The American College of Radiology, with more than 30,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice guidelines and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice guidelines and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice guideline and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review, requiring the approval of the Commission on Quality and Safety as well as the ACR Board of Chancellors, the ACR Council Steering Committee, and the ACR Council. The practice guidelines and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice guideline and technical standard by those entities not providing these services is not authorized.

2007 (Resolution 42)*

ACR–AAPM–SIIM PRACTICE GUIDELINE FOR DIGITAL RADIOGRAPHY

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the guidelines, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in the guidelines when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the guidelines. However, a practitioner who employs an approach substantially different from these guidelines is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to these guidelines will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of these guidelines is to assist practitioners in achieving this objective.

KEYPOINTS

The intent of this document is to provide guidance and assistance in the understanding and clinical use of digital radiography equipment in order to deliver optimal image quality at appropriate radiation doses, and to ultimately provide excellent safety and care for patients undergoing digital radiography examinations. An introduction to the realm of digital radiography and its definition are presented in section I, followed by motivations for the paradigm shift from analog screen-film to digital imaging in section II. As new capabilities and complexities arise with digital imaging devices, the qualifications and responsibilities of personnel — including the physician, medical physicist, radiologist assistant, radiologic technologist, and image management specialist, — are affected as outlined in section III.

A large gap exists between the knowledge and experience of those who use analog screen-film and those who use digital radiography, and therefore a significant portion of the guideline (section IV) is devoted to image acquisition devices and image characteristics (subsection A), image data compression methods and concerns (subsection B), image transmission system environment (subsection C), image display device requirements and characteristics (subsection D), work or room environment (subsection E), archiving and retrieval (subsection F), security (subsection G), and reliability and redundancy (subsection H). A comparison of screen-film and digital detectors in subsection A.2 illustrates major differences, such as the wide latitude exhibited by digital devices and their ability to compensate for underexposures and overexposures with image preprocessing and postprocessing capabilities that are not possible with film. On the one hand, retakes

due to inappropriate exposure are reduced, but overexposures can easily be hidden as there is no direct feedback given by the image presentation.

Other advantages and limitations of digital radiography include the flexibility to postprocess the image and, in some detectors, the ability to reduce dose. Flexibility can also be a disadvantage due to the steep learning curve to understand the nuances of digital image acquisition, processing, and display and the disconnection between cause and effect (e.g., variations in radiographic technique do not elicit easily discernible variations in image presentation). In subsection A.3, factors affecting digital image quality are reviewed in some detail to provide a better understanding some detail to provide a better understanding of the characteristics of detection efficiency, dynamic range, spatial resolution, noise, and contrast resolution that are essential in the creation of the optimal image at a low dose. Digital detectors can be operated over a range of incident exposures, tailored to a specific examination, and in subsection A.4, speed class and exposure class as applied to digital radiography are described. The lack of feedback in a digital device and resultant image can lead to a phenomenon known as "dose creep," explained in subsection A.5, which in turn generates a need for exposure indicators for digital detectors as expressed in subsection A.6. The group most sensitive to radiation exposure is the pediatric population, so special concerns for digital radiography of infants and children are addressed in subsection A.7. Examinations such as portable bedside radiography that require manual techniques also require technique charts that are available to assist the technologist in performing these tasks, so in subsection A.8, methods to determine proper exposure factors are provided, and several examples in appendices B through F illustrate charts used by various institutions. In general radiographic rooms with automatic exposure control (AEC) devices, it is important to understand the nuances of their use with digital radiography devices, as discussed in subsection A9. Realizing that the total radiography system is only as good as the weakest link, significant attention is also devoted to guidelines for display requirements and characteristics in subsection D. Section V in the guideline deals with the details of documentation, section VI reviews the importance of radiation safety in imaging and the concept of "as low as reasonably achievable" (ALARA), and section VII discusses quality control procedures for performance monitoring, testing of digital radiographic equipment and displays, and implementation of a quality control program. Upon first installation of a digital radiography device, acceptance testing is strongly recommended (section VIII), and followup procedures and suggestions for written survey report documentation are given in section IX.

Finally, Appendix A presents a glossary that should be helpful in learning the lexicon and terminology common to digital radiography.

I. INTRODUCTION AND DEFINITION

This guideline was developed collaboratively by the American College of Radiology (ACR), the American Association of Physicists in Medicine (AAPM), and the Society for Imaging Informatics in Medicine (SIIM).

Increasingly, medical imaging and patient information are being managed utilizing digital data during acquisition, transmission, storage, display, interpretation, and consultation. The management of these data during each of these operations may have an impact on the quality of patient care.

"CR" and "DR" are the commonly used terms for digital radiography detectors. CR is the acronym for computed radiography, and DR is an acronym for digital radiography. CR uses a photostimulable storage phosphor that stores the latent image, which is subsequently processed using a stimulating laser beam. It can be easily adapted to a cassette-based system analogous to that used in screen-film (SF) radiography. Historically, the acronym DR has been used to describe a digital X-ray imaging system that reads the transmitted X-ray signal immediately after exposure with the detector in place.

There are several types of detectors that can be classified as DR systems, including automated (cassette-less) CR systems, and some DR systems that are adapted to a cassette-based X-ray system. Thus, the historical nomenclature becomes less relevant as technology advances, since distinct classification into the two broad categories of CR and DR is no longer possible. More appropriate is the distinction between "cassette-based" versus "cassette-less" operation. In this guideline, the term digital radiography will be used to refer to all types of digital radiographic systems, including those historically termed CR and those historically termed DR.

There are many ways to categorize the current state-of-the-art digital radiography technology. One categorization considers 1) form factor, 2) image acquisition time, and 3) X-ray signal conversion methodology. The concept of "cassette-based" versus "cassette-less" operation is defined using the term *form factor*. A cassette-based digital detector uses the SF paradigm that allows the use of existing imaging modality infrastructure and provides excellent positioning flexibility. On the other hand, labor-intensive handling of cassettes and the need to wait for the image, often with batch-mode processing, lead to a loss of time efficiency. Cassette-less operation indicates the ability to acquire the X-ray signal, and, without

subsequent user intervention, produce an image at a local workstation for review and manipulation.

By *image acquisition time*, a distinction is made regarding the ability to acquire an image nearly instantaneously over the full field of view (FOV) with a large area detector versus the sequential, long scan time acquisition of a slot scan device. *X-ray signal conversion* is the method by which the X-rays are converted to the output signal of interest; it is usually described as either an indirect or direct radiation detection scheme. All digital detectors produce an output signal, usually in the form of electrons that represent a quantity of charge corresponding to the number of X-rays absorbed in a given detector element (*del*) in the detector. The charge is then converted to a digital number value for storage in the image matrix. *Indirect* refers to the conversion of X-rays into secondary information carriers, such as light via a scintillator, prior to conversion to charge. *Direct* refers to the conversion of X-rays into electron/hole pairs and the direct collection of charge using semiconductors as the X-ray converter, without a secondary conversion event. Advantages and disadvantages can be ascribed to each of the digital detectors in these broad categories, which may be helpful when trying to determine the best solution for a given clinical task or imaging application.

This guideline is applicable to the practice of cassette-based and cassette-less digital radiography. It defines motivations, qualifications of personnel, equipment guidelines, data manipulation and management, and quality control and quality improvement procedures for the use of digital radiography that should result in high-quality radiological patient care. This guideline also includes a brief review of the differences between digital radiography and SF radiography in terms of imaging characteristics such as sensitivity, dynamic range, noise, and spatial resolution. A brief overview is provided of current receptor technologies available for the clinical practice of digital radiography, of display device capabilities, and of the requirements for the use of digital radiography in image interpretation. A glossary of commonly used terminology (Appendix A) and a reference list are included.

In all cases for which an ACR practice guideline or technical standard exists for the modality being used or the specific examination being performed, that guideline or standard will continue to apply when digital image data management systems are used.

II. MOTIVATIONS FOR USING DIGITAL RADIOGRAPHY

A. Motivations for the use of digital radiography in clinical practice include, but are not limited to:

1. The significantly larger range of X-ray intensities that can be imaged by digital receptors compared to analog systems.
2. Independence of displayed contrast from kVp setting through adjustment of the display window width.
3. Independence of displayed brightness from mAs setting through adjustment of the display window level.
4. The availability of image processing and computer aided detection (CAD) and diagnosis algorithms for image enhancement and analysis.
5. Easier and more reliable generation of accurately labeled and identified image data.
6. The ability to electronically transmit data to an appropriate storage medium from which it can be electronically retrieved for display for formal interpretation, review, and consultation.
7. The ability to transmit data to remote sites for consultation, review, or formal interpretation.

B. Components of the performance of high-quality digital radiography include, but are not limited to:

1. Development of validated imaging protocols so that consistency of image quality and radiation dose can be established and maintained between rooms and between sites.
2. Utilization of appropriate compression of image data to facilitate transmission or storage, without loss of clinically significant information.
3. Archiving of data to maintain accurate patient medical records in a form that may be retrieved in a timely fashion.
4. The ability to retrieve data from available prior imaging studies to be displayed for comparison with a current study.
5. The ability to apply image processing for better display of acquired information.
6. Adherence to applicable facility, state, and federal regulations.
7. Maintenance of patient confidentiality.
8. Minimization of the occurrence of poor image quality.
9. Minimization of the delivery of inappropriate ionizing radiation dose to patients.
10. Promotion of clinical efficiency and continuous quality improvement.

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

Individuals performing digital radiologic procedures must be appropriately trained in the proper use of the imaging equipment and must have the appropriate level of knowledge necessary to obtain optimal information for

each requested procedure. In all cases, the operator should be a physician, a radiologist assistant, a licensed and/or registered radiologic technologist, a radiation therapist, or a nuclear medicine technologist. The radiologist assistant, technologist, or radiation therapist must be under the direct supervision of a qualified licensed physician.

A. Physician

1. Physicians utilizing digital radiography should understand the basic technology of image acquisition, transmission, manipulation, processing, archival, retrieval, and display, including the strengths, weaknesses, and limitations. They should be knowledgeable in how to optimally utilize the image viewing equipment. Where appropriate, the interpreting physician must be familiar with the principles of radiation protection, the hazards of radiation exposure to both patients and radiological personnel, and patient and personnel monitoring requirements. The physician performing the official interpretation must be responsible for the quality of the images being reviewed and understand the elements of quality control of digital image management systems.[1]
2. The physician must demonstrate qualifications as delineated in the appropriate ACR Practice Guideline or Technical Standard for the particular diagnostic modality being interpreted.
3. The physician should have a working knowledge of those portions of the digital imaging chain from acquisition to display that affect image quality and that have the potential for producing artifacts.

B. Qualified Medical Physicist

A Qualified Medical Physicist shall be on site or available as a consultant.

A Qualified Medical Physicist is an individual who is competent to practice independently in one or more of the subfields in medical physics. The American College of Radiology considers certification and continuing education and experience in the appropriate subfield(s) to demonstrate that an individual is competent to practice one or more of the subfields in medical physics and to be a Qualified Medical Physicist. The ACR recommends that the individual be certified in the appropriate subfield(s) by the American Board of Radiology (ABR), the Canadian College of Physics in Medicine, or for MRI, by the American Board of Medical Physics (ABMP) in magnetic imaging resonance physics.

The appropriate subfields of medical physics for this standard are Diagnostic Radiological Physics and Radiological Physics.

A Qualified Medical Physicist should meet the ACR Practice Guideline for Continuing Medical Education (CME). (ACR Resolution 17, adopted in 1996 – revised 2008, Resolution 7)

C. Registered Radiologist Assistant

A registered radiologist assistant is an advanced level radiographer who is certified and registered as a radiologist assistant by the American Registry of Radiologic Technologists (ARRT) after having successfully completed an advanced academic program encompassing an ACR/ASRT (American Society of Radiologic Technologists) radiologist assistant curriculum and a radiologist-directed clinical preceptorship. Under radiologist supervision, the radiologist assistant may perform patient assessment, patient management and selected examinations as delineated in the Joint Policy Statement of the ACR and the ASRT titled "Radiologist Assistant: Roles and Responsibilities" and as allowed by state law. The radiologist assistant transmits to the supervising radiologists those observations that have a bearing on diagnosis. Performance of diagnostic interpretations remains outside the scope of practice of the radiologist assistant. (ACR Resolution 34, adopted in 2006)

D. Radiologic Technologist, Nuclear Medicine Technologist, and Radiation Oncology Therapist

The radiologic or nuclear medicine technologist or radiation therapist must be certified by the appropriate registry and/or possess unrestricted state licensure.

1. The technologist must meet the qualification requirements of any existing ACR guideline or standard for acquisition of a particular examination.
2. He or she must be trained to properly operate those portions of the image data management system with which he or she must routinely interact. This training should include as appropriate:
   a. Image acquisition technology
   b. Image processing protocols
   c. Proper selection of examination specific options
   d. Image evaluation

[1]The ACR Rules of Ethics state: "It is proper for a diagnostic radiologist to provide a consultative opinion on radiographs and other images regardless of their origin. A diagnostic radiologist should regularly interpret radiographs and other images only when the radiologist reasonably participates in the quality of medical imaging, utilization review, and matters of policy which affect the quality of patient care."

e. Radiation dose indicators
f. Patient safety procedures

E. Image Management Specialist

The image management specialist should be qualified to assess and provide problem-solving input, initiate repair, and coordinate system-wide maintenance programs to assure sustainable high image quality and system function. This individual should also be directly involved with any system expansion and archive programs.

