Digital radiography has become the norm in U.S. hospitals. The ability to view images, postprocess, and transmit the images systemwide immediately are distinct advantages. Yet, these technical advances create challenges for the radiology community, including the need to re-educate the workforce and prevent unnecessary radiation exposure. This education process is even more important for those who image children, where maintaining diagnostic image quality at a properly managed dose is critical. Because children are more sensitive than adults to the potential effects of ionizing radiation, particular attention to technique and its relationship to patient dose is important.1,2 This article emphasizes the need for attention to the basics of radiography and the importance of a standard approach in pediatric digital radiography.

The purpose of this article is to:

- Review the basics of radiography.
- Explain the differences between film-screen radiography and digital radiography.
- Discuss the meaning of the exposure indicators in digital radiography.
- Introduce the new International Electrotechnical Commission (IEC) exposure terminology standard.
- Expound on the applicability of the new IEC terminology in quality assurance.

**Imaging Basics**

The basics of radiologic technique are as important today as they were in the past. However, a standard approach to pediatric radiography requires calipers and technique charts that can be difficult to find in many digital radiography departments. If present, these measurement devices and reference guides provide ideal starting points for accurate patient exposure. The anatomically programmed radiography (APR) presets provided by the manufacturer may not be appropriate for children. The medical imaging physicist, radiologist, radiologic technologists, and manufacturer should work together to develop technique charts for pediatric patients that are either printed or programmed into the unit’s APRs.

The **Box** outlines the proper actions when performing digital radiography examinations on children. Pediatric exposure should follow the as low as reasonably achievable (ALARA) principle and only the clinically indicated region should be exposed. Grids only should be used when the body part thickness dictates their need. Grid use is discouraged when the patient’s body part thickness measures less than 10 cm to 12 cm. To avoid exposure of extraneous body parts, technologists must properly collimate before the exposure rather than using electronic cropping of the image after the exposure. Automatic exposure control (AEC) has many advantages, but it may not work well for pediatric patients with small bodies. If AEC is used, a technologist should avoid covering AEC cells with gonadal or breast shields. Overall, applying the basic principles of radiography is vital for optimization of image quality at a low dose in digital radiography.
Special Report
Image Gently: Pediatric Digital Radiography

Box

**Actions to Ensure Optimal Digital Radiographic Imaging in Children**

- Measure body part using calipers.
- Position patient properly.
- Avoid using grids for body parts less than 10-12 cm thick.
- Collimate prior to exposure.
- Shield gonads and breasts when possible.
- Use automatic exposure control only when appropriate.
- Use technique chart based on thickness for “child-size” technique.
- Review exposure indicators and image quality.

**Film-Screen vs Digital Screen Radiography**

Traditional film-screen systems use overall optical density on the film as an exposure indicator; the final optical density of the film is related to the patient’s exposure. A film that is too light or too dark is associated with underexposure or overexposure, respectively. The technologist receives immediate and direct feedback regarding exposure from the appearance of the processed film. Optimized exposure factors (kVp and mAs) are based upon the body part, its thickness, and relative speed of the film-screen combination. Examinations where AEC cannot be used (when the body part is smaller than the detector of the AEC), require the technologist to use technique charts, experience, and judgment to set manual radiographic technique to ensure image quality standardization within the department.

**Digital Radiography**

Beginning in the 1980s, computed radiography (CR) and direct digital radiography (DR) systems were introduced in clinical departments to replace the analog film-screen images. CR uses a photostimulable phosphor image receptor placed by the technologist in a reader to digitize the image after the x-ray exposure is complete. DR uses an electronic image detector capable of digitizing the image without intervention by the technologist. CR and DR make up digital radiography and provide many benefits over film-screen radiography. Digital systems boast larger latitude than film because of image processing of the digital image. The technologist may use a much wider range of patient exposure because digital image processing can compensate by 100% for underexposure and more than 500% for overexposure. Digital image processing adjustment of the brightness, contrast, and grayscale makes exposure appear appropriate; therefore, visually judging the radiographic technique and patient exposure is inappropriate. Underexposed images may be recognized by a noisy/grainy appearance (quantum mottle), but overexposed images are typically sharp, visually pleasing images with low levels of noise; the additional radiation used to obtain the overexposed image can go unnoticed. This may result in needless overexposure and potential harm to the patient.

