ACR–AAPM–SIIM–SPR PRACTICE PARAMETER FOR DIGITAL RADIOGRAPHY

The American College of Radiology, with more than 40,000 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 parameters 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 parameters and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice parameter 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 and approval. The practice parameters 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 parameter and technical standard by those entities not providing these services is not authorized.

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents 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 practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, 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 this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and 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 the guidance in this document 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 purpose of this document is to assist practitioners in achieving this objective.

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1 *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the "ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures (Revised 2008)" sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.*

I. INTRODUCTION

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

The intent of this document is to provide guidance and assistance in the understanding and clinical use of digital radiography (DR) equipment (other than mammography) to deliver necessary image quality at an appropriate radiation dose and to ultimately provide excellent safety and care for patients undergoing digital radiography examinations. An introduction to the realm of digital radiography, including definitions, is presented in this section. 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 II.

This practice parameter is applicable to the practice of digital radiography. It defines qualifications of personnel, equipment guidelines, data manipulation, data management, quality control (QC), and quality improvement (QI) procedures for the use of digital radiography that should result in optimal radiological patient care.

Medical imaging and patient information are managed using 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 and outcomes.

For the purpose of this document, the practice of digital radiography refers to projection X-ray imaging that uses a digital X-ray detector to capture the X-ray image. Digital X-ray detectors are typically classified as either computed radiography (CR) or digital radiography (DR). CR uses a photostimulable storage phosphor that stores a latent image, which is subsequently read out using a stimulating laser beam. DR is used to describe any X-ray detector that electronically reads out an X-ray signal immediately after exposure. Despite the fact that DR has been used for a specific acquisition technology, both CR and DR refer to digital detection methods, and both should be considered as part of this practice parameter.

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

Medical imaging is performed only when there is a valid clinical indication to do so and when the findings are likely to affect clinical decision making. Each formal request for medical imaging requires adequate clinical information to justify the study. ACR Appropriateness Criteria® should be considered when choosing the appropriate imaging procedure for the clinical situation. Examinations that are not medically necessary should not be performed.

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [1].

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

Individuals performing digital radiography 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, or a licensed and/or registered radiologic technologist. The radiologist assistant or technologist performing digital radiography procedures must be under the supervision of a qualified licensed physician.

A. Physician
   1. Images must be obtained under the supervision of, and interpreted by, a licensed physician with the following qualifications:
      a. Certification in Radiology, Diagnostic Radiology, or Interventional Radiology/Diagnostic Radiology (IR/DR) by the American Board of Radiology, the American Osteopathic Board of Radiology, the Royal College of Physicians and Surgeons of Canada, or the Collège des

Médecins du Québec.
or

b. Completion of a diagnostic radiology residency program approved by the Accreditation Council for Graduate Medical Education (ACGME), the Royal College of Physicians and Surgeons of Canada (RCPSC), the Collège des Médecins du Québec, or the American Osteopathic Association (AOA) to include radiographic training on all body areas and documentation of a minimum of 6 months of formal dedicated training in the interpretation and formal reporting of general imaging for patients of all ages.
or

c. Physicians not board certified in radiology or not trained in a diagnostic radiology residency program who assume the responsibilities for digital radiography should limit themselves to the specific anatomic areas pertinent to their specialty practice.
and

2. Physicians should understand the basic technology of digital radiography: image acquisition, transmission, manipulation, processing, archiving, retrieval, and display, including the strengths, weaknesses, and limitations of different methods. They should be knowledgeable in how to optimally use the image viewing equipment. Where appropriate, the interpreting physician must be familiar with the principles of radiation protection and radiation monitoring requirements as they apply to both patients and personnel. The physician performing the official interpretation[1] must be responsible for the quality of the images being reviewed and understand the elements of QC of digital image management systems[2]. 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 and/or changes in image quality.
and
3. The physician must have documented training and an understanding of other medical imaging modalities (eg, fluoroscopy, CT, ultrasound, MRI, nuclear medicine) to determine the best imaging examination to answer clinical questions and ensure diagnostic efficiency and patient safety.

Maintenance of Competence

All physicians interpreting radiography examinations should demonstrate evidence of continuing competence in the interpretation and reporting of those examinations.

4. Continuing Medical Education

The physician's continuing medical education should be in accordance with the ACR Practice Parameter for Continuing Medical Education (CME) [2] and should include CME in radiography as is appropriate to the physician practice.

