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Medical imaging has undergone dramatic changes and technological breakthroughs since the introduction of digital radiography. This article presents information on the development of digital radiography and types of digital radiography systems. Aspects of image quality and radiation exposure control are highlighted as well. In addition, the article includes related workplace changes and medicolegal considerations in the digital radiography environment.

After completing this article, the reader should be able to:
- Discuss the discovery of x-rays and how they are created.
- Define digital radiography and describe how it differs from film-screen radiography.
- Define digital radiography and describe how it differs from film-screen radiography.
- Describe the image acquisition and readout process for computed radiography, indirect digital radiography, and direct digital radiography systems.
- Identify various factors that affect digital image quality and appearance.
- List factors used to determine radiation exposure to patients who have digital radiography examinations.
- Discuss changes that should occur in the workplace when implementing digital radiography.

In 1895, German professors from the University of Würzburg performed experiments examining the properties of cathode rays and the effects of electrical current through low-pressure gases. Continuing to investigate the effects of cathode rays passing through different types of vacuum tube equipment, Professor Wilhelm Conrad Roentgen noticed that as the rays were emitted from the tube, a barium platinocyanide plate across the room would fluoresce. Placing objects of differing thicknesses in the path of what he called x-rays, Roentgen was able to record varying transparencies of the objects on the photographic plate. One object placed in the path of the x-ray was the hand of Roentgen’s wife. When the plate was developed, the shadows of his wife’s hand bones were visible. At that moment, Wilhelm Conrad Roentgen became the first radiographer and the first “roentgenogram” was created. After weeks of intense and secretive experimentation, Roentgen reported his findings to the local medical society in Germany. Six years later, in 1901, he was awarded the Nobel Prize in Physics for his discovery.

Producing X-Rays
Since the first roentgenogram, advancements in medical imaging have been profound. Over the past 120 years, medical imaging has evolved from the invention of the x-ray tube by William Coolidge in 1915 to the subsequent development of imaging technologies, such as computed tomography and nuclear medicine. Although techniques and equipment have been refined over the past century, the production of x-rays essentially has remained the same.

X-rays are created in a glass vacuum tube housed inside a protective metal
encasement (see Figure 1). A negatively charged cathode sits at one end of the x-ray tube that also contains a tungsten filament. The other end of the tube contains a positively charged anode and a thick copper rod with a small, angled tungsten target. When an x-ray is produced, the filament on the cathode end of the tube is heated, emitting electrons through the process of thermionic emission.

The electrons are accelerated by high voltage and focused to the anode side. When the electrons hit the tungsten target, x-rays are produced. These rays are guided by the angled tungsten target and directed toward the patient through the window of the tube wall. The x-rays pass through the intended area of the patient’s body where part of the x-ray beam is absorbed through attenuation. On the opposite side of the body, detectors or film capture the exit beam rays and a clinical image is produced. Image production and processing are dependent on the mechanism used to capture the attenuated rays.

**Film-Screen Radiography**

Following the discovery of the x-ray and the invention of the radiograph, the most common way to capture exit beam rays was through conventional, or film-screen, radiography. In film-screen radiography, the film acts as the medium for image acquisition, display, and storage. Typically, a piece of radiographic film is placed on 1, or between 2, intensifying screens that emit light when struck by x-rays. The light exposes the film in proportion to the amount and energy of the incident x-rays on the screen. The film is then processed with chemicals, and the image appears on the sheet of film.

Although film-screen radiography can provide an adequate image, problems can occur if the operator is not properly trained or makes small errors in technique. Poor image quality can result from incorrect determination of radiation exposure settings. Fixed dose latitude and fixed nonlinear grayscale response limit the information that can be captured on the film and the potential for reducing patient dose. In addition, film-screen radiography can be expensive because of costs associated with purchasing film and processing materials. Storage, organization, retrieval, and dissemination of film also present expenses and obstacles for a radiology department, such as lost films or space for files.
Digital Radiography

Digital imaging has been defined as “any imaging acquisition process that produces an electronic image that can be viewed or manipulated on a computer.” This definition applies to many types of images, but digital images acquired using radiation are referred to as digital radiography. Although digital subtraction angiography (a type of fluoroscopy used in interventional radiology), developed in 1977, is thought to be the first digital imaging system, the first digital system for general radiography was introduced in 1980 and required cassette-based storage-phosphor image plates. Over the next decade, many improvements were made and its use became widespread. By 1990, technology had evolved, and a new type of digital radiography system appeared that used sensors to detect attenuated x-rays and did not require cassettes. These completely digital systems facilitated the use of PACS to store and transfer images. Although film-screen and cassette-based systems still are used by some providers, the trend is moving toward completely digital systems. In 2013 it was estimated that newly installed film-screen systems made up only 1% of the market. In 2016, the American Registry of Radiologic Technologists (ARRT) Board of Trustees voted to remove film-screen topics from the image production section of the certification exam and expand digital imaging topics effective January 1, 2017. In addition, beginning in 2017, Medicare is going to reduce payments by 20% for providers using film-screen systems and 7% to 10% for providers using cassette-based systems, further solidifying the adoption of completely digital radiography systems.