This specialist, as well as any necessary support personnel, should be available in a timely manner in case of malfunction to facilitate return to optimal system functionality. The specifics of business continuance should be detailed in a document exchanged by the customer and the servicing agency, particularly if an outside support person or the vendor must be engaged to effect repairs.

IV. EQUIPMENT SPECIFICATIONS

Specifications for equipment utilized in digital image data management will vary depending on the application and the individual facility's needs, but in all cases should provide image quality and availability appropriate to the clinical needs, whether that need be official interpretation or secondary review.

To ensure the enterprise-wide availability of features and performance when purchasing digital radiographic and connected equipment, consideration of the manufacturers' statements of conformance with the current ACR-NEMA (National Electrical Manufacturers Association) Digital Imaging and Communications in Medicine (DICOM) standard is strongly recommended. Also consideration of periodic upgrades incorporating the expanding features of that standard should be part of the ongoing quality control program. Compliance with the Radiological Society of North America (RSNA) and Healthcare Information and the Management Systems Society (HIMSS) Integrating the Healthcare Enterprise (IHE) Initiative, as embodied in the available technical frameworks, is also strongly recommended for all new equipment acquisitions.

A. Acquisition

Image acquisition should be performed in accordance with the appropriate ACR modality or examination guideline or standard.

1. General requirements
   a. At the time of acquisition the system must have capabilities for capturing demographic as well as imaging information such as accession number, patient name, identification number, date and time of examination, name of facility or institution of acquisition, type of examination, patient or anatomic part orientation (e.g., right, left, superior, inferior), amount and method of data compression, and display of the total number of images acquired in the study. This information, except for the number of images acquired, must be associated with the images when transmitted. These fields should be formatted according to the DICOM standard.
   b. The ability to record patient date of birth, gender, and a brief patient history is recommended.
   c. The ability to record kVp, mA, exposure time, beam filtration, and radiation exposure indicator is imperative, particularly for cassette-based and cassette-less DRs that have a direct interface to the X-ray generator information. Use of the DICOM "DX" object is recommended instead of the more limited "CR" object for digital radiography [1]. It is also recommended that grayscale softcopy presentation state objects be used to transmit annotations, shutter, and display look-up tables (LUTs).[2].

2. Comparison of screen-film and digital receptors

   There are several fundamental differences between SF systems and digital (CR or DR) systems in terms of the physical processes involved in image acquisition. The different processes introduce different constraints on the factors determining image quality, such as spatial resolution, contrast, and noise. Here we briefly describe the basic operation of each system and then discuss the most important acquisition-related factors affecting image quality for each.
   a. Screen-film
      In SF radiography, an X-ray photon absorbed in the screen deposits energy which is converted into the production of multiple visible light photons that travel through the screen and, in turn, deposit energy in the film grains in the emulsion layer(s) of the film. The image information is stored in the film emulsion during an exposure through the accumulation of exposed grains. Regions of the film with a greater density of exposed grains have higher optical density and appear dark following film processing, and thus correspond to regions of greater X-ray absorption in the screen. However, the

relationship between optical density and the number of absorbed X-rays is nonlinear. For analog SF radiography, the acquisition, display, and storage of the image are intrinsically nonseparable. This means that acquisition techniques must be used that result in acceptable film darkening while at the same time maximizing image contrast. Since the range of acceptable optical density is limited by viewbox luminance and the response of the human visual system, maximization of image contrast occurs at the expense of exposure dynamic range. This is referred to as the exposure latitude (see glossary for further explanation) and it is quite narrow in SF radiography compared to digital radiography.

Limitations in SF radiography include narrow exposure latitude, the need for chemical processing, inefficient mechanical handling, incompatibility with electronic transmission and image enhancement, and higher costs for film materials and labor. Its chief advantages are high spatial resolution, consistency of image appearance, and the accumulated experience of radiologists, medical physicists, and technologists in using SF radiography in an optimal manner.

Screen-film images can be converted to a digital form using a film digitizer to produce an "equivalent" digital image. The characteristics of the output digitized image are chiefly those of the SF image, with its inherent advantages and disadvantages as listed above. There are two major digitizer types; one based on laser point scanning, using a light collection guide, the other based on optical line transmission scanning, using an array of charge-coupled devices (CCD) photosensors [3]. In general, the laser systems typically have more accurate conversion of high optical density values to corresponding grayscale digital values, and the CCD array scanners have a more reliable operation and higher resolution. Film digitizers should output the DICOM radiographic imaging (RG) information object descriptor with patient demographic data and acquisition method and must meet the minimum spatial frequency resolution requirements of 2.5 lp/mm at the film plane for conventional digital radiography images. In general, film digitizers introduce additional noise in the digital image, especially in regions of high optical density, and the effective output grayscale range is limited. Digitization and image processing of films in an attempt to overcome poor film image quality is not recommended.

b. Computed radiography

In photostimulable storage phosphor (CR) systems, X-ray photons are absorbed in the storage phosphor, also known as the imaging plate (IP). Unlike conventional screens, deposition of X-ray energy in storage phosphors results in the storage of a portion of the energy in highly localized, metastable areas called f-centers, which serve as energy wells. During an X-ray exposure, the image is built up in the phosphor through the accumulation of f-centers. Following the exposure, plate readers scan a (red) laser beam over the surface of the IP. In one implementation the laser beam sweeps across the IP (scan direction) and in combination with IP translation (subscan direction) the beam extracts the latent image from the IP. The plate reading time depends on the size of the detector and the scan speed of the reader. Some newer readers use a line-scan approach (the laser illumination on the plate is a line) rather than a point-scan approach to increase readout speed, but the principle is the same in both approaches. At each location, the energy of the incident laser photons triggers a de-excitation of the f-centers, resulting in the prompt emission of (indigo) light photons. A portion of these photons are detected by a photosensitive device (usually a photomultiplier tube [PMT] for point-scan readers or a linear solid state photodiode array for line-scan readers), whose output is then digitized and stored. Although the amount of photostimulated light detected is proportional to the number of f-centers and thus to the number of absorbed X-rays at that location (i.e., the relationship between the PMT signal and the number of absorbed X-rays is a linear one), nonlinear amplification of the PMT signal prior to digitization is typically employed. The resulting raw pixel values are subsequently processed for display using a combination of segmentation, rescaling, and filtering algorithms. The size of the image matrix is a function of the IP dimensions (18×24 cm, 24×30 cm, 35×35 cm, 35×43 cm, and custom sizes) and the pixel sampling pitch (typically 100 μm to 200 μm in general radiography). Typical output image sizes

vary from 8 to 16 MB for radiography, with a typical matrix size of approximately 2 k by 2.5 k pixels. A detailed description of technical issues associated with CR imaging is given in the report of AAPM Task Group 10 [4].

c. Digital radiography

DR systems encompass a number of different technologies that are rapidly evolving. At this time, the majority of DR systems utilize thin film transistor (TFT) arrays, commonly known as flat panel arrays. Recently, systems based on CCDs technology have been introduced for general purpose and chest radiography, using either scanned, slot shaped detectors [5-7], a single CCD, or tiled arrays of CCDs optically coupled to larger area X-ray-to-light converters. TFT arrays are composed of a matrix of discrete detector elements (*dels*), each of which contains a transistor. The transistors operate as gates. When turned off, electric charge cannot flow; when turned on it can flow. During an X-ray exposure, the gates are turned off, and the image is built up in the dels in the form of electric charge, with the amount of charge in each del proportional to the number of X-rays absorbed in that region of the detector (again, a linear relationship).

The means by which X-ray energy is converted to stored electrical charge varies somewhat between manufacturers but can be broadly classified according to whether it involves an intermediate conversion of X-ray energy to visible photons (indirect flat panel devices) or not (direct flat panel devices). In an indirect device, an X-ray-to-light converter, similar to that used in SF imaging, is placed in contact with the TFT array. Each del of the TFT array contains a light sensor (a photodiode) to convert the fluorescent light to stored electric charge. In a direct device, a layer of material is deposited directly onto the TFT array. When an X-ray photon is absorbed in this *photoconductor* material, an electric charge is generated and collected in the dels of the TFT array. For both indirect and direct flat panel detectors, following the X-ray exposure the TFT array gates are turned on one row at a time, and the amount of charge stored in each del of that row is transferred through “drain” lines to a row of charge amplifiers at the edge of the array for digitization and storage. The entire detector is read out by successively turning on all of the rows in a sequential fashion, and storing the digital data in corresponding locations in the output digital image matrix.

d. Advantages and limitations of computed radiography and digital radiography

The main limitations of CR and DR are higher initial cost (especially for DR), lack of familiarity on the part of both radiologists and technologists with electronic image display and with on-line softcopy reading (versus alternator-based batch mode reading), and the lack of consistent feedback to the technologist concerning the use of optimal acquisition techniques. The latter problem, along with the much larger dynamic range of digital systems, has led to a gradual increase in patient radiation dose, an issue discussed in more detail below [8-10].

Advantages of CR and DR include separation of acquisition, display, and archiving, which allows tremendous flexibility using image processing functions such as those that adjust the level (analogous to the brightness) and window width (analogous to the contrast) of the image grayscale presentation. However, display contrast is limited by the inherent image signal-to-noise ratio (SNR), because as the signal contrast is increased, so is the visibility of the noise. Other advantages include, anatomy-specific presentation and disease-specific algorithms; in most but not all cases better X-ray detection efficiency and higher detective quantum efficiency (DQE) permitting lower dose to the patient; the ability to use a second “computer reader” to assist the radiologist; reduction in the number of image retakes due to under or overexposure; and elimination of labor-intensive handling and distribution of images during the acquisition process.

3. Factors affecting image quality

Just as with SF radiography, there are a number of factors that impact the quality of the image in digital radiography. Contrast, detail, and noise are the primary factors we associate with image quality, and they play a major role in CR and DR. There are some additional factors that are the result of the digital nature of the process, and they are discussed below.

a. Detection efficiency

For SF, CR, and DR, the efficiency with which incident X-rays are absorbed is determined by the absorber's thickness, density, and composition. Efficiency can be increased by increasing material density or absorber thickness (usually at the expense of spatial resolution), or through incorporating materials having atomic numbers that provide a good match between the X-ray spectrum coming out of a patient and the absorption characteristics of the material [4].

b. Dynamic range

In digital chest radiography, the ratio of the maximum to minimum X-ray exposures incident on the detector surface is greater than 100:1 [11]. For high quality digital radiography, the receptor must be able to maintain good contrast resolution over this range. The dynamic range of an imaging system is the ratio of the largest and smallest input intensities that can be imaged. For all systems, the smallest useful intensity is determined by the intrinsic system noise. The signal must be large enough to exceed this noise, combined with the X-ray quantum noise. The largest intensity is determined by receptor saturation. The dynamic range of SF systems, often referred to as the latitude, is determined by the loss of contrast at low and high exposure levels (the toe and shoulder, respectively, of the H&D curve). For SF systems, the dynamic range depends on the screen and film characteristics, ranging from approximately 10 to 100 [11]. By comparison, the response curve of CR systems is linear (the photostimulated light output is directly proportional to X-ray exposure) over approximately four orders of magnitude (a ratio of 10,000:1) [4].

The dynamic range of DR systems is determined at the low end by the system noise and at the high end by the charge holding capacity of the dels. When this capacity is filled, the detector must be read out to remove the charge before any subsequent exposure. The dynamic range of typical TFT arrays used in general radiography, with del size of 150 - 200 microns, is approximately three to four orders of magnitude (a ratio of 1,000:1 to 10,000:1) [12,13].

c. Spatial sampling

All digital detectors sample the continuously varying X-ray fluence at their input at discrete locations separated by some interval called the sampling *pitch*. In CR systems, the sampling pitch is the distance between adjacent laser beam positions during plate readout. In DR systems, the pitch is the center-to-center spacing between dels. The spatial frequency at which sampling occurs determines how well high frequency fluctuations in X-ray fluence (those that occur over short distances in the imaging plane) are imaged by the digital system.

The sampling frequency of a system with sampling pitch p is 1/p. For example, if the pitch is 100 microns (=1/10 mm), the sampling frequency is 10 per mm (10 mm^{-1}). The highest spatial frequency in the incident X-ray fluence that can be reliably imaged (the Nyquist frequency) is one half of the sampling frequency, or 1/(2p). Thus a system with 100 micron pitch can image frequencies up to 5 cycles per millimeter.

If the X-ray fluence incident on the receptor contains information at frequencies higher than the Nyquist frequency and the presampling modulation transfer function (MTF) is nonvanishing at these frequencies, false image signals may occur at low frequency. This phenomenon, called *aliasing*, produces large-scale artifacts in the image and reduces our ability to see fine details in the image.

d. Spatial resolution

Spatial resolution is the ability of an imaging system to allow two adjacent structures to be visualized as being separate, or the distinctness of an edge in the image (i.e., sharpness). Spatial resolution losses occur because of blurring caused by geometric factors (e.g., the size of the X-ray tube focal spot, light diffusion in the receptor), detector element effective aperture size, and motion of the patient relative to the X-ray source and image receptor.

Spatial resolution is measured by subjective or objective methods. Subjective measurement is achieved with a bar pattern of alternating radio-opaque bars and radiolucent spaces of equal width, imaged to determine the limiting resolution in line pairs per unit of distance, usually expressed

in units of lp/mm. Intrinsic detector resolution is measured by fixing the bar pattern to the receptor surface to eliminate focal spot blurring. System resolution (including the effects of the focal spot blur) is measured with a bar pattern placed at a clinically relevant distance above the receptor.