B. Qualified Medical Physicist

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 (ACR) considers certification, 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 strongly 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, the American Board of Science in Nuclear Medicine (ABSNM), or the American Board of Medical Physics (ABMP).
A Qualified Medical Physicist should meet the ACR Practice Parameter for Continuing Medical Education (CME) [2].
The appropriate subfield of medical physics for this parameter is Diagnostic Medical Physics (including medical physics certification categories of Diagnostic Radiological Physics, Radiological Physics, and Diagnostic Imaging Physics). (ACR Resolution 17, adopted in 1996 – revised in 2008, 2012, 2022, Resolution 41f)

A Qualified Medical Physicist must be on site or available as a consultant. See the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Radiographic Equipment [3].

C. Non-Physician Radiology Provider (NPRP)

NPRPs are all Non-Physician Providers (eg, RRA, RPA, RA, PA, NP, ...) who assist with or participate in portions of the practice of a radiologist-led team (Radiologists = diagnostic, interventional, neurointerventional radiologists, radiation oncologists, and nuclear medicine physicians). The term "NPRP" does not include radiology, CT, US, NM MRI technologists, or radiation therapists who have specific training for radiology related tasks (eg, acquisition of images, operation of imaging and therapeutic equipment) that are not typically performed by radiologists.

The term 'radiologist-led team' is defined as a team supervised by a radiologist (ie, diagnostic, interventional, neurointerventional radiologist, radiation oncologist, and nuclear medicine physician) and consists of additional healthcare providers including RRAs, PAs, NPs, and other personnel critical to the provision of the highest quality of healthcare to patients. (ACR Resolution 8, adopted 2020).

D. Radiologic Technologist

The radiologic technologist should be certified by the appropriate registry and must possess the training and licensure required by state and/or local regulations.

Additional specific qualifications and responsibilities include:

a. The individual must meet the qualification requirements of any existing ACR practice parameter or technical standard for acquisition of a particular examination.
b. The individual must be trained to properly operate those portions of the image data management system with which the individual must routinely interact. This training should include as appropriate:
    i. Image acquisition technology
    ii. Image processing protocols
    iii. Proper selection of examination specific options
    iv. Image evaluation
    v. Radiation dose indicators
c. The individual must be trained in radiation safety and patient safety procedures.

E. Imaging Informatics Professional

See the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4]. The imaging informatics professional 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.

The responsibilities and experience for an imaging informatics professional include:

Maintenance of the network for all informatics systems (eg, Radiology Information System [RIS], Picture Archiving and Communication System [PACS], speech recognition systems, and computer servers and desktops).

[1] 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.

[2] 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."

III. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for radiography should provide sufficient information to demonstrate the medical necessity of the examination and allow for its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). Additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state's scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

IV. DOCUMENTATION

Physicians officially interpreting examinations[1] using digital image data management systems should render reports in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [5].

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

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V. EQUIPMENT SPECIFICATIONS

Specifications for equipment used in digital image data management will vary depending on the application and the individual facility's needs, but in all cases, they should provide image quality and availability appropriate to the clinical needs.

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 QC program should be designed to maximize the quality and accessibility of diagnostic information.

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Radiographic Equipment [3].

V. EQUIPMENT SPECIFICATIONS

A. Image Availability and Information Standardization

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–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 QC program. Compliance with the Radiological Society of North America and Healthcare Information and 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.

Specifications and usage guidelines related to standards and interoperability include:

1. Digital radiographic devices must provide images that conform to the DICOM standard "CR" or "DX" service class objects. These objects' header fields specify 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 body part orientation (eg, right, left, superior, inferior), amount and method of data compression, and total number of images acquired in the study.

2. The use of DICOM modality work lists is recommended to help ensure the quality and accuracy of the information captured in the DICOM metadata (eg, header or structured report).

3. The use of the DICOM "DX" service class object is recommended instead of the more limited "CR" object for digital radiography [6].

4. It is recommended to use DICOM grayscale soft-copy presentation state (GSPS) objects to transmit annotations, shutter, and display lookup tables (LUTs) [7]. Where GSPS is not available or not supported by PACS, the use of a values-of-interest lookup table (VOI-LUT) within the "CR" or "DX" service class object is suggested.

5. Details related to image acquisition, such as tube potential (kV), tube current (mA), exposure time, beam filtration, source to image distance, the International Electrotechnical Commission (IEC) 62494-1 detector exposure indicator (EI), target exposure index (EI_T), deviation index (DI), and organ-specific postprocessing algorithm employed, should be recorded in the DICOM metadata.