The physical principles of creating x-rays with digital radiography are the same as with film-screen radiography; however, data acquisition, image processing, viewing, and storage differ. In place of film and intensifying screens, digital radiography uses detectors to measure and convert the attenuated rays from the patient into electronic signals. These signals are then recorded, digitized, and quantified into a grayscale that represents the amount of x-ray energy that was deposited at a given point.

Postprocessing software organizes the data into a clinically meaningful image that is displayed on a computer monitor. Although the image displayed can be altered to compensate for technique errors, best practice is to select the appropriate exposure technique factors for the patient’s size and condition and follow the as low as reasonably achievable (ALARA) principle. The final component of a digital radiography system is image storage. Radiographic images must be stored for comparison and legal purposes. Short-term archiving generally is available on all systems, and long-term archival systems, such as PACS, are necessary to ensure the image is available at a later date, sometimes years later. PACS is used for digital storage of images and serves as a means to transfer images across networks and between medical providers. Because images are stored and distributed electronically, many of the costs originally associated with storage and dissemination of film-screen radiographs are eliminated after transitioning to digital radiography and PACS.

Because digital radiography practice still is transitioning to completely digital technology, many terms and techniques relating to DR are not yet standard or universally accepted. This article focuses on 3 types of digital radiography: computed radiography, indirect digital radiography, and direct digital radiography.

Computed Radiography

Computed radiography (CR) was introduced commercially in 1983 and initially was referred to as cassette-based digital radiography. Although cassetteless CR systems are available, only cassette-based CR systems will be discussed. Acquiring an image using CR is comparable to acquiring an image using film-screen radiography. The radiographer positions the patient, centers the x-ray beam, and sets technical details. The primary difference between film-screen radiography and CR is the composition of the cassette.

The CR cassette, or image plate, comprises various layers needed to acquire an image. Behind the protective layer of the cassette is the phosphor layer. This layer is known as the active layer because it contains a photo-stimulable phosphor that collects electrons during an exposure. The next layer is electroconductive to absorb and reduce static electricity and generally is made of felt or foam to prevent dust accumulation. Next, a support layer gives the imaging plate some strength. Newer cassettes might contain a light shield or color layer that absorbs
After exposure, the radiographer attaches patient demographic information to the cassette via a barcoding system and then inserts the cassette into a reader to obtain the image. The imaging plate is removed from the cassette and scanned by a laser. Typically, manufacturers use a helium laser or solid-state laser diodes for the signal extraction process. The laser scans the imaging plate, producing a photostimulated luminescence, which is converted into an electrical signal and digitized by an analog-to-digital converter.

After digitization, a computer processes the signal and displays the digital image on a monitor. At this stage, image quality can be assessed and postprocessing adjustments can be made before images are sent to the radiologist for interpretation. Typically, the entire

**Figure 2.** Computed radiography image acquisition process. © ASRT 2016.
readout process takes 30 to 40 seconds. While still in the reader, the imaging plate is erased by exposure to a high-intensity light beam. This process allows the cassette to be reused for future exposures (see Figure 2).

The introduction of CR systems to the medical imaging profession brought many advantages. Although technologists still handle cassettes with each exposure, postprocessing benefits and a dynamic range that can produce data over a wider range of x-ray exposure values make the system desirable. Image postprocessing in CR facilitates slight adjustments to brightness after acquisition by the technologist or radiologist, decreasing the need for repeat exposures for images with minor technical deficiencies. This decreases the need for repeat exposures caused by suboptimal technical factors. In addition, cassette-based CR systems have been easier to integrate into existing radiology departments because the equipment is similar to that used with film-screen radiography. However, CR readers and image viewers are an additional expense.

Similar to film-screen radiography, CR systems are portable and easy to use when caring for patients who are not ambulatory and require bedside examinations. Physical space and resources to store hard copy images are eliminated as image viewing typically occurs via a computer monitor. Image accessibility also is improved because the need to physically track down a hard copy image no longer exists. Last, the cost to copy and distribute the images decreases significantly as transport expenses are nearly eliminated with PACS, and the cost of materials needed to copy images is minimal. The electronic image is accessible immediately for radiologists and can more easily be shared with referring or consulting physicians via PACS.

Although many technologists are excited to move from film-screen to digital technology, CR has limitations and disadvantages. For example, compared with film-screen radiography, x-ray detection with a CR system is inefficient. CR imaging plates have a lower detection efficiency, which results in a need for higher radiation dose for proper exposure. This affects image quality also because the spatial resolution of CR images typically is lower than the spatial resolution of film-screen radiographs. However, several studies have shown that the diagnostic value of CR is at least equivalent to that of film-screen radiography, and many newer CR systems have overcome spatial resolution problems.