For digital systems, the resolution may be different in the row and column directions, often requiring separate evaluations. The limiting resolution is the frequency at which the bars and spaces can no longer be visualized. Objective measurements by MTF are obtained by measuring the transfer of signal amplitude (contrast) of sinusoidal patterns (of various frequencies) from incident X-rays to the output. The system MTF is determined by the product of the individual MTF components along the signal chain. The system MTF can be measured by imaging a test object containing a narrow slit or a sharp edge. For most DR examinations (except possibly digital fluoroscopy) a limiting system spatial resolution of at least 2.5 mm^{-1} is essential and higher resolution is desirable for specialized applications (e.g., 5.0 mm^{-1}).

i. In SF imaging, spatial resolution is determined primarily by the thickness of the screen, since the light produced when an X-ray photon is absorbed is emitted in all directions from that point. Thicker screens provide more distance for the light to spread before reaching the film and have poorer spatial resolution. The film has very high resolution and is not responsible for spatial resolution degradation. A conventional 400 speed SF system for general radiography has a spatial resolution limit (the smallest visible set of bars in a bar pattern image) of approximately 7 line pairs per millimeter (7 mm^{-1}). In mammography, where very thin screens are employed, the limiting resolution is often greater than 15 mm^{-1}.

ii. In CR imaging, the primary source of spatial resolution loss is due to the scattering of the laser light beam during image plate readout. Laser light scatter results in de-excitation of locations in the phosphor that are somewhat larger than the size of the laser beam, and potentially larger than the separation between laser positions. As a result, the actual blur extends beyond the pixel size. Since thicker phosphors result in a greater scattering depth and more blur, CR systems have been introduced that permit the plate to be read from both sides [12]. Also, CR systems with a structured crystalline geometry allow a greater thickness and enhanced detection efficiency without the corresponding loss of spatial resolution [14].

iii. Spatial resolution in DR systems depends primarily on two factors. The first factor for indirect systems is the spread of light photons in the X-ray to light conversion process, and this can be important. It results in blurring similar to that described above due to the spread of photons within the screen of an SF system. To minimize visible photon spread, several manufacturers of indirect DR systems use *structured converters*, in which the converter material (usually cesium iodide) is formed into narrow, parallel columnar structures, oriented so that the X-ray photons are incident along the long dimension of the columns. The advantage of this structure is that the majority of the light exiting the converter onto the TFT array has been internally reflected along the length of the columns. The internal reflection process thus confines the light photons to a region close to the actual location of the X-ray absorption. This approach permits improved absorption efficiency through thicker absorbers (longer columns) without as much spatial resolution degradation as seen in unstructured converters constructed using the same thickness. Direct conversion DR systems do not suffer from this effect, because the spread of the electrons within the photoconductor material as they are accelerated towards the TFT array is minimal.

The second factor affecting spatial resolution in DR is the size of the del itself. Since all X-rays absorbed within a single del during an exposure contribute to a single quantity (the summed charge read from that del),

there is no way to distinguish different absorption locations within a del. Therefore, structures in the patient smaller than the del size are smeared out, and their contrast is reduced (this is known as the partial volume effect). Such structures may thus be undetectable unless they are inherently high contrast objects (e.g., a micro-calcification smaller than a del may be recognized as a calcification because its attenuation properties are so different from those of the other tissue in the del).

e. Noise

In radiography, noise can be defined as any fluctuations in the image that do not correspond to variations in the X-ray attenuation of the object being imaged. Image noise is typically measured by illuminating the receptor with a uniform X-ray fluence, then measuring the variance (the square of the standard deviation) in selected regions of the resulting image. A more informative measure of noise can be obtained by estimating the noise power spectrum (NPS), which characterizes the spatial frequency dependence of the noise [15]. Knowledge of the frequency response of noise in an imaging system is important because there are a number of additional noise sources in DR, such as aliasing and electronic noise that are not present in SF systems.

i. Ideally, image noise is dominated by the X-ray quantum noise. However, all image receptors contain some internal sources of noise. Random noise (noise not correlated with particular locations on the receptor) typically cannot be corrected for, and it adds to the random noise of the X-ray quanta. Examples of random noise include film granularity noise in SF and electronic noise in CR and DR. Internal noise that has a fixed correlation to locations on the receptor is called fixed-pattern noise. Sources of fixed-pattern noise include spatial variation in screen thickness in SF, position-dependent light collection efficiency in CR plate readers, and variations among preamplifier gains in DR.

One advantage of digital imaging is that fixed-pattern noise can be largely eliminated through digital post-processing. This is typically performed by obtaining a set of nominally identical images using a uniform X-ray flood field. Averaging the flood images results in a single image in which the magnitude of the X-ray noise is small compared to the magnitude of the fixed pattern noise. This image is stored and used as a map to remove the fixed pattern noise from all subsequent images in a process called flat fielding.

Detector artifacts are common in digital systems as a result of spatial variations in the sensitivity of the receptor, causing the image to have structure that is unrelated to the tissues. Bad dels, typically aligned in columns and rows, may occur during the manufacturing process. The locations of such point and line defects are typically identified and stored, and adjacent neighbor response values are averaged and used as a substitute value for the missing data. The number and proximity of detector defects that are allowable without affecting image quality remain to be specified.

ii. Digitization of the analog detector output voltage to form discrete pixel values introduces a type of noise called quantization noise. Digital imaging systems use an analog to digital converter (ADC) to sample and quantize the image data. The maximum number of grayscale values that can be encoded is equal to 2^N bits. For example, an 8 bit ADC encodes 2^8 or 256 discrete digital values over the signal amplitude range (these values are often called ADUs - analog to digital units). An insufficient number of quantization steps will introduce signal encoding errors that increase the quantization noise. Digital detectors for projection radiography typically use from 10 bits to 14 bits (1,024 to 16,384 unique ADUs) in the output image to keep quantization noise small. Some systems use nonlinear (e.g., logarithmic) amplification prior to digitization, which can further reduce the quantization error, particularly in the low output signal response range of the detector [16].

iii. Scatter radiation is another source of image degradation in radiography, and

it acts in the same manner as other noise sources. Scatter reduces the available dynamic range of X-ray intensities at the exit side of the patient. The primary effect of scatter is a reduction of subject contrast. It also decreases the SNR because it contains no signal but does contain Poisson quantum noise. Scanned slot DR detectors possess inherent scatter rejection capability and do not require the use of a grid.

Area detectors employed in CR, DR, and SF radiography should be used with an antiscatter grid in clinical imaging situations where scatter dominates (usually patient thicknesses in excess of 10 cm). They are often not used with pediatric and extremity imaging. The use of grids is especially important in CR because of the increased scatter sensitivity of barium halide (k-edge approximately 35 keV) compared to SF screens such as gadolinium oxysulfide (k-edge approximately 50 keV) [4]. When using the stationary grids (e.g., snap-on grids [also known as grid caps, portable grids]) used in portable X-ray and for lateral tabletop exposures), consider the use of high frequency grid strips of >60 lines/cm (152 lines/inch) to avoid grid aliasing patterns caused by insufficient sampling. Consultation with the vendor for an appropriate grid is recommended.

When using scatter grids with digital detectors, an increase in exposure technique (mAs) is necessary only because of incomplete transmission of the primary radiation by the grid in order to compensate for a decrease in the SNR ratio. This is different than in SF radiography, where compensation is required for removal of both primary and scattered radiation in order to achieve the correct film optical density range. For this reason, adjustment of radiographic technique upward according to the Bucky factor (defined as the increase in exposure required to obtain the same optical density as with no grid) may likely overestimate the appropriate technique increase for digital receptors.

f. Contrast resolution

Contrast resolution (radiographic contrast) refers to the magnitude of the signal difference between the structure of interest and its surroundings in the displayed image. It is expressed in terms of the optical density difference between two adjacent areas on an SF image or as the relative brightness difference between the corresponding areas in a digital image displayed on a monitor. For both SF and digital imaging, radiographic contrast is influenced by subject contrast and receptor sensitivity. However, in digital imaging, contrast in the displayed image can also be altered by adjustment of display parameters independent of the acquisition parameters.

Subject contrast is the relative difference in X-ray exposure on the exit side of the patient and is the result of the attenuating properties of the tissues under study. Attenuation is strongly dependent on the X-ray energy spectrum and is determined by the target material, kV, and total beam filtration. Subject contrast is further reduced by the presence of scatter. Receptor sensitivity is defined as the amount by which the output (optical density for SF or ADU value for CR and DR) changes per unit change in exposure to the receptor. In digital detector design, sensitivity can, to a certain extent, be selected through electronic gain settings, but this must be done with an awareness of the range of exposures that must be simultaneously measured, taking into account the detector response energy dependence. With a properly designed image acquisition system, the dynamic range should be adequate to measure the entire range of intensities from that of the unattenuated beam outside the patient to that through the densest, thickest part of the anatomy. The signal stored in digital form is directly (or logarithmically) proportional to the amount of radiation transmitted through the patient. For this reason, the stored “for-processing” image reflects the inherent subject contrast very faithfully, provided the image receptor is operated in the linear (or log-linear) portion of its response curve.

For CR and DR, image processing (usually proprietary to the device’s manufacturer and not under control of the radiologist) is used to determine display contrast by establishing

the relationship between raw pixel values and grayscale levels. This produces the final "for presentation" image for interpretation on either hardcopy film or softcopy displays. Discussion of image processing, including contrast enhancement and spatial frequency processing, is presented in subsequent sections.

g. Detective quantum efficiency

The detective quantum efficiency (DQE) is a useful descriptor of image receptor performance because it takes into account detection efficiency, spatial resolution, and noise. DQE describes the relative efficiency in maintaining the SNR level available in the imaging process, and is defined as $\frac{SNR^2_{out}}{SNR^2_{in}}$, where the SNR^2_{in} is the SNR of the exposure incident on the receptor, numerically equal to the input fluence. The SNR is the ratio of the relative magnitudes of the image signal to the noise. Thus, DQE can be considered the system's SNR transfer efficiency. Efficient SNR transfer is important because the detection performance of both human and ideal observers improves with increasing SNR [17-21].

DQE is generally plotted versus spatial frequency, DQE (*f*). A perfect system has a DQE (*f*) of unity at all spatial frequencies. Real systems lose efficiency at higher spatial frequencies because of decreasing spatial resolution and increasing noise sources. DQE (*f*) is determined by quantitative measurements of the modulation transfer function, MTF(*f*), to determine the spatial resolution and the noise-power spectrum, NPS(*f*), to determine the noise characteristics, both as a function of spatial frequency, using an accurately known input exposure to the detector. The exposure required to achieve a given SNR in the image is inversely related to the system DQE. Therefore, systems with higher DQE require less exposure for a given image quality (SNR) than do systems with lower DQE [22]. DQE is important in CR and DR because these technologies can offer significantly improved DQEs compared to SF systems.

4. Speed class and exposure class

SF based image receptors utilize a standardized speed class related to the exposure required to obtain an appropriately exposed radiograph. Typically, 100, 200, and 400 speed (or higher) SF systems are used clinically. Many digital radiography systems are designed with a means to provide an estimate of the incident exposure based on a similar concept and have adopted the "speed class" nomenclature. At least one digital radiography vendor employs a similar index called "exposure class". Neither "speed class" nor "exposure class" is exactly equivalent to "speed" since the energy sensitivity of CR and DR is quite different than that of SF. Nevertheless, with current usage, the most widely used is speed class.

Digital radiography systems can be operated with speed classes higher than that conventionally used in SF. Film-based imaging provides immediate feedback to the technologist and radiologist concerning the delivery of the proper radiation exposure to the patient. If the optical densities in the film image are too great, the patient received too much radiation relative to the proper value, while reduced optical densities indicates a reduced radiation exposure.

When digital image receptors replace SF image receptors, the brightness and contrast in the displayed image on the monitor are independent of the exposure used during acquisition. Only the noise in the image changes with the exposure. Radiologists react negatively to digital images with excessive noise (low patient exposure), but rarely complain about images with reduced noise due to excessive patient exposures. This leads to the potential for dose creep in CR and DR.

5. Dose creep in CR/DR and its prevention

Dose creep results from the gradual increase in patient exposure over time after digital image receptors replace conventional SF systems [8]. It occurs because an increase in radiation dose decreases noise in images and reduces the number of complaints by radiologists about image quality. Technologists quickly recognize this and gradually increase patient doses by adjusting radiographic techniques upward. The qualified medical physicist should monitor for dose creep on a consistent, ongoing basis, as it is a recurring phenomenon.

One effective way to eliminate dose creep is to develop validated radiographic technique charts for all performed examinations as a function of patient size. If these factors are entered into the anatomical programming of state-of-the-art X-

ray generator controls, the technologist simply selects the radiological examination and patient size at the beginning of the case and is assured the use of standard radiographic technique factors and standard radiation exposure regardless of whether the examination is conducted with the image receptor on the tabletop with manual techniques or in the Bucky tray using the automatic exposure control [23].

6. Exposure indicators for digital radiography

Currently, most CR manufacturers provide an exposure indicator on images displayed on the image reader workstation. However, this information may not be transferred over to the Picture Archiving and Communication System (PACS) or may appear buried in the DICOM information page of the patient. Most PACS systems can display the exposure indicator on the image. Check with your PACS vendor and insist that this information be displayed on each image. Today, the various numerical exposure indicators used by the different CR manufacturers are not easily comparable. To compound the problem further, most DR manufacturers do not provide an exposure indicator on their processed images, or the information is not transferred to PACS and is not recoverable.