Image acquisition and image processing varies between vendors and equipment type, which requires adjustment of techniques by the technologist and further complicates the process. Techniques required to produce diagnostic-quality digital radiographs may be different from those used for film-screen imaging. Further, different digital detectors may require alternative techniques because of variances in the efficiency of the detector materials, which may lead to confusion about appropriate exposure techniques with varying levels of image quality at facilities with more than 1 vendor or detector system. Operators should determine a standard approach to producing consistent, high-quality digital radiographs, based not on image density as with film-screen, but on feedback provided from the exposure at the detector and individual image quality analysis.

**Exposure Indicators in Digital Radiography Ensuring Adequate Exposure**

The goal of acquiring a diagnostic x-ray has not changed with digital radiography; it still requires an image with appropriate quality and corresponding low dose to the patient, particularly children. The digital acquisition process reduces repeat radiographs as a result of incorrect exposure because of image processing, but both underexposures and overexposures need to be eliminated. Underexposure compromises image quality while overexposure delivers a greater dose than necessary to the patient. The technologist must receive feedback on the appropriateness of his or her chosen radiographic technique for each digital radiograph. The lack of visual verification of the exposure factors’ appropriateness forces technologists to evaluate exposure factors by the...
means of an exposure indicator.

The exposure indicator provides feedback by indicating the relative exposure at the image receptor, which is dependent on the efficiency and sensitivity of the digital receptor to incident x-rays. Without an exposure indicator, verification of the appropriate exposure factor selection is impossible. These changes have led to a steep learning curve for practicing technologists as they must understand the distinctions of digital image acquisition, processing, and display and the disconnection between cause and effect, when applied to radiation exposure.

**Proprietary Vendor Terminology**

Currently, the manufacturers of digital radiography equipment use distinctly different ways of determining and reporting the exposure indicator (see Table 1). This has created confusion for technologists, radiologists, and physicists. Wide variations exist in terminology, units, mathematical formulas, and calibration conditions of these exposure indicators. This confusion grows when the technologist must work with systems from more than 1 vendor, or when proper training is not provided for the available unit.

Fuji’s (Tokyo, Japan) sensitivity number (S) mimics the concept of “speed class” familiar to technologists who have used film-screen radiography. Carestream (Rochester, New York) labels its exposure indicator “exposure index,” which represents the average pixel value of the clinical region of interest. The Agfa (Mortsel, Belgium) CR exposure indicator, \( \text{lgM} \), represents the logarithm of the median exposure value within a region of interest. Most DR manufacturers were slow in developing exposure indices at the image receptor. Instead, many relied on dose-area product (DAP), kerma-area product (KAP), or other quantities that estimate dose to the patient. Patient doses of properly exposed digital radiographs vary dramatically as the size of the body part changes. Therefore, DAP or KAP does not provide useful information to the technologist with respect to the adequacy of radiation exposure to the detector.

More than 15 other vendors also have their own proprietary names, formulas, and units. Some systems are logarithmic and some are linear; in some systems the exposure indicator increases in value to correlate with exposure; in other systems the exposure indicator decreases in value to correlate with exposure. The many system values result in confusion of the technologist that could be avoided by the development of 1 universal exposure indicator used by all manufacturers.