In addition, the imaging plates used with CR systems are damaged easily. Similar to film cassettes, imaging plates frequently are dropped, cracked, and scratched with typical use. CR cassette readers also can introduce artifacts on images or damage the plate. Undesirable densities, or artifacts, on the processed image can happen with CR cassettes. For example, cracks in the imaging plate can cause lower x-ray attenuation to be seen on the image, and the adhesive used to attach identifying lead markers to the plates can leave a residue that causes artifacts on the processed image. Finally, if static electricity is present, objects such as dust or hair can cling to the plate, also creating artifacts. These limitations helped prompt the development of new technology.

Indirect and Direct Digital Radiography

Digital radiography using detectors was introduced to the medical imaging profession in the 1990s. Digital radiography that uses sensors to detect attenuated x-rays can be divided into 2 groups: indirect digital radiography and direct digital radiography. In these types of systems, sensors are enclosed permanently in the body of the x-ray equipment; therefore, physical transportation of a latent image is not required because cassettes are not used. Instead, detectors convert x-rays into electrical charges that are sent directly to the image processing system to create a digital image in less than one second. Although indirect digital radiography and direct digital radiography appear similar in the physical state, indirect and direct detectors differ in how x-rays are captured and processed and in the quality of the image created (see Figure 3).

Indirect digital detectors earn their name because x-rays have to go through a 2-step process before creating the analog signal needed for image display. After exposure, x-ray photons are absorbed and converted to visible light by a scintillator. The light then is converted into an electrical charge that is sent to an image processor for image display. There are 2 primary indirect detector technologies that use this process: a charge-coupled device (CCD) and indirect flat panel...
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CCDs. The more CCDs, the larger the size of the detection area. CCDs convert the light into an electrical charge that is released, and the analog signal is sent to an analog-to-digital converter to translate the charges into a digital signal for image display.13 CCD-based systems are considered inferior to flat-panel systems and can produce images that are distorted, demagnified, and have subpar image quality.13

Indirect flat panel detectors are the more commonly used indirect digital detector in medical imaging departments because of their superior image quality. After exposure and x-ray conversion to light by a

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Figure 3. Indirect radiography systems and direct digital radiography systems appear similar in the physical state but differ in how x-rays are captured and processed. Systems using indirect detectors go through a 2-step process requiring a scintillator before creating the signal needed for image display. Systems with direct detectors convert x-ray photons directly into an electrical charge using a photoconductor.
Abbreviations: CCD, charge coupled device; ADC, analog-to-digital converter. © ASRT 2016.
scintillator, the light is converted to an electrical charge by an array of photodiodes. The charge pattern from the diodes is read out by a thin-film transistor array. An analog signal is created and then sent to the analog-to-digital converter to translate the charges into a digital signal for image acquisition.6

Direct flat-panel detectors differ from indirect detectors in that the x-ray photons are converted directly into an electrical charge.12 Direct conversion occurs through a photoconductor. A typical photoconductor uses lead iodide, lead oxide, thallium bromide, gadolinium compounds, and most often, selenium because all these materials have a high intrinsic spatial resolution.11 The charge pattern is recorded by the thin-film transistor array, and the analog signal is then sent to the analog-to-digital converter to translate charges into a digital signal for image acquisition.6

Similar to CR systems, systems using indirect and direct detectors have had a dynamic effect on medical imaging departments and professionals. Because darkrooms and chemicals are not needed for processing a latent image, physical storage space for processing materials, radiographs, and the manpower to file, organize, and retrieve images are eliminated. Image accessibility and distribution become easy and cost-efficient because radiographs can be accessed electronically. In addition, a wide exposure latitude produces acceptable images when inappropriate technical factors are set.12 This, in turn, decreases the number of failed exposures and repeated examinations.12 Radiologists also can optimize display of images electronically at their workstations to evaluate anatomy appropriately.15

A big advantage of systems using indirect and direct detectors is that cassettes are not required, which means radiographers do not have to transport cassettes when performing an examination.6 This makes the radiographer’s work less strenuous, helps improve efficiency, and reduces the time needed to acquire images.4 Because images are available immediately after exposure, radiographers spend less time on image processing. This is a drastic improvement in workflow compared with film-screen radiography and CR. Most importantly, systems using indirect and direct detectors provide better image quality than do CR systems and require a lower radiation dose to obtain adequate images.6

Because the sensors used to detect x-rays are housed within the radiography unit, equipment conversion can be costly. When converting to digital radiography, departments have to retrofit radiography rooms or purchase entirely new equipment.12 Either option presents considerable cost to the organization in addition to the inconvenience and effect on patient volume while a room is out of commission during construction and installation.