The AAPM formed Task Group 116 to address the lack of a uniform exposure indicator on digital radiography images. Its report, "Recommended Exposure Indicator for Digital Radiography," defines standardized radiation exposure conditions from which a relative exposure indicator can be defined. Since the major manufacturers of digital radiographic image receptors participated on the task group, this standardized exposure indicator should migrate into their future products. See "exposure latitude" in Appendix A – Glossary for more information. Appendix B of this report summarizes several of the exposure indices currently used by different manufacturers.

7. Pediatric imaging issues

As with all imaging examinations involving ionizing radiation, CR and DR should be performed using the lowest possible radiation exposure to the patient (ALARA [as low as reasonably achievable]), especially pediatric patients who are believed to be up to 10 times more sensitive to ionizing radiation than adults [23-24], additional care should be taken to minimize patient dose. This suggests that the exposure delivered to the digital image receptor should be approximately 0.4 to 0.8 mR for chest and abdominal examinations [24]. However, adopting a policy of reduced exposure levels to the image receptor to achieve ALARA in pediatric imaging increases the possibility of unacceptably high quantum noise, and thus reduces the margin for error in selecting the parameters that affect the beam quality. Also, the achievable reduction in exposure at the plate depends on how well the digital system is optimized for pediatric imaging, and on the nature of the particular disease being diagnosed [25].

Commitment and effort on the part of staff are required to achieve ALARA in pediatric imaging. First, the multiple X-ray machines of a given type in a department require validation, calibration, and matching to insure the same exposure for similar radiographic technique parameters. The actual exposure required to produce clinically acceptable images for a given digital receptor is a function of the digital receptor's DQE. The goal is to produce similar image quality in all images regardless of the device chosen and regardless of the size of the pediatric patient. Second, all CR readers and/or DR image receptors should be adjusted to provide a uniform response to the recorded X-ray image pattern in space. Third, all monitors on all diagnostic display workstations should be tested and calibrated to provide a uniform appearance of displayed images. These topics are addressed in more detail elsewhere [26].

Pediatric patients provide unique challenges when imaged with digital radiography. Uncooperative pediatric patients may require sedation or anesthesia. The range in size from the neonate to the young adult patient requires a wide range in radiographic technique factors and a digital image receptor that properly processes an X-ray pattern in space that may or may not cover the entire image receptor. The decision to use an anti-scatter grid must be carefully considered as a function of patient size. Standard positioning aids used to immobilize pediatric patients may generate unacceptable artifacts when used with digital image receptors. Since the X-ray pattern from a pediatric chest compared to an adult chest, for example, has a different dynamic range and other characteristics [23], display parameters used by the digital

acquisition device to properly display the digital image may need to be unique as a function of patient size. Display parameters require further alteration if gonadal shielding or orthopedic implants appear in the displayed image. Finally, since scoliosis examinations are common in children, the digital image receptor must provide an efficient method to generate images up to 36 inches in length without doubly exposing some sections of the patient's anatomy.

8. Determining proper exposure factors for standard examinations

Exposure (technique) charts are part of the standard of care expected by the Joint Commission and are required in many states. For example, in Ohio, exposure charts are required and must include specification of the body part, thickness, and image receptor components to be used for the procedure. Internationally, most countries require regular use of exposure charts. It is necessary to check county, state, and/or local regulations for any specific requirements. It may also be required to compute estimates for entrance skin exposures for these charts. This is relatively simple to implement using a spreadsheet based on the exposure charts for an individual practice.

Exposure charts are an essential quality assurance component of any diagnostic X-ray imaging department. They are especially important in CR and DR, where the wide exposure latitude makes it possible to obtain clinical images that are severely underexposed, resulting in noisy images, or grossly overexposed, resulting in possible data saturation as well as high patient doses. Improper exposures in digital radiography are more likely to go unnoticed since image processing can correct these deficiencies to a much greater degree than SF systems can due to the wide latitude of the image receptor. Exposure charts are critical in the portable X-ray environment with CR, since manual technique factors are normally required. An underexposed radiograph will have unacceptable noise, while an overexposed radiograph may appear to be of exceptional quality at the expense of patient dose.

The first challenge is to understand what constitutes a properly exposed radiograph [27-29]. In SF systems, the limited dynamic range of the film determines the exposure latitude. In the digital world, wider exposure latitude is permitted, to take into account the differing energy responses of the systems and the variability introduced in the dose estimation scheme.

Appendix B provides a suggested range of exposures to facilitate identifying whether or not a proper radiograph has been obtained. The lgM, S-Number Exposure Index and S-Value are representative exposure indicators used by several CR vendors. If a particular system's exposure indicator is different, the detector exposure column can be used as a guide. Note that it is recommended not to repeat overexposures unless information has been lost.

At the low dose end of the scale, it is important for the radiologist and technologist to review underexposed radiographs to develop a comfort level for which radiographs need to be repeated. It is useful to provide some guidance to the technologist with respect to how to correct an improperly exposed radiograph (see Appendix C).

Exposure charts must be tailored for each DR X-ray system and detector combination [30]. There is considerable variability in image receptor response due to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size. Many CR/DR systems also permit the choice of several exposure (speed) classes. Technique factors for each clinically used speed class should be constructed. In addition, exposure charts should be designed to function over the wide range of adult patient sizes seen in our clinics today, and over the even wider range for pediatric applications.

Given a table of body part thicknesses with suggested technique factors, one can derive, using a spreadsheet program, a full table of values using knowledge of the effect of thickness and kVp on the penetration of the beam. There are also several commercial programs that can be tailored to DR. Typically; the entire exposure chart is calibrated to a single set of exposures based on a common body part like the abdomen. A water tank or anthropomorphic phantom can be used to develop appropriate techniques for the abdomen radiograph**.** Water works better than acrylic or aluminum because the scatter characteristics are more comparable to the clinical situation. As discussed previously, scatter characteristics can be quite different for

DR than for SF. It is also necessary to measure grid transmission factors (see section IV, A, 3, e, iii) for the undertable and wall Bucky assemblies as well as for any snap-on grids that may be used with the X-ray machine. Once the exposure factors have been determined that result in an appropriate radiograph for the abdomen with the various image receptors, all other mAs values are interpolated using corrections for distance, Bucky factors, speed class, patient thickness and machine output. The exposure chart is then cleaned up by rounding mAs values to match available mAs stations on the machine. An example of an exposure chart developed for CR is shown in Appendix D.

Similar exposure charts should be constructed for the use of portable X-ray equipment. The X-ray output of a portable radiography unit is generally substantially lower than that of a three-phase or high frequency stationary X-ray machine. This reduced output capability results in increased exposure times compared to conventional radiography. As a result, patient motion is a common image degradation factor. This factor, coupled with the difficulty in positioning grids correctly in a portable setting, results in frequent exposures being taken without the use of a grid, also degrading overall image quality. Manual techniques are used since phototimers are usually not available in the portable setting. An example of an exposure chart suitable for portable radiography in an emergency department trauma setting is shown in Appendix E.

Another issue to consider, particularly for portable radiography, is achieving reproducible image quality for repeated studies such as portable chest images that are used for radiographic detection and evidence of incremental changes. Important for the radiologist is *consistent acquisition techniques* by the technologist, including kVp, mAs, geometry (source-to-image distance (SID), patient positioning), orientation of imaging receptor cassette, use of a grid, technologist positioning markers, and consistent use of image processing parameters that are optimized for the specific study. Acquisition protocols and technique charts with minimal parameters and variables (e.g., using crosswise image acquisition for all adult chests with decubitus grids, using a fixed SID of 127 cm [50 inches], 110 kVp, and adjusting only mAs as a function of estimated patient girth) are key to establishing the desired reproducibility of image presentation (orientation, magnification, image enhancement) on the radiologist display workstation. An example of an exposure chart specifying these requirements for adult chest portable imaging and other adult examinations is shown in Appendix F.

9. Automatic exposure control

In CR, phototimers are frequently employed with wall and undertable Buckys in emergency, inpatient and outpatient radiology department settings. These automatic exposure control (AEC) units are designed to turn off the X-ray generator when an appropriate exposure level has been received at the image receptor. AECs work well if properly calibrated and properly positioned over clinically important areas of the patient. They fail if placed incorrectly or if pathology in the AEC region of interest causes a significantly different density than expected.

AEC devices are energy dependent and may require calibration at multiple kVps to function properly over a wide range of patient sizes. Some X-ray generators have preprogrammed energy response curves, and these units may not work as well with CR as with conventional SF receptors since they were probably manufactured to be matched to typical SF energy and scatter characteristics. In this situation, calibrate the wall Bucky for chest work and the undertable Bucky for abdomen procedures or whatever is the most common procedure performed on that image receptor at your institution.

In DR, the AEC is normally built into the image receptor assembly, and it works in a manner similar to the phototimers used in SF radiography. However, the number or area or the photosensitive elements may differ from the configurations normally used with conventional SF systems, depending on vendor implementation.

Most X-ray generator phototimers are designed to be calibrated for multiple image receptor speeds, usually designated by names such as regular, chest, and detail cassettes. AECs can be calibrated to multiple speed classes such as 400, 200, and 100 to cover a variety of different CR/DR receptors and/or specific clinical situations like pediatrics [31-32]. Some CR vendors permit a variety of speed classes in their software, so the speed class on the X-ray console

must be manually selected to match the speed class appropriate for that procedure. This can lead to errors if technologists are not vigilant in matching the X-ray generator speed class to the CR reader speed class.

With some implementations of CR, the AEC unit must be calibrated based on cassette size instead of speed class. Check with the vendor to know which method is most appropriate. In DR, the speed class may also be user selectable, and it is necessary to be vigilant to insure that technologists are using the appropriate speed classes, especially for pediatrics. It is usually set automatically in DR systems with an integral X-ray tube assembly.

B. Data Compression

Data compression may be performed to facilitate transmission and storage. The type of medical image, the modality, and the objective of the study will determine the degree of acceptable compression. Several methods, including both reversible (lossless) and irreversible (lossy) techniques, may be used under the direction of a qualified physician or practitioner, with minimal, if any, reduction in clinical diagnostic image quality. If compression is used, algorithms recommended by the DICOM standard should be employed, including wavelet compression methods such as JPEG-2000. The types and ratios of compression used for different imaging studies transmitted and stored by the system should be selected and periodically reviewed by the responsible physician to ensure that appropriate clinical image quality is being retained in the compressed images. Some regulatory agencies require that the compression ratio used be indicated on the compressed image. (See the ACR–SIIM Practice Guideline for Electronic Medical Information Privacy and Security.)

C. Data Transmission

The environment in which the studies are to be transmitted will determine the type and specifications of the transmission devices used. In all cases, for official interpretation, the digital data received at the end of any transmission must have minimal loss of clinically significant information. The transmission system must also have adequate error-checking capability. (See the ACR–SIIM Practice Guideline for Electronic Medical Information Privacy and Security.)

The DICOM Transmission and Storage Standard should be referred to for best practice implementation. Ideally, all vendors should use the DICOM DX Image Information Object for digital radiography so there is consistency between all vendor implementations.

D. Display Capabilities

There are two different guidelines for display devices, depending on the image size used for rendering the official interpretation: small matrix size (e.g., computed tomography [CT], magnetic resonance imaging [MRI], ultrasound, nuclear medicine, digital fluorography, and digital angiography) and large matrix size (e.g., digital radiography, digitized radiographic films, and digital mammography). This guideline reviews only the use of large matrix size images and does not include digital mammography. Specific guidelines for digital mammography can be found in the ACR–AAPM–SIIM Practice Guideline for Determinants of Image Quality in Digital Mammography. The present guidelines apply to primary displays, which are those used for the official diagnostic interpretation. Secondary radiographic image displays (e.g., those used by nonradiologists, technologists, and clinical staff) do not need to adhere to these specific guidelines provided the displays are not used for official interpretation purposes.

1. Display workstations used for official interpretation of digital radiographs should be capable of the following:
   a. The ratio of maximum luminance to the minimum luminance of a display device for images should be at least 50. Maximum luminance of grayscale monitors used for viewing digital conventional radiographs should be at least 171 cd/m^2. The contribution of ambient light reflected from the display surface should be included in luminance measurement considerations since some level of ambient light is always present.
   b. The contrast response of the display should comply with the AAPM Task Group 18 recommendations [33]. Contrast response should not deviate from the DICOM Grayscale Standard Display Function (GSDF) contrast values by more than 10%.
   c. A minimum of 8 bit luminance resolution (bit depth) is required. Nine-bit or higher is recommended if the “for presentation” image data is greater than 8 bits in depth. In general, the higher the luminance ratio of the display, the larger the bit-depth resolution that is advised.
   d. An ability to select the image sequence and the preferred display format should be available. Hanging protocols should be flexible and tailored to user preferences with proper labeling and orientation of images. Fast and easy navigation between new and old studies should be feasible.

e. Accurately associating the patient and study demographic information with the images of the study performed is essential.
f. Window and level adjustment tools must be available, since the full dynamic range of most images cannot be displayed on most digital devices. Preset window/level settings are recommended to improve ease of use.
g. Zoom (magnification) and pan (roaming) functions capable of meeting guidelines for display at the originally acquired spatial resolutions should be used rather than requiring the user to move closer to the display.
h. Image rotation and flipping tools are essential. Following this operation, image labeling should be preserved.
i. Calculating and displaying accurate linear measurements, region of interest and pixel value determinations (mean and standard deviation) should be possible using units appropriate for the modality, if those data are available and can be accurately calibrated to the acquisition device.
j. It should be possible to display prior application of irreversible compression ratio, processing, or cropping.
k. All the images acquired in the study need to be fully accessible during interpretation. Although they need not all be displayed simultaneously, the use of dual monitors to display more images is desirable.
l. Clinically relevant technical parameters of the acquired image data should be accessible (e.g., mAs, kV, bit depth, exposure time, and matrix size). It is imperative that the *exposure value* (see glossary), if available, be displayed on the PACS image in order to assess technique for dose, quality, and feedback to the technologists.

