which emphasizes that radiographers must be diligent in ensuring the appropriate kVp, backup time, image receptor and detector (or detectors) have been selected. Radiographers may need to use manual technique selection in pediatric radiography where the part is smaller than the AEC detector. In the case of manual technique selection, radiographers should measure part thickness with calipers to select the appropriate technique factors for each patient from proven APR settings.

Collimation/Shielding

Appropriate collimation and minimizing the anatomy exposed to radiation can reduce radiation dose to pediatric patients. As with adult examinations, proper alignment is critical to ensure essential anatomy is included in the image. Demonstration of the "silver lining," the edge between the collimation and the electronic mask, assures that all of the exposed area of the patient has been included on the image. According to Bomer et al, failure to include the entire exposed field due to excessive masking may prevent the interpreting practitioner from fully diagnosing the image and may allow for excess exposure to go unnoticed. According to Fauber, proper shielding also can help reduce dose. Lap shields and half-shields can help protect children's gonads. Specially shaped shields can be helpful for male gonads or female breasts. It is important, however, with some digital radiography systems that shields not interfere with the software's ability to identify the exposure field. Protocols can be established that allow for the use of a shield on one projection when multiple projections in the same area of the gonads are required. However, radiographers must use manual technique, not AEC, when a lead shield is in the exposure field to prevent excess radiation exposure. Radiographers should follow department protocols regarding collimation and shielding for pediatric examinations.

Positioning and Immobilization

Because pediatric patients have more trouble complying during positioning and image capture, the anatomy might not be centered accurately or consistently within collimation boundaries, when compared with adult positioning. 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 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 on for interpretation. The radiographer is responsible for critically assessing each image for the following:

- correct patient and examination information
- exposure indicator

- processing errors
- required anatomy
- positioning accuracy
- artifacts
- image appearance
- underexposure
- overexposure
- overpenetration

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

Image Appearance

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 "fixes" 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 overpenetration. The exposure error remains regardless of what occurs during imaging processing.

Underexposure appears on the digital image as quantum noise/mottle that is clearly visible in the thicker portions of the anatomy contained in the image. Overexposure and overpenetration result in a loss of image contrast throughout the image because of the increase in radiation striking the image receptor. In the event of overexposure or overpenetration, there is an overall grayed-out appearance to the image. The anatomy still is visible, but the image's appearance is less than optimal. A significant overexposure or overpenetration can result in a reduction in the ability to see all anatomical structures normally visible in the image because of saturation, or an overall dark appearance. 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.

Exposure Indicator

Due to 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 (EI) associated with the digital imaging system. Monitoring the EI for each image helps to track and eliminate trends that can lead to dose creep. Radiographers should assess EIs as part of image critique, keeping in mind the variability among vendors and the limitations of the EI.

Exposure indicators have been developed by most equipment manufacturers. The purpose of the EI is to allow the radiographer to assess the level of exposure the receptor has received and thereby determine 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 dose and exposure indicator has created confusion for radiographers who work with equipment from multiple manufacturers, or of different ages 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 the American Association of Physicists in Medicine (AAPM), manufacturers are implementing an international standard for EIs called IEC 62494-1. The IEC standard provides common EI values for use with all types of digital image receptors. The standard EI values do not provide an actual patient dose, but instead provide an estimated value of the incident radiation exposure to the detector for each acquired image.

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

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

Exposure Indicator Limitations

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 processing of the image data, a portion of the sequence involves the identification of exposure field borders. Errors during exposure field recognition can cause inaccurate standard deviation readings; 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 numbers, manufacturers and physicists devised a "standard 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. The table in the appendix illustrates this system. The AAPM proposed -0.5 to +0.5 as a target range.

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.

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

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. Artifacts on digital images can be classified by cause, and include detector defects, image processing and exposure. The appearance of artifacts on these systems might be described in terms of their brightness, size, shape, and location on the image. Regardless of the detector configuration, radiographers should prevent artifacts whenever possible. They should also determine the cause of any artifact on a digital image, report it, and repeat the image as needed according to departmental policy.

Detector Artifacts

Flat-panel detectors are highly integrated and use complex electronic systems. They can be wired or wireless and cassette-based or cassette-less. Detector failure can result in the appearance of artifacts such as the loss of an individual pixel, the loss of rows or columns of pixels, or loss of an entire segment of the image. Mishandling or dropping of the image receptor that causes damage to the flat-panel detector or the readout electronics also can result in detector artifacts. These can appear on the image as narrow bands or a large rounded area where no signal/image is visible.