**Image Quality and Appearance**

Optimal image quality remains essential for radiologists evaluating diagnostic radiographs. Image quality depends on the age of the x-ray equipment, applied dose, accurate calibration, and other aspects, such as pixel size, signal-to-noise ratio, and dynamic range.5 With an inadequate image, diagnoses of medical conditions are in jeopardy and leave the radiologist and corresponding health care facility legally responsible. Therefore, understanding the factors that go into creating a quality image using digital radiography while maintaining the ALARA principle is essential.

*Spatial resolution* refers to the visible sharpness of the image and the ability to present fine details that help the radiologist differentiate between objects.12 In film-screen radiography, the crystal size and thickness of the phosphor layer determine spatial resolution.7 In CR, the thickness of the phosphor layer plays a role, but the size of the pixels also contributes to the spatial resolution of an image. The thinner the phosphor layer, the higher the resolution.7 The smaller the pixels, the sharper the image and the better the spatial resolution.12

The sharpness of images acquired with direct or indirect digital radiography systems depends on the detector’s physical characteristics.12 For example, the type of material used for the detector affects image sharpness. Spatial resolution for indirect and direct digital radiography systems is higher than that of images acquired with CR detectors but lower than spatial resolution on film-screen radiographs.12 Although the sharpness of a digital image can be altered after processing, excessive processing leads to increased image noise. Furthermore, increasing the radiation applied to the detector does not improve spatial resolution.6 No matter which system is used to acquire an image, setting the appropriate technical factors is crucial.
Varying depths of contrast are needed on any image to see anatomy appropriately. Low contrast, represented by many shades of gray, makes it difficult to differentiate between structures, whereas very high contrast makes the image appear black and white and decreases visibility of the structures. There are 2 types of contrast in digital imaging. Subject contrast refers to the absorption of the x-ray beam by the patient’s tissues. Display contrast applies to the image adjustments on a computer monitor after processing. 

Density resolution or dynamic range are terms that refer to the range of gray levels seen on the image. This range is critical when evaluating image quality because the ability to show deep grayscale without overexposing a patient provides the potential to find pathology. The bit depth of a pixel directly controls the number of shades of gray available for display. Essentially, the greater the bit depth, the better the density resolution of the image. Deep bit depth improves image quality in digital radiography.

Noise is a term used to describe any unwanted interference with the x-ray signal detection. Electronic noise refers to interference caused by the radiographic system. Quantum noise refers to any interference caused by the number of x-ray photons making contact with the detector. This is controlled by the technical factors set by the radiographer at the time of exposure. Low exposure factors produce fewer x-ray photons and a grainy image. Higher exposure factors can produce a better image but unnecessarily increase the radiation dose to the patient. Various software systems from manufacturers have applications that help reduce noise. With digital equipment, higher kilovoltage peak (kVp) and lower milliampere seconds are appropriate. Ultimately, finding the appropriate technique is critical to image quality when using digital radiography equipment.

An artifact is a distortion or error in an image that is unrelated to the subject being studied. Artifacts are distracting to the interpreting radiologist and unwanted in medical imaging. It is important that radiographers and radiologists understand how artifacts arise and how they can reduce or remove them from images. CR artifacts can arise from several sources, but the most frequent causes are objects or defects in the imaging plate, errors with digital image processing in the CR reader, and technologist error (eg, incorrect choice of radiographic technique, improper orientation of the cassette, and incorrect use of image processing equipment). Flat-panel digital detectors used in indirect and direct digital radiography often produce image artifacts caused by flaws in the detector or defective pixels and poor performance of the electronics within the system.

X-ray image quality begins with the signal profile captured by the x-ray detector. With direct and indirect digital radiography, the detector should sense even small amounts of incoming x-rays and have a high dynamic range. It is critical that subtle findings be detected without adding artifacts to the image. Detective quantum efficiency (DQE) is a fundamental physical variable related to image quality in radiography. It is the best and most widely accepted measurement for efficiency of a detector in converting x-ray energy into an image signal. An ideal imaging system would record all x-rays accurately, earning it a DQE of 100%. However, imaging systems never have a DQE of 100% because of inefficiencies in detecting the incident x-rays and internal sources of noise. DQE also varies because it depends on the exposure technique used.

Digital radiography systems using indirect or direct detectors have a higher DQE than CR, whereas CR has a higher DQE than film-screen radiography. The maximum reported DQE for film-screen radiography and CR systems typically is less than 30%, whereas the DQE range for systems using indirect or direct detectors is between 35% and 75%, depending on the material used for the detector. High DQE values indicate that less radiation is needed to achieve identical image quality. An increasing DQE while radiation exposure factors remain constant is a sign of improved image quality. DQE varies by manufacturer and should be considered when the system is purchased.