2. Monitors used for official image interpretation should provide the following elements of display capability (in the following discussion, MP refers to "megapixels" – the number of pixels contained in the display):
   a. A 5 MP (2,048 x 2,560) monitor (usually in portrait mode with a diagonal dimension calling for 54 cm [21 inches]) exceeds the minimum matrix size stipulated by the ACR standard of a resolution of at least 2.5 lp/mm at the detector plane when acquiring a 35 x 43 cm image (equivalent to 14" x 17") and thus is sufficient for viewing all types of CR/DR images in a single view [32-33].
   b. A 1 MP (1,000 x 1,200), 2 MP (1,200 x 1,600), or 3 MP (1,500 x 2,000) monitor will not permit full simultaneous viewing of 35 x 43 cm images at a detector plane resolution of 2.5 lp/mm. For those images, zooming and roaming display functions are required to achieve a correspondence between the detector element matrix and the display pixel matrix, so that resolution of the display monitor does not limit the resolution of the partially displayed image. This is true for any size image where the detector element matrix size exceeds the display pixel matrix size.
   c. Matrix size should be as close to the "for processing" image data as possible, or attainable with magnification.
   d. All monitors and corresponding video graphics cards used for primary diagnosis or for image adjustment and evaluation (e.g., a technologist review monitor) must provide a means to be calibrated to and conform to the current DICOM GSDF perceptual linearization methods.
   e. Following AAPM Task Group 18 recommendations, the MTF at the Nyquist frequency of the display should be greater than 35%.
   f. The relative noise levels of uniformly exposed digital receptors of various types and specifications for incident air kermas of 4.4 to 8.8 µGy (0.5 to 1.0 mR) range from approximately 2% to 4%. A display device should not add more than a third of the overall noise in a typical image, limiting the display relative noise to 0.6% to 1.2%.
   g. Veiling glare, the spread of light within the display, can reduce contrast; thus the glare ratio should be greater than 400 for primary displays.
   h. Reflections from ambient light sources should be kept at a minimum even when displays have antiglare coatings. Indirect and backlight incandescent lights with dimmer switches rather than fluorescent are recommended. Light colored clothing and lab coats can increase reflections and glare. The intrinsic minimum luminance of the device should not be smaller than the ambient luminance.
   i. The color tint of the display (blue, gray, yellow, etc.) is based on user preferences, but should be uniform across the display area, and monitor pairs should be color matched from the same manufacturing batch.

j. Any electronic device used within 2.5 meters (about 10.8 feet) of a patient must have UL2601 certification [34].

3. When the display systems are not used for the official interpretation, they need not meet all of the characteristics listed above. If they are being used by the technologist to judge image quality during acquisition, consideration should be given to using a display as similar as possible to the diagnostic one in terms of maximum and minimum luminance, contrast ratio, ambient lighting, and conformance to the DICOM GSDF. The display resolution need not be the same as long as zoom and pan (roaming) are easily available to the user so that the full intrinsic resolution of the image can be viewed.

   Additional display considerations include:

   a. Liquid crystal display (LCD) versus cathode ray tube (CRT) displays with regard to static and dynamic image display and viewing angle needs and restrictions:
      i. Flat-surface displays are preferred over those with curved surfaces.
      ii. On-axis viewing is comparable for CRTs and LCDs, but off-axis degradations in contrast are still possible with many LCDs and should be taken into account when viewing images on LCDs from nonorthogonal angles. Angular performance should not lead to a deviation of the contrast response from the DICOM GSDF by more than 30% within the operating ranges of the viewing angles (<30 degrees usually).
      iii. Protective shields on LCDs add to reflections and should not be used if possible.
      iv. Both CRT and LCD displays require about 30 minutes of warm-up time to reach maximum performance.
   b. Monochrome versus color displays with regard to luminance capabilities – typically color displays have lower luminance and thus lower contrast ratios than monochrome displays and are generally not recommended for viewing of certain radiographic modalities (chest, bone, mammography). There are currently no accepted standards or guidelines available for calibrating color displays when viewing grayscale radiographic images, so care should be taken. The DICOM GSDF can be applied to color displays but does not fully address this issue of calibration of color displays.
   c. Desirable display features include remote performance monitoring, calibration, and quality control.
   d. Monitor set matching of contrast ratio, brightness, and color are generally accomplished with the DICOM GSDF, although color does not have a standard calibration method to date.
   e. Viewing conditions should be optimized by controlling reading room lighting to eliminate reflections on the monitor and lowering the ambient lighting level as much as is feasible. Ambient lights should not be turned off completely nor turned up completely. About 20 lux is generally sufficient to avoid most reflections and still provide sufficient light for the human visual system to adapt to the surrounding environment and the displays.
   f. The time required to display an image on the workstation should be 3 seconds or less.

E. Work and Room Environmental and Ergonomic Considerations

With digital displays and their associated computers, it is necessary to insure adequate airflow, optimal temperature, and controlled humidity. It may be necessary, depending on the particular environment, to have direct ventilation for each workstation that is controllable by each user for personal comfort. Water-cooled computers should be considered if placed in confined spaces. Avoid placing monitors in the same area as light boxes and alternators. If necessary, place them at 90 degrees rather that 180 degrees to reduce reflections. Separate each display workstation from others with partitions that can be moved and/or reconfigured depending on consultation needs.

It is also important to minimize noise from computers, fans, and other sources at digital workstations. Water-cooled computers should be considered since they are quieter than fan-cooled computers. Proper shielding (via movable walls, for example) should be considered to minimize noise between workstation areas, especially to isolate dictation systems from each other. If clinicians visit the reading area for consultation, consideration should be given to enlarging the space and using larger wall partitions to reduce interference from conversation.

Proper chairs with appropriate lumbar support and adjustable height controls (including armrests) are recommended to avoid injuries and excessive fatigue. The workstation table should be height adjustable, and the keyboard mouse and monitors should be designed to maximize comfort and efficiency.

Dictation tools, internet access, and other reference tools should be readily accessible and easy to use during image interpretation. Consider ergonomically designed input devices and alternatives to the traditional mouse and trackball interfaces.

F. Archiving and Retrieval

1. Digital imaging data management systems should provide storage capacity capable of complying with all facility, state, and federal regulations regarding medical record retention. Images stored at either a transmitting or receiving site should meet the jurisdictional requirements of the acquisition and transmitting site. Images interpreted off-site need not be stored at the receiving facility provided they are stored at the transmitting site. However, if the images are retained at the receiving site, the retention period requirement of that jurisdiction must be met as well. The policy on record retention must be in writing.
2. Each examination data file must have an accurate corresponding patient and examination database record that includes patient name, identification number, accession number, examination date, type of examination, and the facility at which the examination was performed. It is desirable to have space available for storage of a brief clinical history.
3. Prior examinations must be retrievable from archives in a time frame appropriate to the clinical needs of the facility.
4. Each facility should have policies and procedures for archiving digital image data equivalent to the policies that currently exist for protecting hardcopy storage media to preserve both image and medical records.
5. The exchange of imaging information should be conducted in accordance with the IHE initiative [35] through use of current standards developed by DICOM [38] and HL7 [39] (see Glossary).

G. Security

Medical images are subject to United States privacy laws such as the Health Insurance Portability and Accountability Act (HIPAA) of 1996 and applicable state privacy requirements. Digital image data management systems should provide network and software security protocols to protect the confidentiality of patient identification and image data as well as appropriate user accessibility and authentication. There should be measures to safeguard the data and to prevent intentional or unintentional corruption of the information. For teleradiology purposes the use of additional software and hardware devices such as virtual private networks may be required to insure patient privacy. (See the ACR–SIIM Practice Guideline for Electronic Medical Information Privacy and Security.)

H. Reliability and Redundancy

For facilities practicing electronic radiology, quality patient care depends on the stability and reliability of the digital image data management system. Written policies and procedures must be in place to ensure continuity of care at a level consistent with those for hardcopy imaging studies and medical records within a facility or institution. This should include internal redundancy systems, backup telecommunication links, and a disaster plan. The disaster plan should be tested to make sure no information is lost or miscommunicated.

V. DOCUMENTATION

Physicians officially interpreting examinations[3] using digital image data management systems should render reports in accordance with the ACR Practice Guideline for Communication of Diagnostic Imaging Findings.

If reports are incorporated into the data management system, they should be retrievable with the same conditions of timeliness and security as the imaging data.

VI. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, radiologic technologists, and all supervising physicians have a responsibility to minimize radiation dose to individual patients, to staff, and to society as a whole, while maintaining the necessary diagnostic image quality. This concept is known as "as low as reasonably achievable (ALARA)."

Facilities, in consultation with the medical physicist, should have in place and should adhere to policies and procedures, in accordance with ALARA, to vary examination protocols to take into account patient body habitus, such as height and/or weight, body mass index or lateral width. The dose reduction devices that are available on imaging equipment should be active; if not, manual techniques should be used to moderate the exposure while maintaining the necessary diagnostic image quality. Periodically, radiation exposures should be

[3]The ACR Medical Legal Committee defines official interpretation as that written report (and any supplements or amendments thereto) that attach to the patient's permanent record. In health care facilities with a privilege delineation system, such a written report is prepared only by a qualified physician who has been granted specific delineated clinical privileges for that purpose by the facility's governing body upon the recommendation of the medical staff.

measured and patient radiation doses estimated by a medical physicist in accordance with the appropriate ACR Technical Standard. (ACR Resolution 17, adopted in 2006 – revised in 2009, Resolution 11)

VII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR web page (http://www.acr.org/guidelines).

Any facility using a digital image data management system must have documented policies and procedures for monitoring and evaluating the effective management, safety, and proper performance of acquisition, digitization, processing, compression, transmission, display, archiving, and retrieval functions of the system. The quality control program should be designed to maximize the quality and accessibility of diagnostic information.

A. Performance Characteristics to be Monitored

Performance monitoring must be performed on each digital radiography device.

1. Performance testing and monitoring of computed radiography (CR) equipment should be performed in accordance with the equipment manufacturer specifications, applicable industry guidelines, and state and federal regulations. In the absence of adequate manufacturer procedures, guidelines, or standards, the recommendations for the performance testing methods and frequencies contained in AAPM Task Group Report No. 10: Acceptance Testing and Quality Control of Photostimulable Storage Phosphor Imaging Systems [4], should be followed.
2. Performance testing and monitoring of digital radiography (DR) equipment should be performed in accordance with the equipment manufacturer's specification, applicable industry guidelines, and state and federal regulations [4].
3. Performance testing and monitoring of official or primary interpretation display devices should be performed in accordance with applicable recommendations in the ACR Quality Control Manual, the equipment manufacturer's specifications, specific vendor guidelines, and state and federal regulations. In the absence of adequate manufacturer procedures, guidelines, or standards, the recommendations for the performance evaluation of display devices testing methods and frequencies contained in AAPM Task Group Report No. 18: Assessment of Display Performance for Medical Imaging Systems [33], should be followed. It should be noted that CRT and LCD devices tend to have different characteristics and may not degrade in the same ways or at the same rates. The same holds true for color versus grayscale devices. Devices from different manufacturers may also degrade at different rates. In all cases it is necessary to monitor the display parameters on a regular basis (at least monthly, possibly more frequently as the displays get older since they tend to drift more with age). Regular visual inspection also needs to be done on a monthly basis to check for things like dead pixels that automatic QA systems may not detect [40].

B. Quality Control Program

A continuous quality control (QC) program shall be established for all digital radiography units with the assistance of a medical physicist. The medical physicist, in consultation with the manufacturer, should determine the frequency of each test and the methodology of each test performed. An on-site radiologic technologist shall be identified to be responsible for conducting routine QC.

The QC program should include the recommendations for quality control testing methods and frequencies contained in AAPM Task Group Report No. 10: Acceptance Testing and Quality Control of Photostimulable Storage Phosphor Imaging Systems for CR Equipment [4].

The results of the QC program shall be monitored annually by the medical physicist. If measured values of QC parameters fall outside the control limits, the physicist shall initiate appropriate investigative or corrective actions. A medical physicist should be available to assist in prescribing corrective actions for unresolved problems.

VIII. ACCEPTANCE TESTING

Initial performance testing shall be performed upon installation and should be completed before first clinical use. This testing shall be more comprehensive than periodic performance and compliance testing and should be consistent with current acceptance testing practices for digital radiography. Specific tests to be performed depend on the type of equipment and the manufacturer's recommendations. The AAPM has a document available that describes pertinent acceptance tests for photostimulable storage phosphor systems (computed

radiography acquisition devices) [2], many of which are applicable to other digital radiography acquisition devices (CCD and flat panel systems). A general document for acceptance testing and quality control procedures of digital radiography devices that includes state-of-the-art flat panel and CCD-based imaging systems is being formulated by a new AAPM task group and should be available in 2008.