6. All exposure events in a radiographic examination and related data should be stored as a DICOM Radiation Dose Structured Report (RDSR). This provides complete exposure information for dose monitoring but can allow for calculation of reject rates.

V. EQUIPMENT SPECIFICATIONS

B. Acquisition

Image acquisition should be performed in accordance with examination specific ACR practice parameters and technical standards.

1. The following information should be visible on all images:
    a. Patient identification
    b. Facility identification
    c. Examination date and time
    d. The side (right or left) of the anatomic site imaged
    e. Identifier of person performing the examination

2. All facilities performing radiography should have protocols for the standard view or views of each anatomic area of interest. These should be designed to optimize diagnostic information while minimizing radiation exposure.

3. Appropriate collimation should be used to limit exposure to the anatomic area of interest.

4. Institutional policies/procedures for grid sue (or lack thereof) or software-based scatter corrections should be established and implemented in consultation with a Qualified Medical Physicist.

5. Detector EIs for digital radiography

    Considering the wide exposure latitude of digital radiographic devices, the visual appearance of brightness and contrast in radiographic images is a poor indicator of the appropriateness of the exposure delivered to the image receptor. Digital radiographic devices can create satisfactory images over a wide range of input exposures, including exposures that are significantly greater than are clinically necessary. For images acquired with higher than desired exposure, the patient unnecessarily receives excessive radiation dose. Images acquired at lower than required exposures may have unacceptably high noise levels.
    To provide feedback on the appropriateness of an acquisition technique for a particular patient, anatomy, and view, vendors provide EIs that are related to the incident air kerma to the detector. Vendor-specific EIs,

still in use in digital radiography, are not easily comparable or similarly applied. This can make it difficult for technologists to interpret exposure feedback if they are required to use systems with different types of EIs. Additional information on EIs is described in the IEC report 62494-1 [8].

To be able to provide feedback to technologists, the EI, EI_T, and DI should be configurable for display on the acquisition workstation as best fits the practice QA workflow.

The intended purpose of the DI is to provide an exposure-appropriateness index that can be compared across vendor systems and relieves the technologist from having to memorize system-specific target EI values, EI_T. For the DI to provide useful feedback about acquisition technique, the EI_T must be set appropriately. Although the IEC standard EI may be in use between vendor systems, this does not mean different systems will share the same target values, EI_T. Target values, EI_T, vary with the DR system, image receptor type, anatomy, view or positioning, processing parameters, and patient size. Target values, EI_T, should be set with radiologist feedback and selected to minimize the exposure to the patient while providing diagnostic images (ie, with sufficient signal to noise ratio). Ongoing monitoring and review of DI data with consultation of a Qualified Medical Physicist should be a component of the ongoing QC program [9]. The target exposure values, EI_T, needs to be accessible and editable by the qualified personnel, as determined by the practice.

6. Exposure creep

In digital radiography, excessive exposure to the detector can produce high-quality images with improved noise properties. Unless there is an understanding that these higher quality images come at the cost of increased patient exposure and strategies are in place to control patient exposure, a radiologic practice may experience "exposure creep" [10]. Exposure creep results when there is negative radiologist feedback for high-noise images made with low exposures but a lack of negative feedback or even positive feedback for low-noise images made with high exposures. As technologists respond to this feedback, patient exposures may gradually increase over time. A Qualified Medical Physicist should be consulted to implement an ongoing QC program to monitor appropriateness of DR exposures using DI data as described in the previous section. Use of modern radiation dose-monitoring software platforms may help in monitoring DI distributions and setting of appropriate target exposure values, EI_T, for various examinations and various age groups.

Exposure creep can also be prevented by using validated radiographic techniques as a function of patient size for all performed examinations. Technique charts should encourage the use of appropriate automatic exposure control (AEC) settings (single cell versus a combination of multiple AEC cells) for most of the body radiographic examinations. The AEC system is designed to deliver calibrated and reproducible doses to the image receptor across a wide range of operating conditions, including X-ray beam quality and patient size. Often these factors are entered into the anatomical programming of X-ray generator controls. If the technologist uses these programs, the facility is very likely to use appropriate radiographic technique factors with the appropriate level of radiation exposure. Consistent and optimal AEC performance is critical to radiation dose management and image quality. Qualified Medical Physicists should perform the appropriate tests to ensure the expected performance of AEC modules [11].