In addition to DQE, modulation transfer function is an objective physical measurement used when determining image quality from various digital radiography systems. As with DQE, the detector used to capture attenuated x-rays has a dynamic effect on image quality. Modulation transfer function is described as the ability of the detector to transfer its spatial resolution characteristics. Similar to DQE, a perfect transfer of spatial
and contrast information would earn the image a rating of 1. As spatial frequency increases, the modulation transfer function value decreases. The higher the modulation transfer function value, the better the detector can provide spatial resolution data.\textsuperscript{6}

Regardless of the equipment, technologists should understand factors that affect image quality and dose and continue to acquire high-quality images with minimal patient dose.

**Radiation Exposure Control**

Setting appropriate technical factors is crucial. Although medical imaging technology has improved, the fundamentals of an ideal imaging system have not changed. ALARA remains a priority with the implementation of advanced technology. With more digital systems earning higher DQE ratings, it is clear that digital radiography systems can provide diagnostic quality images while lowering patient radiation exposure.\textsuperscript{6}

The most obvious way to minimize patient exposure is through a decrease in the number of failed or unnecessary images.\textsuperscript{6} With film-screen radiography, images might need repeating for various reasons that include improper patient positioning or technical factors. When the exposure is too low, the film is underexposed and the image is too light and therefore unacceptable. When the exposure is too high, the film is overexposed and the image is too dark and unacceptable for interpretation. In either case, the radiographer would have to expose the patient to radiation again to acquire an acceptable image.

With digital radiography, image contrast and brightness are independent of the dose delivered. This is possible because the dynamic ranges of imaging plates and detectors are wider than with film-screen radiography, minimizing the effects of overexposure or underexposure.\textsuperscript{6} It is possible for a digital radiograph acquired with an exposure that is slightly too low or too high to be acceptable because of digital image post-processing.\textsuperscript{6} If the exposure is low, a high level of noise might be seen on the image, but if the exposure is high, acceptable images still can result.\textsuperscript{12} This creates a problem regarding patient radiation dose with digital radiography.

Technologists aim to provide excellent patient care while acquiring the best possible images for radiologists. With digital radiography, the fear of producing a noisy image with a low exposure inadvertently encourages technologists to use higher exposure factors because overexposure still results in an acceptable image.\textsuperscript{12} The use of a higher than necessary radiation exposure to a patient to overcompensate for and avoid noise from an underexposure is referred to as exposure creep or dose creep.\textsuperscript{12}

In an effort to monitor radiation exposure using digital radiographic equipment, manufacturers developed a numerical parameter to measure exposure data.\textsuperscript{12} In a general sense, this parameter is referred to as an exposure indicator (EI). EIs are displayed on the digital image and correspond to exposure to the imaging plate or digital detector. They are used to monitor patient dose while maintaining acceptable image quality. Although an acceptable range is given by the equipment manufacturer, it should not take the place of proper technique or serve as verification that proper technique was used.\textsuperscript{12} The parameters help ensure an adequate exposure has reached the image receptor.\textsuperscript{14} The parameter depends on several factors, including kVp, filtration, patient positioning, source-to-image receptor distance, collimation, beam centering, and image processing algorithms.\textsuperscript{12}

EIs do not represent an equivalent for patient entrance dose; rather, they should be used for dose management.\textsuperscript{14} Each manufacturer of digital equipment has its own name, symbol, and calculation method for its EI.\textsuperscript{14} For a technologist who works on a number of manufacturers’ systems, the disparity between each can lead to confusion and uncertainty regarding EIs. For this reason, in 2009, the American Association of Physicists in Medicine (AAPM), the Medical Imaging and Technology Alliance, and the International Electrotechnical Commission gathered with physicists and digital radiography manufacturers to develop a way to standardize the EI in all digital radiography systems.\textsuperscript{14} From their meetings came a published report released by the AAPM that provided a unified method for generating EIs.\textsuperscript{14} It also was proposed that manufacturers use consistent terminology and develop a uniform response relationship between receptor exposures and EIs.\textsuperscript{14} The report suggested identifying target exposures for various examinations and establishing a clinically relevant exposure level indicator.\textsuperscript{14}
The AAPM also proposed that feedback to the radiographer related to the level of exposure for an image be displayed immediately following image capture. This feedback is referred to as a deviation index (DI). 16 The DI was established as an indicator to help the operator determine whether radiographic technique was chosen appropriately for a given examination. 15 When the appropriate technique is used to expose the detector, the DI is equal to zero. 11 When the detector has been underexposed, a negative number displays, and when overexposed, a positive number is generated. For example, if the DI reads +1, overexposure to the detector by 25% has occurred, whereas a reading of −1 indicates underexposure by 20%. 14 The range typically is narrower for examinations using automatic exposure control vs manual setting of technique factors by a technologist. 15