IX. FOLLOW-UP PROCEDURES AND WRITTEN SURVEY REPORTS

The medical physicist shall report the findings to the physician(s), to the responsible professional(s) in charge of obtaining or providing necessary service to the equipment, and, in the case of the consulting physicist(s), to the representative of the hiring party, and, if appropriate, initiate the required service. Action shall be taken immediately by verbal communication if there is imminent danger to patients or staff using the equipment due to unsafe conditions. Written survey reports shall be provided in a timely manner consistent with the importance of any adverse findings.

1. As a minimum QC check for acquisition workstation and secondary display devices, a test image, such as the SMPTE RP-133 (Society for Motion Picture and Television Engineers) test pattern or AAPM TG-18 QC pattern, should be captured, transmitted, archived, retrieved, and displayed at appropriate intervals, to test the overall operation of the system under conditions that simulate its normal operation. A spatial resolution test should be used to demonstrate that at least 2.5 lp/mm resolutions are visible.
2. As a test of the display fidelity, SMPTE pattern data files sized to occupy the full area used to display images on the monitor should be displayed. The overall SMPTE image appearance should be inspected to assure the absence of gross artifacts (e.g., blurring or bleeding of bright display areas into dark areas or aliasing of spatial resolution patterns). All display monitors used for primary interpretation should be tested at least monthly. For the dynamic range test, both the 5% and the 95% contrast areas should be visible and distinctly different than the respective adjacent 0% and 100% areas.
3. If a hardcopy imager is present, testing of its accuracy and stability should be performed and documented according to the manufacturer's recommendations.
4. If using hardcopy film, the viewbox luminance should be sufficient to meet the diagnostic needs of the imaging procedure and applicable industry standards and/or recommendations, when available, according to the manufacturer's recommendations.

The use of digital imaging and digital image data management systems does not reduce the responsibilities for the management and supervision of radiologic examinations. Facilities and physicians providing remote imaging services should participate in a documented ongoing quality assurance program at least equivalent to that of the originating facility. Summaries of the quality control monitoring should be provided to the originating facility.

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APPENDIX A

Glossary

1. Analog signal - a form of information transmission in which the signal varies in a continuous manner and is not limited to discrete values.
2. Archive - a repository for digital medical images in a picture archiving and communications system (PACS), typically with a specific purpose of providing either short-term or long-term (permanent) storage or subsequent retrieval of images. Erasable or nonerasable media may be utilized in an archive.
3. Baud - the number of events processed in 1 second, usually expressed in bits per second (bps) or kilobits per second (kbps). Typical telephone rates are 14.4 kbps, 28.8 kbps, and 56 kbps. DSL connections have maximum bandwidth of 1.5 Mbps, Cable modems 3-15 Mbps, and Ethernet connections can range from 10 Mbps up to several Gbps.
4. Bit (binary digit) - the smallest unit of digital information that a computing device handles. It represents one of two possible states: off or on (0 or 1). All data in computing devices are processed as bits or strings of bits.
5. Bit depth - the number of bits used to encode the signal intensity (grayscale) of each pixel of the image.
6. Bits per second - see throughput, baud.
7. Byte - a grouping of 8 bits used to represent a character or numeric value.
8. Candela – SI unit of luminance intensity typically expressed as candela per square meter (cd/m^2).
9. Carrier - see Data carrier.
10. CCD (charge-coupled device) - a photoelectric device that converts light information into electronic information. CCDs are commonly used in television cameras and image scanners and consist of an array of sensors that collect and store light as a buildup of electrical charge. The resulting electrical signal can be converted into digital values and processed in a computer to form an image.
11. CCD scanner - a device that uses a CCD sensor to convert film images into electronic data.
12. CMOS – complementary metal oxide semiconductor: a photosensitive device consisting of an array of individual picture elements (pixels) etched on a crystalline silicon wafer and manufactured using the standard random access memory production process. Light falling upon the array produces a proportional charge that is stored in each element. Inter-connections between pixels allow for direct addressing, digitization of the accumulated charge, and refreshing the array for the next image capture event.
13. Compression ratio - the ratio of the size of the original image file to the compressed image file. For example, a compression ratio of 2:1 would correspond to a compressed image with one-half the file size of the original.
14. Consultation system - a teleradiology system used to determine the completeness of examinations, to discuss findings with other physicians, or for other applications with the knowledge that the original images will serve as the basis for the final official interpretation rendered at some later time by the physician responsible for that report.
15. Contrast ratio – the ratio of the luminosities of the brightest and darkest luminance signals from a digital display device.
16. Co-processor - a device in a computer to which specialized processing operations are delegated, such as mathematical computation or video display. The advantage of a co-processor is that it significantly increases processing speed.
17. CPU (central processing unit) - the device in a computer that performs the calculations. It executes instructions (the program) and performs operations on data.
18. CR (computed radiography) - an imaging system that uses a storage phosphor plate instead of film as the image detector contained in the cassette. A laser beam scans the latent image on the exposed storage plate to produce the digital data that is then converted into an image.
19. CRT (cathode ray tube) - one type of monitor or display device in digital radiology systems. A CRT works by moving an electron beam across the back of the screen, lighting up phosphor dots on the inside of the glass tube and illuminating the active portions of the screen. Successive lines from the top to the bottom create the entire image of the screen.
20. Data carrier - the signal that is used to transmit the data. If this signal is not present, there can be no data communication between modems.
21. Data communication - all forms of computer information exchange. Data communication may take place between two computers in the same building via a local area network (LAN), across the country via telephone, or elsewhere by a wide-area network (WAN).
22. Data compression - methods to reduce the data volume by encoding it in a more efficient manner, thus reducing the image processing and transmission

times and storage space required. These methods may be reversible or irreversible.

23. Data transfer rate - the maximum speed at which information is transferred between devices, such as a scanner and a computer; between components within a device, such as between storage and memory in a computer; or between teleradiology stations.
24. Dedicated line - a telephone line that is reserved for the exclusive use of one customer. It can be used 24 hours a day and usually offers better quality than a standard dial-up telephone line but may not significantly increase the performance of data communication.
25. Del - acronym for detector element. The del is the smallest area of a digital detector discrete array over which the signal is measured. The dimension of the del "aperture" is rectangular (usually square). In some detectors, the active area is a smaller fraction of the total area of the pixel because of the placement of necessary data lines and charge storage devices inside the pixel area. The ratio of del size to pixel size is known as the "fill-factor".
26. DICOM (Digital Imaging and Communications in Medicine) - a standard for interconnection of medical digital imaging devices, developed and sponsored by the American College of Radiology and the National Electrical Manufacturers Association, consisting of a standard image file format and a standard communications protocol.
27. Digital signal - a form of information transmission in which the signal varies in discrete steps, not in a continuous manner.
28. Digitize - the process by which analog (continuous value) information is converted into digital (discrete value) information. This process is a necessary function for computer imaging applications because visual information is inherently in analog format, and most computers can only utilize information in a digital form. Digitization consists of two steps: sampling in space, which affects the spatial resolution, and quantization in signal intensity, which affects the grayscale bit depth and may give rise to quantization noise.
29. Direct image capture, also known as digital radiography (DR) - the capture or acquisition of digital image data in digital format, requiring no separate laser scanner or film processor.
30. dpi (dots per inch) - in conventional radiography, resolution is commonly expressed in line pairs per millimeter (lp/mm). Film digitizer resolution is commonly expressed using units of dots (pixels) per inch.
31. DQE - detective quantum efficiency, a term used to describe the effectiveness of an imaging system in maintaining the SNR during the imaging process. Some DR systems have significantly higher DQE than SF systems, resulting in lower patient doses and/or improved image quality.
32. Dynamic range - the difference in signal intensity, or frequency, between the largest and smallest signals a system can process or display. The optical density is the difference between the lightest and darkest useful regions of the image. Increasing the number of bits per pixel in a digital image increases the dynamic range of the image.
33. Exposure class - similar to the term "speed" used with SF systems. Exposure class is used to describe the nominal radiation exposure required to obtain a proper radiograph. The new term is used instead of speed to reflect the significantly different energy response that digital detectors have when compared to SF systems.
34. Exposure indicators - a quantitative method to estimate the nominal *incident* radiation exposure required to obtain a proper radiograph. This is a manufacturer-dependent value. Fuji CR uses the *sensitivity number (S number)*, a value that is similar to screen-film speed and inversely related to incident exposure. Agfa CR uses *lgM*, the log of the median exposure determined from the segmented area on the imaging plate, which increases logarithmically with the incident exposure. Kodak CR uses e*xposure index*, a value that represents the relative measure of the X-ray exposure in the segmented, anatomical regions of the image and increases logarithmically with the digital values in the image. Konica CR uses *S value*, a value similar to the *S number* with similar relationships to incident exposure, but estimated and calculated in a different manner compared to Fuji. Imaging Dynamics (a DR company) uses *f-number*, a relative value based upon the same concept as photography in describing relative light intensity ranges, where in this situation, negative values represent lower exposures and positive values represent higher exposures than the desired "nominal" exposure. Other manufacturers have their own unique exposure value estimates. Users of a particular digital system must understand the meaning of the incident exposure index in order to determine that the exposure was appropriate (See Appendixes B and C). The manner in which the vendor identifies the parts of the image that have received direct X-ray exposure or are collimated has an effect on the calculated exposure index and may lead to errors.
35. Exposure latitude - the range between the minimum and maximum exposures that will produce an acceptable range of densities for diagnostic purposes. Furthermore, it is considered the "margin for error in setting a proper technique." Exposure latitude is distinguished from the term "latitude" which is defined similarly as "the range of X-ray exposures

that deliver ODs in the usable range." Thus, for the same screen-film detector, the exposure latitude is necessarily a smaller ratio than the latitude, because the exposure latitude takes into account the full extent of X-ray exposures and corresponding densities within the range. Similarities in these two terms lead to errors in communication between technologists, medical physicists, and radiologists.

36. File - a set of digital data that have a common purpose, such as an image, a program, or a database.
37. Fill-factor - the ratio of the active charge collection area to the total physical space occupied by the detector element. Digital flat-panel detectors with better resolution (smaller del dimension) often have a lower fill-factor and poorer charge collection efficiency.
38. G (giga) - stands for the number 1 billion. It is used primarily when referring to computer storage capacities; for example, 1 GB = 109 megabytes.
39. Grayscale - the number of different shades of levels of gray that can be stored and displayed by a computer system. The number of gray levels is directly related to the number of bits used in each pixel: 2 bits – total gray levels, 8 bits = 256 gray levels, 10 bits = 1,024 gray levels, and 12 bits = 4,096 gray levels.
40. Grayscale monitor - a black-to-white display with varying shades of gray, ranging from several shades to thousands, thus being suitable for use in imaging. This type of monitor also may be referred to as a monochrome display. (See also monochrome monitor)
41. GSDF (grayscale standard display function) - DICOM (Part 14) standard that defines a grayscale display function for monochrome image display device, based on perceptual linearization and defined for the luminance range of 0.05 to 4,000 cd/m^2. It was developed in part to facilitate similarity in grayscale between different image display devices independent of luminance.
42. Hard disk drive - an internal computer device used for storage of data.
43. Hardware - a collective term used to describe the physical components that form a computer. The monitor, CPU, disk drives, memory, modem, and other components are all considered hardware. If you can touch it, it is hardware.
44. HIS (hospital information system) - an integrated computer-based system to store and retrieve patient information, including laboratory and demographic information, billing data, and radiology reports.
45. HL7 (Health Level Seven) - a volunteer, not-for-profit international community of health care experts and information scientists collaborating to create standards for the exchange, management, and integration of electronic health care information. Among its products are standards to permit the interconnection of RIS, HIS, computer billing systems, and the PACS and smooth exchange of information between these systems.
46. IDE (integrated drive electronics) - a type of interface used for hard disk drives that integrates the control electronics for the interface on the drive itself. Its purpose is to increase the speed at which information can be transferred between the hard disk and the rest of the computer.
47. Image - a computer's digital representation of a physical object.
48. Image compression - reduction of the amount of data used to represent an image. This is accomplished by encoding the spatial and contrast information more efficiently or discarding some nonessential or redundant information, or both.
49. Interface - the connection between two computers or parts of computers. It consists mainly of electronic circuitry.
50. Irreversible compression - compression that results in some permanent alteration of digital image data. This is sometimes referred to as lossy or non-bit preserving compression.
51. ISDN (integrated services digital network) - a switched network with end-to-end digital connection enabling copper wiring to perform functions such as high-speed transmission, which frequently requires higher capacity fiberoptic cable.
52. K (kilo) - stands for the number 10^3 bytes. In the context of digital imaging, it is used as part of binary arithmetic and stands for 2^{10} = 1,024 (e.g., 1 kilobyte = 1,024 bytes).
53. LAN (local area network) - computers in a limited area linked by cables that allow the exchange of data.
54. Laser film scanner - a device that uses a laser beam to convert an image on film into digital image data.
55. LCD (liquid crystal display) - one type of monitor or display device in digital radiology systems. LCD displays use two sheets of polarizing material with a liquid crystal solution between them. An electric current passed through the liquid causing the crystals to align so that light can or cannot pass through them.
56. Leased line - same as a dedicated line.
57. Lossless - see reversible compression.
58. Lossy - see irreversible compression.
59. Luminance - a photometric measure describing the amount of light passing through or emitted from a particular surface (e.g., monitor or display device) and falls within a given solid angle. The SI unit for luminance is candelas per square meter (cd/m^2).
60. LUT (look-up table) - a table used to map image index numbers to output display values on a digital device.
61. M (mega) - stands for the number 1 million = 10^6 (e.g., a megahertz in 10^6 Hertz).
62. Matrix size: Small - defined as images from CT, MR, ultrasound, nuclear medicine, and digital

fluorography. Large - defined as images from digital radiography and digitized radiographic films.