Unnecessary patient exposure will also increase if the repeated imaging rate increases. In addition to monitoring of DI, analysis of repeated and/or rejected image counts should be monitored as part of a comprehensive DR QA program.

7. Radiographic technique considerations for digital radiography
    a. Determining proper technique charts for standard examinations

    Exposure (technique) charts are part of the standard of care expected by the Joint Commission and are required by regulations in many states. It is necessary to check state and/or local regulations for any specific requirements. Computation of estimates for entrance skin exposures for these charts may also be required.

    Because of the wide latitude of digital image receptors and the availability of image processing to alter the brightness and contrast of images, the visual appearance of images can be made similar over a wide range of acquisition techniques. The primary effects of modifying an acquisition technique are changes in:

1. The level of noise in the image
2. The exposure duration and potential for patient motion artifacts
3. Patient radiation exposure
4. Potential artifacts (in DR) related to detector saturation and image lag

Baseline or initial exposure technique charts are typically provided by equipment manufacturers, either as prescriptions for manual radiographic technique or programmed examination-specific options in the X-ray generator.

Exposure technique charts must be tailored for each digital radiography X-ray generation detector and processing combination as well as patient population and size [12]. There is considerable variability in image receptor response owing 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.
In addition, exposure charts should be designed to function over a wide range of adult and pediatric patient sizes [11]. This task of building optimized technique charts is a team effort involving the technologist, radiologist, administrative leadership, and the Qualified Medical Physicist, and is a continuous process requiring collaborative efforts of each member of the team [13].

b. AEC

AEC systems are designed to terminate the exposure when the desired dose has been received at the image receptor. This dose may vary as a function of X-ray beam energy, with the presence or absence of an antiscatter grid, or with the sensitivity (often misstated as "speed") setting of the AEC. AEC works well when the AEC system is properly calibrated and the body part being imaged is centered over the active AEC region(s) (cells). AEC may fail to deliver the desired receptor dose if the desired anatomy is not centered over the active region(s), if the incorrect region(s) is selected, or if an object within the active region(s) of the AEC system is of a markedly different density than tissue (eg, a prosthesis in the hip of a patient) [12,14]. If this is anticipated, an appropriate size-based manual (fixed) techniques should be used. If the AEC system is covered by such an object, the backup timer must be configured to terminate the exposure prior to the regulatory maximum milliamperes being delivered [15].

c. Assessing appropriateness of exposure

As described in section III.B.2, the DI should be reviewed for each clinical exposure and compared with the desired range for the specific body part and view acquired. These ranges can be used to develop radiographic technique charts or to monitor for dose creep in a practice. For absolute DI values to be clinically meaningful, the EI_T must be set appropriately. In typical clinical practice, wide distributions of the DI are observed. It is important that each practice review DI data to establish recommended limits and targets for QI. Clinical radiographs can be acceptable across a wide range of receptor doses, and a DI value that is extreme should not be cause for immediately repeating an image without careful review and a potential consult with a radiologist. Whenever feasible, images should be reviewed for diagnostic quality before the patient is released. Repeat imaging should be performed as appropriate for diagnostic quality. Extreme DI values should be logged for review at periodic QI committee meetings [9].

d. Pediatric imaging considerations

As with all imaging examinations involving ionizing radiation, digital radiography should be performed using the lowest radiation exposure to the patient that is consistent with image quality requirements. This is especially important when imaging pediatric patients, who are more sensitive to ionizing radiation than adults [14,16]. However, reducing exposure without assessing image quality increases the possibility of unacceptably high quantum noise. Also, the appropriate reduction in exposure to the image receptor depends on how well the digital system is optimized for pediatric imaging and on the nature of the particular condition being diagnosed [17].

Commitment and effort on the part of the technologist to achieve exposure reduction in pediatric imaging consistently is of paramount importance. Optimization issues in pediatric imaging and relevant topics are addressed in more detail elsewhere [18].

Pediatric patients present unique challenges when imaged with digital radiography. Patients range in size from the neonate to the young adult, requiring a wide range of radiographic technique factors. Spatial resolution demands are higher in pediatric imaging owing to smaller body parts being imaged. Clinical use of AEC with children offers additional challenges since the pediatric organs being small may result in partial coverage of active AEC regions, resulting in artificially shortening of the radiographic exposure.