With each body part and position, a suitable DI range should be established by imaging department personnel or the radiologist, and it should be available for the technologist at the time of imaging. 15 Improper positioning or collimation can alter the DI and produce an inaccurate reading. 11 Exposure information for each radiograph should be recorded for each examination and become part of the patient’s record. 11 It is imperative that as digital radiography increases in use, radiographers understand the acceptable EI and DI parameters for the equipment they use to ensure quality images and prevent dose creep. 14

The concern regarding the amount of radiation exposure patients receive during a medical imaging examination is not new. With each new radiation-producing technology brought to market, concerns about patient dose are shared by patients and health care providers. Ionizing radiation is carcinogenic, so it is important that the benefits of the examination ordered outweigh the risks. 14 Digital radiography brings advantages to radiography, and the technology’s wide dynamic range should decrease the amount of repeat examinations, yet the issue of dose creep has inspired various initiatives in an effort to ensure that decreased patient dose remains a priority.

Initiatives to Decrease Patient Dose

Initiatives to prevent dose creep and unnecessary radiation exposure to patients start in the radiology department, and a department should have these strategies in place. Implementing the use of radiographic technique charts can keep technologists’ settings more consistent between examinations. 11 Technique charts should take into account the anatomical area under study as well as patient size. 11

Technique charts must be tailored for each piece of imaging equipment. 16 Although many factors go into determining the appropriate technique, significant differences are seen between equipment manufacturers and types of detectors. Installing technique options directly into the generator controls can standardize technique selection and prevent dose creep. 14 Technique charts do not take the place of a radiographer’s assessment of the patient when making alterations to the technique for pathology or unusual circumstances. 11

Automatic exposure control is another method used to lower patient exposure and prevent dose creep. 12 Automatic exposure control units are designed to turn off the x-ray generator when an appropriate exposure level has been received at the image receptor during an exposure. 16 This is done through the use of 3 to 5 radiation detectors, or ionization chambers. 12 Automatic exposure control is used in film-screen radiography and digital radiography imaging methods because it works well when calibrated correctly, the patient is positioned properly, and appropriate chambers and sensitivity settings are selected. 12 Automatic exposure control can be used for most examinations, but if the anatomy of interest is too small to cover at least one of the radiation detectors, automatic exposure control will not work and should not be used. 12

Quality management programs within a radiology department can be initiated in each area of practice. These types of programs are seen in the clerical, technical, and administrative areas of the department and help to guide policies. Quality management programs can contribute significantly to the detection of patterns outside the range of appropriate dose or technique to improve radiation dose and radiation safety. Recording technique and exposure information for each examination leaves a trail that can be evaluated by radiologists, physicists, and managers.
to help address unfavorable trends and resolve problems before they become a concern.\textsuperscript{12}

Quality management programs should be implemented for all aspects of the equipment and mechanisms used for acquiring and displaying the image to identify trends and ensure repeat images are not due to equipment errors or improper settings.\textsuperscript{12} Maintaining current information and communication with imaging equipment manufacturers also is vital to ensure current data is used.\textsuperscript{12} As long as the department has a culture that encourages safety, open communication, and nonpunitive reporting, quality management programs can help radiologic technologists maintain the ALARA principle.\textsuperscript{16,17}

Initiatives to decrease patient radiation dose and dose creep are not confined solely to the radiology department. Radiation exposure from medical procedures frequently is addressed at a global and national level and, as a result, campaigns have been developed to draw attention to radiation safety and dose. These campaigns were initiated to educate medical professionals and the general public. In 2008, the Image Gently campaign was initiated by the Alliance for Radiation Safety in Pediatric Imaging.\textsuperscript{11} Addressing the concern of childhood radiation exposure was critical as media reported a link between CT scans and childhood cancer. Although the campaign was intended to focus on pediatric CT examinations initially, general radiation exposure to children from all types of medical imaging quickly was added to the campaign’s focus. In 2011, the Image Gently campaign released information directly related to the digital imaging of children.\textsuperscript{11} The campaign published a checklist that radiographers can use to help emphasize their mission and encourage quality management programs for pediatric imaging.\textsuperscript{18}

To view the Digital Radiography Safety Checklist published by the Image Gently campaign, visit asrt.org/as.r?YGcVjC.