63. Memory - electronic circuitry within a computer that stores information.
64. Modem - a device that converts digital signals from a computer to pulse tone signals for transmission over telephone lines; a cable modem goes over fiber.
65. Monochrome monitor - a computer display in which an image is presented as different shades of gray from black to white. (see also gray-scale monitor)
66. Mouse - an input device that allows the computer user to point to objects on the screen and execute commands.
67. MTF (modulation transfer function) - the spatial frequency response of an imaging system or component. It is expressed as a graph of the percentage of available contrast versus the spatial frequency.
68. NPS (noise power spectrum) - the frequency response of an imaging system to noise. In CR and DR, the noise spectrum is not white (uniform) due to aliasing and other noise sources. As a result, it is important to measure the noise frequency response of the imaging system.
69. Operating system - software that allocates and manages the resources available within a computer system. UNIX, LINUX, Mac-OS, and Windows are examples of operating systems.
70. Optical disk - a computer data storage disk that uses optical devices such as a laser to write digital data to the disk.
71. PACS - (picture archiving and communication system) – a network of computers, monitors, and network equipment to store, transmit, and display digital images.
72. Pixel (picture element) - the smallest piece of information that can be displayed on a CRT or LCD monitor. It is represented by a numerical code within the computer and displayed on the monitor as a dot of a specific color or intensity. An image is composed of a large array of pixels of differing intensities or colors.
73. Protocol - a set of guidelines by which two different computer devices communicate with each other.
74. RAM (random access memory) - a type of temporary memory in a computer in which programs are run, images are processed, and information is stored. The amount of RAM that a computer requires varies widely depending on the specific application. Information stored in RAM is lost when the power is shut off.
75. Removable media devices - portable data storage devices commonly used include memory sticks, compact disks, digital video disks, and tape which require CD, DVD, and tape drives respectively.
76. Resolution - spatial resolution is the ability to distinguish small objects at high contrast. It is affected by sampling and limited by the pixel size. Contrast (grayscale) resolution is the ability of a system to distinguish between objects of different signal intensity. It is affected by quantization and limited by the bit depth.
77. Reversible compression - no alteration of original image information upon reconstruction. This is sometimes referred to as lossless or bit-preserving.
78. RIS - radiology information system.
79. ROM (read-only memory) - a permanent memory that is an integral part of the computer. Programs and information stored in ROM are not lost when the power is removed.
80. SCSI (small computer systems interface) - SCSI is an interface protocol that is used to link dissimilar computer devices so that they can exchange data. SCSI interfaces are most common in image scanners and mass storage devices. This type of interface is well suited for imaging applications.
81. Secondary image capture - the capture in digital format of image data that originally existed in another primary format (e.g., a digital image data file on a CT scanner, or SF radiographic film) through the process of video capture or film digitization.
82. SMPTE - the Society of Motion Picture and Television Engineers; SMPTE patterns can be used for monitor quality assurance evaluations. Many vendors have them available on their computers.
83. Speed class - the concept of conventional screen-film speed (e.g., 100, 200, 400, 600, 800) is applied to the incident exposure that a digital radiography device operates to produce an image of “acceptable” clinical image quality. The speed class for a digital radiography device depends on the device itself (how efficiently X-rays are absorbed and converted into a useful signal), the system gain adjustment (how much amplification is applied to the signals prior to digitization), and the examination requirements (how much exposure is required to achieve appropriate image quality; e.g., extremity radiographs are typically acquired with a 100 speed class setting, while chest x-rays are typically acquired with a 200 to 400 speed class setting). Operation of a system at a higher speed class requires less exposure to the patient but produces higher quantum mottle (noise) and lower SNR in the image. (Also see “exposure indicators”)
84. Software - a name given to the programs or sets of programs that are executed on a computer.
85. Tera (T) - standards for the number 1 trillion = 10^{12}. In the context of digital imaging, it is used as part of binary arithmetic, and stands for 2^{40} = 1,09951162 x 10^{12} (e.g., 1 terabyte = 1,048,576 megabytes = 1,09951162 x 10^{12} bytes).

86. Throughput - a measure of the amount of data that is actually being communicated, expressed in bits per second. It is related to the nominal baud rate, but is usually somewhat less in value due to non-ideal circumstances. Typically, devices with higher baud rates or bandwidth can attain a higher throughput.
87. Veiling glare - diffuse scattering of light within various parts of a display device and electron scattering in the vacuum side of the tube in a CRT device. It reduces contrast in an image in the same manner as scatter reduces subject contrast.
88. Video capture - the process by which images are digitized directly from the video display console of a modality, such as CT, MRI, or ultrasound. The video signal is converted into a digital signal. This process is more efficient and produces better quality images than scanning films that are produced by the same equipment, but are of lesser quality than direct DICOM capture since video capture is normally limited to 8 bits grayscale.
89. Voxel (volume element - a voxel is a three-dimensional version of a pixel. Voxels are generated by 3-dimensional computer-based imaging systems, such as CT and MRI.
90. WAN (wide-area network) - a communication system that extends over large distances (covering more than a metropolitan area), often employing multiple communication link technologies such as copper wire, coaxial cable, and fiberoptic links. The cost of these WANs is presently dominated by transmission costs.
91. WORM (write once, read many times) - a peripheral memory device that stores information permanently, by burning a pit on a CD mirror surface, for example.
92. X-ray converters: materials that absorb X-rays and convert the imparted energy into an output signal that is subsequently digitized, displayed and stored as a digital image. With current technology, three major types of X-ray converters are used for digital radiography: (1) X-ray scintillators convert X-rays into light (Gd_2O_2S – gadolinium oxysulfide and CsI – cesium iodide are the most prevalent), and the light is converted to an electronic signal by a photodiode or CCD device; (2) photostimulable storage phosphors store electrons elevated to semi-stable traps by absorbed X-rays in BaFBr - barium fluoro bromide (and other related phosphors), with subsequent release of the electrons under laser stimulation with release of luminescent light photons and conversion to electronic signal; (3) semi-conductor materials (*a*-Se -- amorphous selenium) absorb X-rays and directly release electron-hole charges which are collected under a high voltage to collection electrodes connected to electronic amplifiers.
93. Zoom and pan - the ability to magnify and roam through a region in the display.

APPENDIX B

SUGGESTED CR CLINICAL TECHNIQUE FACTORS [41]

FUJI (S Number)	AGFA (lgM Value)	Kodak (Exposure Index)	Detector Exposure Estimate (mR)	Indication and Action
>1000	<1.45	<1250	<0.20	Underexposed: REPEAT
601-1000	1.45 – 1.74	1250 – 1549	0.3 – 0.2	Underexposed: QC exception
301-600	1.75 – 2.04	1550 – 1849	0.7 – 0.3	Underexposed: QC review
150-300	2.05 – 2.35	1850 – 2150	1.3 – 0.7	Acceptable range
75-149	2.36 – 2.65	2151 – 2450	2.7 – 1. 3	Overexposed: QC review
50-74	2.66 – 2.95	2451 - 2750	4.0 – 2.7	Overexposed: QC exception
<50	>2.95	>2750	>4.0	Overexposed: QC repeat IF NECESSARY

Based on the vendor's recommendation for what constitutes an appropriately exposed radiograph, one can use this or a similar table to provide guidance to the technologist regarding proper exposure levels. Several CR exposure indices are illustrated in this example.

With too low an incident exposure, the image is dominated by noise, the corresponding SNR is very poor, and the ability to detect subtle differences in X-ray attenuation is compromised. With too high an incident exposure, highly penetrated areas in the image may suffer from saturation effects and loss of contrast that cannot be compensated for with image processing. These recommendations depend on several issues, including the type of CR reader (newer systems, such as the dual-light collection systems, have a higher DQE and will consequently have a lower exposure recommendation for all indications), type of image plate (later-generation image plates may have better exposure performance), quality and calibration settings of the CR reader and image plate, and tolerance of the radiologist to image noise, among other considerations. Continuous analysis and feedback are required to get the optimal range of exposures and indications for a given examination at a given site. Similar guidance can be provided for DR for those systems that provide an indication of the exposure used to obtain a radiograph.

Use caution in applying this chart to any specific CR implementation since X-ray generator output characteristics and CR plate energy sensitivities vary widely.

APPENDIX C

Required Change in mAs to Achieve a Target lgM Value of 2.20

	Underexposed: Increase mAs				Proper Clinical Techniques				Overexposed: Reduce mAs			
	lgM value	Difference from Target lgM	Required mAs Scale Factor		lgM value	Difference from Target lgM	Required mAs Scale Factor		lgM value	Difference from Target lgM	Required mAs Scale Factor	
Underexposed, Repeat	1.40	-0.80	6.31		2.00	-0.20	1.58		2.42	0.22	0.60	Overexposed
	1.42	-0.78	6.03		2.02	-0.18	1.51		2.44	0.24	0.58	
	1.44	-0.76	5.75		2.04	-0.16	1.45		2.46	0.26	0.55	
	1.46	-0.74	5.50		2.06	-0.14	1.38		2.48	0.28	0.52	
	1.48	-0.72	5.25		2.08	-0.12	1.32		2.50	0.30	0.50	
	1.50	-0.70	5.01		2.10	-0.10	1.26		2.52	0.32	0.48	
	1.52	-0.68	4.79		2.12	-0.08	1.20		2.54	0.34	0.46	
	1.54	-0.66	4.57		2.14	-0.06	1.15		2.56	0.36	0.44	
	1.56	-0.64	4.37		2.16	-0.04	1.10		2.58	0.38	0.42	
	1.58	-0.62	4.17		2.18	-0.02	1.05		2.60	0.40	0.40	
	1.60	-0.60	3.98	>>>	**2.20**	**0.00**	**1.00**	<<<	2.62	0.42	0.38	Overexposed, Check for Burnout, Repeat if Necessary
	1.62	-0.58	3.80		2.22	0.02	0.95		2.64	0.44	0.36	
	1.64	-0.56	3.63		2.24	0.04	0.91		2.66	0.46	0.35	
	1.66	-0.54	3.47		2.26	0.06	0.87		2.68	0.48	0.33	
	1.68	-0.52	3.31		2.28	0.08	0.83		2.70	0.50	0.32	
	1.70	-0.50	3.16		2.30	0.10	0.79		2.72	0.52	0.30	
	1.72	-0.48	3.02		2.32	0.12	0.76		2.74	0.54	0.29	
	1.74	-0.46	2.88		2.34	0.14	0.72		2.76	0.56	0.28	
	1.76	-0.44	2.75		2.36	0.16	0.69		2.78	0.58	0.26	
	1.78	-0.42	2.63		2.38	0.18	0.66		2.80	0.60	0.25	
Underexposed Review with Radiologist	1.80	-0.40	2.51		2.40	0.20	0.63		2.82	0.62	0.24	
	1.82	-0.38	2.40						2.84	0.64	0.23	
	1.84	-0.36	2.29						2.86	0.66	0.22	
	1.86	-0.34	2.19						2.88	0.68	0.21	
	1.88	-0.32	2.09						2.90	0.70	0.20	
	1.90	-0.30	2.00						2.92	0.72	0.19	
	1.92	-0.28	1.91						2.94	0.74	0.18	
	1.94	-0.26	1.82						2.96	0.76	0.17	
	1.96	-0.24	1.74						2.98	0.78	0.17	
	1.98	-0.22	1.66						3.00	0.80	0.16	

Example #1 LgM value was 1.80. To get a proper exposure of 2.2, increase the mAs by a factor of 2.5. If the mAs was 20, change it to 2.5 x 20 = 50 mAs. You could also increase the kVp. Remember, a 15% increase in kVp doubles the tube output.

Example #2 LgM value was 3.02. To get a proper exposure of 2.2, decrease the mAs by a factor of 0.16. If the mAs was 20, change it to 0.16 x 20 = 3.2 mAs. You could also decrease the kVp to achieve the same effect.

This conversion factor table provides a rapid means for the technologist to understand how to correct for an improperly exposed radiograph. This example is for one CR vendor implementation (Agfa), using lgM as the exposure indicator. Similar tables can be constructed using the information in Appendix A as a guideline for other vendor exposure settings. Technologists are very familiar with the change required to obtain an appropriate screen-film radiograph, and the same concept is used here to suggest improvements in technique factors with CR, as well as in deciding when to repeat a study.

Use caution in applying this chart to any specific CR implementation since X-ray generator output characteristics and CR plate energy sensitivities vary widely.