Routine use of gonadal shielding is no longer recommended [19,20]. The ICRP tissue-weighting factor for gonads has substantially decreased, from 0.25 in Publication 26 in 1977 to 0.20 in Publication 60 in 1990 and, most recently, to 0.08 in Publication 103 in 2007. Gonadal shields cannot protect against internal scatter, may be positioned incorrectly, may inadvertently move between positioning and exposure [21], may obscure the area of interest and necessitate repeat imaging, and, if they cover the active AEC region(s), may substantially increase radiation exposure. In rare cases, patient shielding may be an effective means of alleviating patient anxiety; in those cases, the priority should be to ensure that the shielding device does not adversely impact the quality of the examination [19].

The decision to use an antiscatter grid must be carefully considered as a function of patient size and field of view (FOV) [22]. If a grid is employed, use of a source-to-image distance consistent with grid focus is recommended to optimize image quality and dose [23,24]. Use of additional filtration, such as 0.1-mm copper or more, is recommended to reduce entrance skin air kerma at the patient surface for pediatric patients. The use of additional filtration may require optimizing the image processing parameters to account for a different X-ray energy spectrum incident upon the image receptor. A clinical team composed of a diagnostic Qualified Medical Physicist, an application specialist from the equipment manufacturer, an experienced technologist, and a radiologist will help achieve this objective in an efficient fashion.

Standard positioning aids used to immobilize pediatric patients may generate unacceptable artifacts when used with digital image receptors. Image processing and display parameters used by the digital acquisition device to properly display the digital image may need to be configured as a function of patient size [16]. Image processing and display parameters may require further alteration if gonadal shielding or orthopedic implants appear in the displayed image. Finally, because 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. Use of newer technology, such as slot scan units for orthopedic imaging, may further reduce dose associated with these examinations. Additional information regarding pediatric imaging best practices can be found at the Image Gently website: www.imagegently.org.

V. EQUIPMENT SPECIFICATIONS

C. Image Processing

For digital imaging, image processing can be divided into 2 parts.

Preprocessing is performed on the raw output of the digital detector and accounts for various performance and engineering deficiencies of the image receptor.

Postprocessing is used to optimize the contrast, sharpness, and latitude of the image to be displayed at the radiologist review work station [25].

Technologists must be trained to understand that the image processing applied to an image is related to, and may be unique to, their selection of anatomy, view, and patient size.

1. Preprocessing

   The image receptor on most digital radiography systems stores an electronic charge that is monotonically related to the amount of radiation energy absorbed. At this stage, the signal (charge) is a linear function of the incident radiation exposure. Preamplifiers and an analog-to-digital converter transform the charge from each detector element to an integer representing the raw data image value. The detector output with no

processing applied is referred to as a raw image. This image is typically not accessible to physicists. Several corrections are applied to the raw image values to obtain values suitable for image processing. These corrections include interpolating **to** account for bad pixels, adjusting for nonuniformity of response of the image receptor in the form of gain correction, and offsetting corrections to account for dark signal.
DR system users should ask the supplier for information indicating the number and type of bad pixels that are being corrected. QC programs should include a process to report any new bad pixels that may develop during the lifetime of the system. Nonuniformity corrections generally require running a system utility program periodically, during which uniform exposures are acquired. Users should identify the required procedure for each type of system being used and ensure that the procedures are being followed. Some manufacturers require calibration to be performed by the technologist, whereas for others it is the service engineer's responsibility [26,27]. The calibration process establishes a relationship between the pixel values and the deposited X-ray energy. Depending on the equipment manufacturer, this relationship may be linear or logarithmic. The type of calibration, number of calibration exposures, and bit depth available varies between different vendors and within a vendor for given systems or detectors. The output of preprocessing a raw image is an image referred to as *For Processing* or *Original* image [28]. This image should be available to the Qualified Medical Physicist for quantitative image quality assessment.
For Processing images
Most DR systems transform the preprocessed value to a value proportional to the logarithm of the input exposure. Logarithmic signals have the property that a fractional change in signal, due to the contrast of adjacent structures, produces a fixed change in the raw image value independent of subject penetration and input exposure. These values are the *For Processing* images values and may be stored in DICOM image objects. The AAPM further recommends specific units for normalized *For Processing* image values [28].
In some operations, users may archive *For Processing* images so that they may be processed at a later date. For example, when reading a current digital chest image, it may be desirable for a prior chest image to be processed using the same method. Another use case involves CAD systems that require *For Processing* images.