Additionally, failure to protect the image receptor from liquids 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. Correction of calibration 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 equipment or replace equipment that is permanently damaged. Detector lag is another potential cause of artifacts when images are taken in rapid succession and a shadow of the previous exposure remains on the subsequent image. This is particularly problematic when the image of a lead anatomical side marker remains.

Image Processing Artifacts

Digital systems use elaborate software to process the image data to produce a specific image appearance. In some cases, the software fails to recognize the edges of the exposure field and can include all data during image processing, resulting in poor image quality. As previously described, radiographers might need to adjust the electronic masking to accurately align it to the exposure field when automatic processing fails to do so in order to gain an image free of image processing artifacts and avoid a repeat exposure of the patient. Poor image processing also can be prevented by the use of appropriate collimation because the inclusion of large areas of direct exposure to the image receptor affects the values of interest used in image processing.

The radiographer's selection of the processing menu (specific to the body part and examination) is also a critical step during the imaging process that helps minimize the likelihood of image processing artifacts. The common display qualities of the image that menu selection can control are brightness, contrast, edge enhancement, and equalization. On some systems, the processing menu also determines how the EI is calculated for each image. In the event a selected processing menu does not produce the desired image appearance, the radiographer must determine whether the production of the image degraded the image's quality or whether the menu selection was at fault. It is important to note that when used inappropriately, edge enhancement and equalization can degrade the diagnostic quality of the image submitted to PACS, and therefore potentially affect the final image interpretation. For example, in arthroplasty, excessive edge enhancement can create a false appearance of the interface between metal and bone.

Exposure-Related Artifacts

The first line of defense for preventing exposure-related artifacts is to properly externally prepare the patient for each examination. Digital image receptors are exceptionally sensitive to small differences in the materials in the exposure field, and therefore demonstrate excellent contrast resolution. However, this causes artifacts from patient clothing or other items on the body to be visible and even prominent on the image. Therefore, it is critical for the radiographer to remove any clothing or items from the exposure field that could potentially create artifacts on the image. This includes items such as fabric that has printing, clothing with small buttons, hair, etc.

As previously described, the selection of appropriate exposure factors is critical to acquiring adequate image quality. Extreme overexposure might be more likely to occur with a direct digital system due to the increased sensitivity to radiation. A large amount of excess exposure results in saturation of the image receptor, causing a failure to display anatomical structures. Extreme underexposure results in quantum mottle/noise in the image appearance that also can hinder the ability to see detail in anatomical structures. Both these potential exposure artifacts can be avoided by the use of standardized exposure technique systems. In addition, backscatter can create an image of the detector electronics. This artifact can be prevented with the use of a smaller field size or lead shielding behind the image receptor. Radiographers play a vital role in artifact identification and determination of their causes.

A best practice in digital radiography is to prevent artifacts by protecting the image receptor from damage by securing the image receptor and using appropriate bagging techniques. In addition, radiographers must prevent artifacts through proper external patient preparation, technique selection, and appropriate image processing practices. Radiographers and their institutions also must *recognize the causes of image artifacts and prevent future artifacts by properly maintaining or acquiring service for the digital radiography equipment and replacing equipment as needed.*

Medical-legal Considerations

The radiographer must review the image from a medical-legal standpoint, considering such indications as ensuring that uniquely identifiable pre-exposure radiopaque (lead) markers were used and are visible on the digital image. The patient name, date of exam, and imaging facility should be embedded in the image data and all anatomic information related to the area of interest should be included. Pre-exposure collimation of the primary beam during film-based radiography is evidenced by the white margin recorded around the exposure field, commonly referred to as the "silver lining." This border documents that all necessary information for a radiographic image has been recorded. Electronic collimation or electronic masking allow the elimination of the white border (silver lining) that surrounds the exposure field, with 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.

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

Following Examination Completion

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

Postprocessing

Digital imaging offers postprocessing capabilities that are not possible with film-screen radiography. Regardless, radiographers should perform postprocessing of digital images only if necessary. Any electronic masking that the radiographer performs on the image should take place only outside of the actual exposure field 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 digital image has original, raw data that should be kept intact. Postprocessing can change the original raw data and the set point that establishes the levels of gray scale assigned to the pixels. A change in the raw data can cause loss of information and thereby affect the viewing capabilities in the PACS system where it will be accessed by the interpreting or referring practitioner for diagnosis. Therefore, radiographers should adjust window level or width settings only if absolutely necessary. As described in the previous section on image processing software artifacts, if radiographers find that the image processing algorithm chosen does not provide adequate image quality, they should identify the cause of the poor image quality and determine appropriate corrective action. The processing algorithms are designed to provide optimum image quality relative to the anatomical part exposed to x-rays. If the processing algorithm consistently provides inadequate image quality, the radiographer should report the problem for adjustment.