APPENDIX D

Computed Radiography Exposure Chart

						Total mAs for Different Body Part Thicknesses								
Procedure	**View**	**Distance**	**Receptor**	**Speed Class**	**kVp**	**Average cm**	**-6 cm**	**-4 cm**	**-2 cm**	**Average**	**+2 cm**	**+4 cm**	**+6 cm**	**+8 cm**
Chest	PA/AP	72	W	200	106	22	1.25	1.67	2.50	3.33	5.00	6.67	10.00	13.33
	LAT	72	W	200	116	30	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
	AP	72	T	200	80	22	1.25	1.67	2.50	3.33	5.00	6.67	10.00	13.33
	LAT	72	T	200	90	30	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
Supine Chest	AP	40	T	200	80	22	0.90	1.20	1.80	2.40	3.60	4.80	7.20	9.60
Ribs / Sternum	AP Above Diaph	72	W	400	60	22	10.00	13.33	20.00	26.67	40.00	53.33	80.00	106.67
	OBL Above Diaph	72	W	400	64	24	15.00	20.00	30.00	40.00	60.00	80.00	120.00	160.00
	AP Below Diaph	72	W	400	76	22	30.00	40.00	60.00	80.00	120.00	160.00	240.00	320.00
Abdomen	AP / PA	40	B	400	80	22	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
	30° OBL	40	B	400	80	24	11.00	14.67	22.00	29.33	44.00	58.67	88.00	117.33
Pelvis / Hip	AP	40	B	400	80	22	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
	LAT	40	B	400	80	22	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
Sacrum	AP	40	B	400	76	20	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
	LAT	40	B	400	80	28	15.00	20.00	30.00	40.00	60.00	80.00	120.00	160.00
Lumbar Spine	AP	40	B	400	80	22	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
	45° OBL	40	B	400	80	26	15.00	20.00	30.00	40.00	60.00	80.00	120.00	160.00
	LAT	40	B	400	80	30	30.00	40.00	60.00	80.00	120.00	160.00	240.00	320.00
	L5 / S1	40	B	400	90	30	30.00	40.00	60.00	80.00	120.00	160.00	240.00	320.00
Thoracic Spine	AP	40	B	400	76	22	6.50	8.67	13.00	17.33	26.00	34.67	52.00	69.33
	LAT	40	B	400	76	30	15.00	20.00	30.00	40.00	60.00	80.00	120.00	160.00
Cervical Spine	AP/Odon	40	B	400	76	13	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
	AP/Odon	72	W	400	76	13	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
	OBL/LAT	72	W	400	76	13	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
	OBL/LAT	72	T	400	76	13	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
Skull	PA/Caldwell	40	B	400	80	19	5.00	6.67	10.00	13.33	20.00	26.67	40.00	53.33
	LAT	40	B	400	76	15	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
	Townes	40	B	400	80	22	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
Sinuses / Facial Bones	PA/Caldwell	40	B	400	76	19	5.00	6.67	10.00	13.33	20.00	26.67	40.00	53.33
	Waters	40	B	400	80	20	5.00	6.67	10.00	13.33	20.00	26.67	40.00	53.33
	LAT	40	B	400	76	15	1.88	2.50	3.75	5.00	7.50	10.00	15.00	20.00
Hand	PA	40	T	100	54	4	1.10	1.47	2.20	2.93	4.40	5.87	8.80	11.73
	OBL	40	T	100	54	6	1.25	1.67	2.50	3.33	5.00	6.67	10.00	13.33
	Fanned LAT	40	T	100	54	8	2.25	3.00	4.50	6.00	9.00	12.00	18.00	24.00
Wrist	PA	40	T	100	60	5	1.10	1.47	2.20	2.93	4.40	5.87	8.80	11.73
	OBL	40	T	100	60	6	1.65	2.20	3.30	4.40	6.60	8.80	13.20	17.60
	LAT	40	T	100	60	7	2.25	3.00	4.50	6.00	9.00	12.00	18.00	24.00
Forearm	AP	40	T	100	64	7	1.10	1.47	2.20	2.93	4.40	5.87	8.80	11.73
	LAT	40	T	100	64	8	2.25	3.00	4.50	6.00	9.00	12.00	18.00	24.00
Elbow	AP	40	T	100	64	7	1.50	2.00	3.00	4.00	6.00	8.00	12.00	16.00
	OBL	40	T	100	64	8	2.00	2.67	4.00	5.33	8.00	10.67	16.00	21.33
	LAT	40	T	100	64	8	3.00	4.00	6.00	8.00	12.00	16.00	24.00	32.00
Humerus	AP	40	T	100	72	8	1.10	1.47	2.20	2.93	4.40	5.87	8.80	11.73
	LAT	40	T	100	72	9	1.80	2.40	3.60	4.80	7.20	9.60	14.40	19.20
Toes	All	40	T	100	60	2	1.10	1.47	2.20	2.93	4.40	5.87	8.80	11.73
Foot	AP	40	T	100	64	7	1.25	1.67	2.50	3.33	5.00	6.67	10.00	13.33
	OBL	40	T	100	64	8	1.65	2.20	3.30	4.40	6.60	8.80	13.20	17.60
	LAT	40	T	100	64	8	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
Calcaneus	PA	40	T	100	68	9	3.50	4.67	7.00	9.33	14.00	18.67	28.00	37.33
	LAT	40	T	100	68	8	3.50	4.67	7.00	9.33	14.00	18.67	28.00	37.33
Ankle	AP/OBL	40	T	100	64	9	1.80	2.40	3.60	4.80	7.20	9.60	14.40	19.20
	LAT	40	T	100	64	8	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
Tibia / Fibula	AP	40	T	100	68	11	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
	LAT	40	T	100	68	10	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
Knee	AP	40	T	100	70	12	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
	LAT	40	T	100	70	11	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
	AP/OBL	40	B	100	70	12	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
	LAT	40	B	100	70	11	2.50	3.33	5.00	6.67	10.00	13.33	20.00	26.67
Femur	AP/LAT	40	B	400	76	16	6.00	8.00	12.00	16.00	24.00	32.00	48.00	64.00
Shoulder	AP/Transax	40	B	400	76	18	3.00	4.00	6.00	8.00	12.00	16.00	24.00	32.00
	Transthoracic	40	B	400	90	40	7.50	10.00	15.00	20.00	30.00	40.00	60.00	80.00
Clavicle	AP/PA	40	B	400	74	16	3.00	4.00	6.00	8.00	12.00	16.00	24.00	32.00
Scapula	AP	40	B	400	74	18	3.00	4.00	6.00	8.00	12.00	16.00	24.00	32.00
	LAT	40	B	400	74	24	5.00	6.67	10.00	13.33	20.00	26.67	40.00	53.33

Example of an exposure chart for computed radiography for a three phase, twelve pulse generator. The image receptor codes are: W = wall Bucky with grid, B = under table Bucky with grid, T = table top non-grid. Distances are in inches. When constructing a clinical exposure chart, the mAs values in this chart are adjusted to match the nearest mAs station available on the generator.

Use caution in applying this chart to any specific CR implementation since X-ray generator output characteristics and CR plate energy sensitivities vary widely.

APPENDIX E

Mobile CR Exposure Chart for Trauma Radiology

Body Part	Position	Patient Size	kVp	mAs	Distance	Speed Class	Grid
CHEST	PA/AP Upright 72"	Small	80	5	72"	200	N
		Average	85	10	72"	200	N
		Large	90	16	72"	200	N
	PA/AP	Small	70	5	40"	200	N
		Average	75	8	40"	200	N
		Large	85	10	40"	200	N
	Lateral-72"	Small	85	10	72"	200	N
		Average	90	20	72"	200	N
		Large	95	32	72"	200	N
	Lateral	Small	75	10	40"	200	N
		Average	80	16	40"	200	N
		Large	90	20	40"	200	N
	AP	Newborn	65	0.5	40"	400	N
	Lateral	Newborn	70	1	40"	400	N
ABDOMEN	AP-Grid	Average	70	48	40"	400	Y
ANKLE	AP	Average	55	12.5	40"	100	N
	Lateral	Average	55	10	40"	100	N
CERVICAL SPINE	AP	Average	60	7.5	40"	400	N
	Lateral-72"	Average	65	15	72"	400	N
ELBOW	AP	Average	55	12.5	40"	100	N
	Lateral	Average	55	10	40"	100	N
FEMUR	AP/Lateral	Average	55	10	40"	400	N
FOOT	AP	Average	52	8	40"	100	N
HAND/WRIST	PA	Average	50	5	40"	100	N
	Lateral	Average	55	8	40"	100	N
HUMERUS	AP/Lateral	Average	55	2.5	40"	100	N
KNEE	AP	Average	55	25	40"	100	N
	Lateral	Average	55	16	40"	100	N
LUMBAR SPINE	AP-Grid	Average	75	48	40"	400	Y
	Lateral-Grid	Average	85	150	40"	400	Y
PELVIS/HIP	AP	Average	55	24	40"	400	N
	AP-Grid	Average	70	60	40"	400	Y
	Lateral-Grid	Average	80	75	40"	400	Y
SHOULDER/CLAVICLE	AP	Average	55	5	40"	400	N
SKULL	AP	Average	60	16	40"	400	N
	Lateral	Average	55	10	40"	400	N
	AP-Grid	Average	75	20	40"	400	Y
	Lateral-Grid	Average	65	10	40"	400	Y
THORACIC SPINE	AP	Average	65	16	40"	400	N

Typical portable radiography exposure chart for CR used in an emergency medicine trauma setting. This example includes the use of three different speed classes, depending on the clinical situation. Note the use of lower kVps, longer exposure times and minimal use of grids in this portable trauma setting compared to the previous fixed three phase generator exposure chart. Use caution in applying this chart to any specific CR implementation since X-ray generator output characteristics and CR plate energy sensitivities vary widely.

APPENDIX F

EXPOSURE CHART

Example of CR Exposure Chart Using Grids & Standardized Parameters

Anatomical Region	Exam	Measurement (CM)	SID	GRID	KVP	Small	Medium	Large
Chest*	Chest Portable AP	20-30 cm	50"	Yes*	110 kVp	6 mAs	10 mAs	12 mAs
Skull	Skull PA/AP	18-21 cm	40"	Yes	80 kVp	12 mAs	20 mAs	30 mAs
	Skull Lateral	14-17 cm	40"	Yes	80 kVp	6 mAs	12 mAs	18 mAs
Spine	Cervical AP	11-14 cm	40"	Yes	80 kVp	6 mAs	12 mAs	18 mAs
	Thoracic AP	20-24 cm	40"	Yes	80 kVp	18 mAs	26 mAs	40 mAs
	Lumbar AP	18-22 cm	40"	Yes	80 kVp	24 mAs	40 mAs	64 mAs
Abdomen	Abdomen (KUB)	18-22 cm	40"	Yes	80 kVp	24 mAs	40 mAs	64 mAs
Pelvis	Pelvis AP	19-23 cm	40"	Yes	80 kVp	24 mAs	40 mAs	64 mAs
	Hip AP	17-21 cm	40"	Yes	80 kVp	20 mAs	35 mAs	50 mAs
	Cross Table Lateral Hip	25-31 cm	40"	Yes	85 kVp	30 mAs	42 mAs	55 mAs
Upper Extremities	Finger	1.5-4 cm	40"	No	60 kVp	1 mAs	1 mAs	2 mAs
	Hand AP/OBL	3-5 cm	40"	No	60 kVp	1 mAs	2 mAs	4 mAs
	Hand Lateral	3-5 cm	40"	No	60 kVp	2 mAs	3 mAs	4 mAs
	Wrist AP/OBL	3-6 cm	40"	No	60 kVp	1.5 mAs	2 mAs	3 mAs
	Wrist Lateral	3-6 cm	40"	No	60 kVp	1.5 mAs	3 mAs	4 mAs
	Forearm AP	6-8 cm	40"	No	60 kVp	2 mAs	3 mAs	4 mAs
	Forearm Lateral	6-8 cm	40"	No	60 kVp	2 mAs	3 mAs	4 mAs
	Elbow	6-8 cm	40"	No	60 kVp	2 mAs	3 mAs	4 mAs
	Humerus	7-10 cm	40"	Yes	80 kVp	6 mAs	10 mAs	13 mAs
	Shoulder	12-16 cm	40"	Yes	80 kVp	7 mAs	12 mAs	15 mAs
Lower Extremities	Toes	1.5-4 cm	40"	No	60 kVp	1.5 mAs	2.5 mAs	4 mAs
	Foot AP/OBL	6-8 cm	40"	No	60 kVp	2 mAs	3 mAs	5 mAs
	Foot Lateral	6-8 cm	40"	No	60 kVp	2.5 mAs	4 mAs	6 mAs
	Ankle AP	8-10 cm	40"	No	60 kVp	3 mAs	5 mAs	7 mAs
Lower Extremities	Ankle Lateral	8-10 cm	40"	No	60 kVp	2 mAs	3 mAs	6 mAs
	Tib/Fib AP	10-12 cm	40"	No	60 kVp	2 mAs	4 mAs	6 mAs
	Tib/Fib Lateral	10-12 cm	40"	No	60 kVp	2 mAs	4 mAs	6 mAs
	Knee AP/Lateral	10-13 cm	40"	No	60 kVp	6 mAs	12 mAs	20 mAs
	Knee AP/Lateral	10-13 cm	40"	Yes	80 kVp	3 mAs	5 mAs	8 mAs
	Femur AP/Lateral	14-17 cm	40"	Yes	80 kVp	15 mAs	25 mAs	40 mAs

*use short dimension (decubitus) grid, position cassette always cross-wise (landscape) (20-25 cm) (25-30 cm) (>30 cm)

Example of an exposure chart developed for bedside CR radiography with standardization of parameters. In this example, all AP chest examinations are performed cross-wise (landscape orientation). All adult chest procedures are performed using a decubitus grid. Patients are inclined, as their condition allows, to get as close to upright as is possible.

Use caution in applying this chart to any specific CR implementation since X-ray generator output characteristics and CR plate energy sensitivities vary widely.

*Guidelines and standards are published annually with an effective date of October 1 in the year in which amended, revised or approved by the ACR Council. For guidelines and standards published before 1999, the effective date was January 1 following the year in which the guideline or standard was amended, revised or approved by the ACR Council.

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