In 2010, the American College of Radiology and the Radiological Society of North America formed the Joint Task Force on Adult Radiation Protection. The task force members sought to address concerns regarding the surge of information about the dangers of ionizing radiation.\textsuperscript{11} The Image Wisely campaign arose from the joint task force, which included input from the AAPM and the American Society of Radiologic Technologists. The main goal of the campaign was to start focused awareness on ways to lower the amount of radiation used in medical procedures.\textsuperscript{11} The campaign’s Web site brings professionals and patients together and provides resources and information regarding radiation exposure.\textsuperscript{19}

The American College of Radiology is one of many partners participating in the Choosing Wisely campaign.\textsuperscript{20} This campaign is an initiative of a foundation established by the American Board of Internal Medicine. Although Choosing Wisely does not pertain solely to medical imaging, it focuses on the appropriate use of health care resources, along with patient safety and high-quality care for patients. The campaign emphasizes primarily duplicated and unnecessary tests and treatments most often occurring in a radiology department. The Choosing Wisely campaign is intended for providers and patients in an effort to encourage conversations related to the overuse of tests. Partnering organizations, such as the American College of Radiology, are providing evidence-based recommendations for patients and providers to reduce unnecessary interventions in care.\textsuperscript{20}

The U.S. government also plays a role in radiation safety and dose reduction. The U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH) has been working on its initiative to reduce unnecessary radiation exposure since 2010.\textsuperscript{11} The initiative first was developed by the International Commission on Radiological Protection to promote justification of an imaging procedure and dose optimization.\textsuperscript{21} The FDA has partnered with professional organizations and industry leaders to ensure radiation protection principles are incorporated into U.S. imaging facilities’ quality management programs. The CDRH emphasizes the imperative that the person performing an examination is properly credentialed and has met training and education requirements. Continued research in medical imaging will guide the future initiatives of the CDRH.\textsuperscript{21}

Changes in the Workplace

The introduction of digital radiography has brought about significant changes for health care organizations,
radiographers, supporting staff, and patients. When implementing digital technology, it is essential that health care administrators and technologists are aware of the changes new technology brings to the workplace and are proactive in continuing to maintain a safe and professional environment. Imaging department safety refers to the physical elements found in the department that could harm staff and patients. Maintaining a safety-minded workplace culture, departmental policies, and employee education ensure a professional and safe environment in digital radiography.

Health care organizations commit financially to a radiology department when they purchase expensive state-of-the-art digital equipment to increase department productivity and image quality. Initially, it might seem that digital radiography simply replaces film-screen technology; however, changing equipment means job duties change. For example, support staff no longer file or retrieve physical film. In general, workers are positioned at a computer monitor performing various duties with electronic images. Radiologists no longer sit in a large reading room with view boxes. They now interpret images in a small office with computer monitors. Although radiographers still spend much of their time delivering patient care, how they acquire images, perform the duties associated, and their level of responsibility has changed with the implementation of digital radiography. The transition of job duties compels department managers to rethink workflow, rewrite job descriptions, and focus on improving workplace culture.

In addition to changes in workflow and job duties, department managers must focus attention on policy development and implementation. Focusing on exposure techniques and quality control of digital radiography equipment should be first and foremost. This helps radiologic technologists and other staff involved understand their responsibilities and maintains consistency among employees in completing various departmental tasks. Competencies for various jobs also should be established to ensure the education provided is adequate; evaluations ensure employees meet their employer’s standards. Incorporating a flowchart can help employees understand their roles as members of a team. Together, these efforts maintain a professional, efficient, and safe work environment.

Digital radiography job functions require training, and the implementation of digital radiography demands education with a strong focus on technology and computer skills. Radiographers might not have all the computer expertise needed at the time of implementation and therefore must be trained. Vendors supplying digital radiography equipment typically have training packages for users that are included or purchased, yet learning a new system requires time and attention. Because of the busy nature of radiology departments, finding time to ensure all workers in the department are trained professionally is a rarity. Instead, a small group of select technologists and supervisors might receive formal training from a manufacturer’s applications trainer and then disseminate the information to other employees.

Assessing employee’s competencies can help ensure that training is consistent and adequate. The employer has a responsibility to provide the initial education related to the new equipment and workflow and follow-up education with technologists and staff. This will ensure that employees remain current and minimize the inadvertent spread of inaccurate or outdated information. Because employers expect efficiency through improved workflow after implementing digital radiography systems, technologists need to adhere to policies and remain committed to their responsibilities as radiographers to be successful in this fast-paced environment.

Regardless of the type of radiography equipment in use, technologists must provide excellent care while acquiring optimal images for the radiologist. Following the ALARA principle and departmental policies ensures safety for everyone. The technologist’s role in determining patient dose is the most critical and because of this, adherence to the profession’s continuing education requirements must remain a priority for ensuring high-quality and safe patient care. Understanding how to select the most appropriate technical factors is the technologist’s responsibility, and radiographers must remain abreast of information on the technology they use.

The American College of Radiology encourages facilities to support consistent in-service education on radiation safety and have technologists hold advanced certification in the specialties and disciplines in which they work. Technologists also are required to abide by the rules and regulations, ethical standards, and
continuing education requirements set forth by the ARRT and their respective states. Equally important, the technologist’s responsibility to patients can be achieved by fostering a strong teamwork environment in which safety and professionalism are emphasized.