Recording of Exposure and Dose Data

All EI and exposure technique information (such as mAs and kVp) should be included with the digital image. All exposure information should be displayed for the radiographer upon image review and should be retained as part of the digital imaging and communications in medicine (DICOM) information imbedded in the DICOM header.

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, particularly cassette-based systems. Radiology departments should work closely with vendors and PACS administrators 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.

Inclusion of exposure information on every final digital radiograph allows radiographers to take note of and use the information for refinement of exposure technique selection in subsequent exposures. Inclusion of 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 values and exposure technique factors be recorded and tracked along with dose information.

It is a best practice in digital radiography to electronically record exposure technique, EI, and dose data with the radiographic image to allow for assessment and refinement of technique selection practices.

Quality Assurance

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

Equipment Acceptance Testing and Calibration

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

Systematic Quality Control

Generators and x-ray tubes generally remain the same when 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.

The guidelines also recommend that an on-site radiographer be responsible for conducting routine QC noninvasive activities. Radiographers should perform daily and periodic checks of equipment that do not require physicist involvement. For example, the radiographer should inspect the digital system daily for possible physical defects, perform weekly phantom testing for image quality and artifacts, and inspect and clean image receptors routinely. It might not be possible to perform every QC test daily, but periodic testing can identify potential equipment malfunction. 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 on a regular basis.

Display Monitor

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

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

Repeat Analysis

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. 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

The advent of digital radiography has revolutionized the radiologic science profession. The technology continues to have a significant effect on workflow in clinical practice and in the radiology department. The change to and appropriate use of DR affects radiographers more than any other staff members. For example, the electronic transmission of images from radiographer to radiologist and other workflow issues have significantly reduced the amount of direct contact between the radiographer and the radiologist, thereby affecting their working relationship. Radiographers have less opportunity to discuss image quality or other issues with interpreting practitioners. 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 this 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 on 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 American Registry of Radiologic Technologists (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 Requirement (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 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. This can be positive if radiographers approach it professionally and as a team, learning from and supporting each other. For example, the ARRT certification exam no longer references film-screen radiography. Radiography programs have adapted to the new exam content specifications and most recent graduates have learned the fundamental physical principles of digital radiography. The current knowledge of entry-level professionals can contribute to a deeper understanding of the advancing technology in practicing radiographers, leading 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, teamwork, nonpunitive error responses, and support from supervisors and hospital management for patient safety. The number of days between serious safety events increased nearly four-fold. 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.

Conclusion

Digital radiography remains a vital tool in the diagnosis of injury and disease, helping to significantly 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 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:

- Review examination orders carefully to prevent unnecessary duplication and to ensure clinical appropriateness as related to the patient's history and indications. If there is a possibility that the examination might not be clinically inappropriate, 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.
- Screen patients for potential pregnancy and perform appropriate written 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.
- 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 upon the specific patient and projection.
- 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 that are adjacent to the x-ray field, the patient, the radiographer, and others.
- Consistently use lead anatomic side markers captured on the original image during the x-ray exposure.
- Use a grid with specifications recommended by the digital imaging equipment vendor, generally for body parts that exceed 10 cm 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, take into account the use of noise suppression (virtual grid) 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 to determine whether adequate exposure has reached the image receptor.
- Recognize that because the EI has limitations, carefully assess whether a repeat exam is necessary.
- Prevent artifacts by protecting the image receptor from damage by securing it and using appropriate bagging techniques.
- Prevent artifacts through proper external patient preparation, technique selection, and appropriate image processing practices.
- Recognize the causes of image artifacts and prevent future artifacts by properly maintaining or acquiring service for the digital radiography equipment and replace equipment as needed.
- Electronically record exposure technique, EI, and dose data with the radiographic image to allow for assessment and refinement of technique selection practices.
- Implement a comprehensive quality assurance program that involves aspects of quality control and continuous quality improvement, including repeat analyses that are specific to the digital imaging system.
- 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.

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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.

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

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

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

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

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.

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

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

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

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

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

Appendix B :

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

Appendix C :

Digital Radiography Systems Review—The Path to a Digital Image

The image signal from the remnant beam exiting the patient to the image displayed on the monitor for each of the following digital radiography systems (CR & 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 fluoro-halide crystals 2. Red helium neon laser	Scintillator—cesium iodide	Scintillator—cesium iodide or gadolinium oxysulfide	X
Converts light into an electrical signal	PMT	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.

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