2. Postprocessing DR image processing operations

    a. Histogram analysis
    The objective of histogram analysis is to determine the span of original image pixel values that correspond to anatomical image information. The histogram shapes vary significantly depending upon the anatomy under consideration. An important aspect of histogram analysis is the identification and segmentation of the background and collimated regions, which have no anatomical information. The useful pixel values are passed on to the postprocessing algorithm for contrast and edge enhancement. The IEC exposure index is based on measures of the clinically relevant histogram in the original image. Failure of the postprocessing software to correctly identify the useful pixel values (values of interest or VOI) can result in both improperly processed images and improperly calculated exposure index. In these cases, images may be overall washed out, too light, or too dark. Technologists should be trained to identify when this occurs and to address this by shuttering or VOI selection followed by reprocessing to avoid unnecessary retakes.

    b. Contrast and frequency enhancement
    Image processing operations are performed on *For Processing/Original* images to obtain *For Presentation* images suitable for interpretation. Suppliers of digital imaging equipment may provide image processing software that can restore the sharpness of edges, enhance detail contrast for images with a wide range of input exposures, and reduce noise [28]. Detail contrast can be enhanced by multifrequency processing that equalizes image brightness over broad areas by operating on low spatial frequencies. Frequency-based processing can also impact noise texture. Radiologists and technologists should familiarize themselves with the appearance of underexposed or noisy images relevant for the image processing in use.

    The parameters used to process images need to be specifically determined for all body parts and views that will be encountered. This also may vary with radiologist preference. Consequently, close cooperation between the equipment manufacturer's installation engineer, application specialist, site

technologist, radiologist, administrator, and the Qualified Medical Physicist is critical to optimization of the image postprocessing process for various examinations in an efficient fashion.

As a part of the operations that transform *For Processing* images to *For Presentation* images, the image values in the anatomical regions of interest, referred to as the VOI, are identified and used to compute an LUT used to display the *For Presentation* values. Earlier systems applied the VOI-LUT in the DR systems and sent these image values within the DICOM object. If using the VOI-LUT, it should be sent, and the image display software should transform the values at the workstation. This allows the user at the workstation to make further adjustment in the grayscale of the image. The VOI are also used to calculate the EI and DI (see section B.2). The edges of the collimated regions of the image should be recognized by the system and the regions outside of the collimators masked to prevent presentation of large bright regions to the radiologist and to ensure accurate computation of the EI. It is preferable that this mask be encoded in the DICOM image as an overlay so that if needed it can be removed to see information that might be near the collimated edge, such as a marker.

3. Electronic Collimation

Electronic collimation is used to electronically mask areas of the digital image before being sent for interpretation or archiving. Although there is controversy regarding the use of electronic collimation, there are situations in which it is necessary and appropriate.
Depending upon the image histogram, the segmentation of the collimated or background regions may not be accomplished properly by the automated algorithm. In such circumstances, the technologist may need to electronically collimate to exclude these areas to improve the grayscale rendering and reduce possible veiling glare from areas that appear very bright. It is desirable to visualize the penumbra of the physical collimators to verify appropriate X-ray beam collimation. This is visualized by a thin, bright band around the image [26]. This millimeter-wide white margin around the image appears bright on the radiographic image because minimal X-rays hit the detector beyond the edges of the collimated beam.
Electronic collimation can be used for inappropriate purposes, such as to hide poor X-ray beam collimation (eg, using too large a field-of-view for a given protocol). Such uses are contrary to good radiation safety practices and pose ethical challenges. Electronic collimation should never be used to mask areas of the image having anatomical information.

V. EQUIPMENT SPECIFICATIONS

D. Image Data Integrity and Transmission

1. Compression

Data compression may be performed to facilitate image transmission and storage. The type of medical image, the modality, and the objective of the study will determine the degree of acceptable compression. For more information on image compression, see the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4].

2. Data transmission

The environment in which imaging studies are to be transmitted will determine the types 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.
Additional consideration should be given for devices that rely on wireless networking capabilities. Such systems are increasingly common in digital radiography, especially those used for bedside radiography. The wireless transmission of information may be between the digital detector and the acquisition workstation (ie, wireless DR detectors) or between the acquisition workstation and the institutional PACS (ie, bedside imaging) or both. Provisions should be made for:

a. The prevention of signal interference and corruption between different systems communicating on

the same wireless network.

b. Appropriate signal encryption to protect patient health information **(**PHI**).**
c. A strategy for loss-prevention and image recovery for images that have interrupted transmission or corrupted transmission, especially for the communication between the detector and acquisition workstation, which is less likely to use a DICOM standard transaction with storage-commitment functionality.
d. A strategy to protect PHI if mobile viewing devices are lost (eg, remote data wipe).