Medicolegal Considerations
Legal issues in health care have become a significant concern in the United States. Mello et al researched the costs of defensive medicine and concluded that physicians’ and health care organizations’ fear of litigation has contributed to the astronomical costs of care. Regardless, litigation is not going away, and health care professionals are well aware of the consequences of medical errors. Health care organizations have been sued for various issues, such as negligent acts related to patient care or the improper release of patient information. The radiology profession is not immune to legal action. Radiologists have a 1 in 3 chance of being sued, most often related to misdiagnosis or failure of timely notification of a patient’s condition.

Radiographers subject themselves and their employer to risk every time they perform a procedure. As radiology departments transition to digital radiography, maintaining standards of care and keeping patient safety a priority will help manage risk. Employee implementation and adherence to departmental and institutional policies can lower risk.

Risk is defined as the chance or possibility of incurring loss or a negative event happening that might cause injury. Innumerable factors contribute to risks—direct and indirect—that lead to harm and injury in a radiology department. Medicolegal considerations are a concern in any radiology department regardless of the equipment used. Ensuring that those working in the department are trained properly and have the appropriate qualifications can minimize risk. Physicians, physicists, and radiographers must have the required professional qualifications; informatics staff also must have qualifications that meet the needs of a department using digital equipment, PACS, and electronic health records systems. Adherence to user guidelines and ensuring department polices match those guidelines can decrease risk to the organization. Finally, radiographers are responsible for image quality. They must review each image from a medicolegal standpoint and adhere to the policies of their departments. To avoid litigation, radiographers must follow policies related to use of lead markers, patient information imbedded in an image, image quality, and exposure techniques.

Conclusion
Digital imaging brings a significant technological advancement to the radiology profession. Although the physical elements used to obtain a radiograph have not changed from the standard method of film-screen radiography, the mechanism used to capture x-rays and convert them into an image is mostly digital. Digital radiography provides advantages for department workflow, efficiency, and image quality. Although digital radiography introduces the problem of dose creep, a technologist’s commitment and adherence to departmental and organizational policies decreases the risk of unnecessary radiation exposure to the patient and possible litigation as it relates to this emerging technology.

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References


1. Image production and processing in radiography is dependent on which of the following?
   a. a patient's body habitus
   b. the mechanism used to capture attenuated rays
   c. technical factors selected by the radiographer
   d. the geographic region in which the examination took place

2. Many of the costs associated with storage and dissemination of film-screen radiographs:
   a. are based solely on the size of the system installed.
   b. increase dramatically following installation of equipment.
   c. are eliminated after transitioning to digital radiography and PACS.
   d. arise from extensive applications training.

3. Which of the following is referred to as the active layer of a computed radiography (CR) cassette?
   a. phosphor layer
   b. electroconductive layer
   c. support layer
   d. light shield

4. When does the latent image on a CR cassette begin to deteriorate?
   a. never
   b. almost immediately
   c. within a few days
   d. after one month

5. Limitations and disadvantages of CR include which of the following?
   1. Imaging plates are damaged easily.
   2. Spatial resolution typically is lower than with film-screen radiography.
   3. Cassette readers can introduce artifacts on images.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3
6. With direct and indirect digital radiography systems, the sensors used to detect attenuated x-rays are:
   a. housed in a portable film-based cassette.
   b. determined by patient size.
   c. enclosed in the body of the x-ray equipment.
   d. input into a reader to obtain the image.

7. Assuming appropriate technical factors have been set, ______ radiography creates images with the highest spatial resolution.
   a. film-screen
   b. computed
   c. indirect digital
   d. direct digital

8. Detective quantum efficiency (DQE) measures:
   a. how efficiently a detector converts x-ray energy into an image signal.
   b. the ability of a detector to transfer spatial resolution characteristics.
   c. radiation dose received by the patient during an examination.
   d. whether the technique used was adequate to obtain a quality image.

9. Which term is used when a technologist selects an exposure technique higher than necessary to avoid noise caused by underexposure in digital radiography?
   a. exposure indicator
   b. digital processing error
   c. dose creep
   d. DQE

10. The American Association of Physicists published a report in 2009 that recommended:
    1. radiography equipment manufacturers use consistent terminology and that a relevant exposure level indicator be established.
    2. radiology departments consider purchasing equipment from only one manufacturer to decrease technologist confusion regarding exposure indicators.
    3. that a deviation index number should be immediately displayed for the technologist to determine whether the radiographic technique was adequate.

11. All of the following are initiatives to prevent dose creep in a digital radiography department except:
    a. standardized technique charts.
    b. use of automatic exposure control when appropriate.
    c. quality management programs.
    d. postprocessing changes to the image to make it acceptable for interpretation.

12. The implementation of digital radiography into a department compels a manager to rethink workflow, rewrite job descriptions, and:
    a. focus on workplace culture.
    b. increase the number of radiologists.
    c. decrease the number of radiographers.
    d. eliminate competencies.