For further details refer to the ACR–AAPM–SIIM Practice Parameter for Electronic Medical Information Privacy and Security and the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4,29].

3. Security

See the ACR–AAPM–SIIM Practice Parameter for Electronic Medical Information Privacy and Security [29].

4. Archiving and retrieval, reliability and redundancy, and work and room environmental and ergonomic considerations

See the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4].

5. Display capabilities

The consistent presentation of images across different workstation display monitors is essential for a quality imaging practice. Image quality is influenced by workstation software, graphic controllers, and display devices, which vary substantially across a range of parameters and display characteristics as described in the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4]. The preferred method to achieve similar display characteristics and consistent image appearance is to implement the DICOM Part 14 Grayscale Standard Display Function (GSDF) [30] calibration procedure for all image display monitors in order to preserve the perceptual variations in pixel values of an image as perceived by a human viewer, even when viewing monitors with different luminance values. Although GSDF calibration is typically a standard practice for primary diagnosis display monitors on medical-grade PACS workstations, manufacturers of radiography devices and technologist QC imaging workstations should also provide calibration procedures and demonstration of quantitative conformance to the DICOM GSDF as part of acceptance testing and periodic QC procedures for their displays. At a minimum, third-party GSDF calibration software should be made available and implemented for all radiography display devices and QC workstations.
Images are viewed by technologists during acquisition, by radiologists during interpretation, and by referring physicians as a part of patient care and should have a similar appearance for all viewers. The following uses emphasize the importance of choosing appropriate display equipment and settings, as well as the importance of regular calibration and maintenance as part of a QC program.

a. Image modifications are most often made by the technologist at the acquisition workstation. Technologists may modify image processing to try to match the appearance desired by radiologists. If the acquisition display does not meet the specifications for consistent presentation of images (as described in the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4]) or is not calibrated or maintained properly, this image modification process is particularly challenging.
b. A primary method for a radiology technologist to discern whether a low-exposure image acquisition needs to be repeated is by comparison of the noise levels in the image with the desired diagnostic appearance. Visualizing image noise may be difficult on poor performing displays. Noise evaluation can be accomplished visually using the TG 18-AFC test pattern and following the methods described in the AAPM Task Group Report 18 document [31].
c. Owing to the nature of use of point-of-care digital radiographic devices (ie, DR mobile X-ray systems), they are often used for primary diagnostic tasks. Given that digital images are

available for immediate review, it is not uncommon for digital radiographic devices to be used at the point of care, such as in mobile imaging. If images are to be officially interpreted at the device rather than on a diagnostic interpretation workstation, digital radiography manufacturers should provide high**,** interpretation-quality, display options as outlined in the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging for displays on these devices on which diagnostic or primary interpretation tasks might be performed or on which images are modified [4].

d. If the technologists are using QC stations for postacquisition image analysis prior to sending the images to PACS, then appropriate display monitors should be provided at the technologist QC station. Ideally these monitors should satisfy the minimum specifications as outlined in the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4].

Guidelines for viewing digital radiography images can be found in the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [4].

VI. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, non-physician radiology providers**,** radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel who work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, application of dose constraints and limits) and the principles of proper management of radiation dose to patients (justification, optimization including the use of dose reference levels). https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1775_web.pdf

Nationally developed guidelines, such as the ACR's Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unnecessary radiation exposure.

Facilities should have and adhere to policies and procedures that require ionizing radiation examination protocols (radiography, fluoroscopy, interventional radiology, CT) to vary according to diagnostic requirements and patient body habitus to optimize the relationship between appropriate radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used, except when inappropriate for a specific exam. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available from the following websites – Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org). These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be periodically measured by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Monitoring or regular review of dose indices from patient imaging should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry and relevant publications relying on its data, applicable ACR Practice Parameters, NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends; 2006, 2009, amended 2013, revised 2023 (Res. 2d).

VII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECITON 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 Quality Control & Improvement, Safety, Infection Control*, *and Patient Education* on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

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Writing Committee – members represent their societies in the initial and final revision of this practice parameter

ACR

Diana E. Carver, PhD, Co-Chair

Ashley Erin Rubinstein, PhD, Co-Chair

Candice A. Johnstone, MD

Jessica Kurian, MD

AAPM

Courtney K. Morrison, PhD

John M. Sabol, PhD

SIIM

Peter A. Harri, MD

SPR

Ellen May-Wai Chung, MD

Priya G. Sharma, MD

Committee on Practice Parameters and Technical Standards – Medical Physics

(ACR Committee responsible for sponsoring the draft through the process)

Mary Ann Keenan, DMP, Chair

Maxwell R. Amurao, PhD, MBA

Katherine P Andriole, PhD

Eric Arthur Berns, Ph.D, FACR

Samuel A. Einstein, PhD

Per H. Halvorsen, MS, FACR

Ralph P. Lieto, MS, FACR

Osama Mawlawi, PhD, FACR

Committee on Practice Parameters and Technical Standards – Medical Physics

(ACR Committee responsible for sponsoring the draft through the process)

Priscilla F. Butler, MS, FACR

Diana E. Carver, PhD

Heidi A. Edmonson, PhD

Tariq A. Mian, PhD, FACR

Douglas E. Pfeiffer, MS, FACR

Ashley Erin Rubinstein, PhD

Committee on Practice Parameters – General, Small, Emergency and/or Rural Practices (GSER)

(ACR Committee responsible for sponsoring the draft through the process)

Candice Johnstone, MD, FACR, Chair

Lynn Broderick, MD, FACR

Justin P. Dodge, MD

Brian D. Gale, MD, MBA

Rachel Gerson, MD ,

Carolyn A. Haerr, MD, FACR

Charles E. Johnson, MD

Mallikarjunarao Kasam, PhD

Steven E. Liston, MD, MBA, FACR

Nathan J. Rohling, DO

Samir S. Shah, MD

Derrick Siebert, MD

Michael Straza, MD, Ph.D

Jennifer L. Tomich, MD

Committee on Practice Parameters – Pediatric Radiology

(ACR Committee responsible for sponsoring the draft through the process)

Committee on Practice Parameters – Pediatric Radiology

Terry L. Levin, MD, FACR, Chair

John B. Amodio, MD, FACR

Jesse Berman, MD

Tara M. Catanzano, MB, BCh

Harris L. Cohen, MD, FACR

S. Brent Colby, MS

Kassa Darge, MD, PhD

Dorothy L. Gilbertson-Dahdal, MD

Lauren P. Golding, MD

Adam Goldman-Yassen, MD

Safwan S. Halabi, MD

Jane Sun Kim, MD

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Erica Poletto, MD

Richard B. Towbin, MD, FACR

Andrew T. Trout, MD

Esben S. Vogelius, MD

Jason Wright, MD

Mahadevappa Mahesh, MS, PhD, FACR, Chair, Commission on Medical Physics

Robert S. Pyatt, Jr., MD, FACR, Chair, Commission on General, Small, Emergency and/or Rural Practice

Richard A. Barth, MD, FACR, Chair, Commission on Pediatric Radiology

David B. Larson, MD, MBA, Chair, Commission on Quality and Safety

Mary S. Newell, MD, FACR, Chair, Committee on Practice Parameters and Technical Standards

Comments Reconciliation Committee

Rachel Gerson, MD, Chair

William F. Sensakovic, PhD, Co-Chair

Richard A. Barth, MD, FACR

Nicholas M. Beckmann, MD

Jessica Kurian, MD

David B. Larson, MD, MBA

Paul A. Larson, MD, FACR

Terry L. Levin, MD, FACR

Comments Reconciliation Committee

Ryan Bosca, PhD

Diana E. Carver, PhD

Ellen May-Wai Chung, MD

S. Brent Colby, MS

Timothy A. Crummy, MD, FACR

Allen R. Goode, MS

Peter A. Harri, MD

Candice A. Johnstone, MD, FACR

David W. Jordan, PhD

Mary Ann Keenan, DMP

Amy L. Kotsenas, MD, FACR

Yonggang Lu, PhD

Mahadevappa Mahesh, MS, PhD, FACR

Courtney K. Morrison, PhD

Mary S. Newell, MD, FACR

Robert S. Pyatt, Jr., MD, FACR

Ashley Erin Rubinstein, PhD

John M. Sabol, PhD

Naimuddin Shaikh, PhD

Priya G. Sharma, MD

Alisa I. Walz-Flannigan, PhD

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