**New IEC Standard for Exposure Indicators**

The radiology community, including radiologists, technologists, and medical physicists, have called for standardized terminology since “The ALARA concept in pediatric CR and DR” conference in 2004. The need

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**Table 1**

<table>
<thead>
<tr>
<th>Fuji S No.</th>
<th>Agfa lgM</th>
<th>Kodak/Carestream Exposure Index</th>
<th>Detector Exposure Estimate (mR)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1000</td>
<td>&lt; 1.45</td>
<td>&lt; 1250</td>
<td>&lt; 0.20</td>
<td>Underexposed: repeat</td>
</tr>
<tr>
<td>601-1000</td>
<td>1.45-1.74</td>
<td>1250-1549</td>
<td>0.2-0.3</td>
<td>Underexposed: QC exception</td>
</tr>
<tr>
<td>301-600</td>
<td>1.75-2.04</td>
<td>1550-1849</td>
<td>0.3-0.7</td>
<td>Underexposed: QC review</td>
</tr>
<tr>
<td>150-300</td>
<td>2.05-2.35</td>
<td>1850-2150</td>
<td>0.7-1.3</td>
<td>Acceptable range</td>
</tr>
<tr>
<td>75-149</td>
<td>2.36-2.65</td>
<td>2151-2450</td>
<td>1.3-2.7</td>
<td>Overexposed: QC review</td>
</tr>
<tr>
<td>50-74</td>
<td>2.66-2.95</td>
<td>2451-2750</td>
<td>2.7-4.0</td>
<td>Overexposed: QC exception</td>
</tr>
<tr>
<td>&lt; 50</td>
<td>&gt; 2.95</td>
<td>&gt; 2750</td>
<td>&gt; 4.0</td>
<td>Overexposed: repeat if necessary</td>
</tr>
</tbody>
</table>

Abbreviation: QC, quality control.

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b This column provides the range of detector exposures that each vendor’s exposure indicator represents.
to adopt uniform standard terminology was reinforced at the 2010 Image Gently Pediatric Digital Radiography Summit. The International Electrotechnical Commission (IEC) published an exposure terminology standard in 2008. The American Association of Physicists in Medicine published its report in 2009. At the 2010 Image Gently summit, all stakeholders agreed to adopt the IEC 62494-1 standard. This standard is applicable to digital radiography systems used in general radiography (eg, CR systems, flat-panel detector systems, and charge-coupled device-based systems). Equipment incorporating the new standard is now being installed in hospitals.

The IEC standard uses 3 terms important to technologists: exposure index (EI), target exposure index (EI_T), and deviation index (DI). Of these values, the DI serves to provide immediate feedback to the technologist regarding proper exposure.5

**Exposure Index**

EI is an index of the exposure at the detector in the relevant image region. Several international bodies have highlighted the importance of EI.4 EI, as defined by the IEC standard, is derived from the image signal-to-noise ratio (SNR), which relates to absorbed energy at the detector (and not the patient) after every exposure event.4,11,14,15 The EI is influenced by the part thickness, artifacts, source-to-image distance, collimation, grids, centering, image plate size, and equipment and detector design.6 The EI value simply indicates the detector exposure.11 If a thick body part is imaged on a digital detector, the exposure technique must be adjusted upward to compensate for increased x-ray attenuation. If a thin patient is imaged on the same detector, the x-ray technique must be reduced to achieve the same number of transmitted x-rays to the detector (same SNR), with the result being the same EI at the lower dose to the patient.3

EI responds linearly to changes in mAs at a fixed kVp.16 When kVp changes and mAs is adjusted to maintain a constant exposure, the EI changes in a nonlinear way.16 This effect is relevant but may not be of clinical significance for kVp in diagnostic radiography. Because of differences in equipment, technical factors, and radiologists’ subjective image preferences, the EI may not accurately indicate variations in radiation exposure among institutions.16 The system can only be used for comparisons between exposures for the same examination on the same type of detector.

Unfortunately, the accuracy of EI during pediatric imaging may be decreased because of the degree of manual collimation or the presence of metal devices. For example, when opening the collimator to include an arm for placement of a peripherally inserted central catheter line in a premature infant, the x-ray field size adjustment can change the EI and complicate the interpretation of EI for the technologist.1 The density of objects within the x-ray beam (eg, shield, metal implants, or pacemakers), the area exposed on the detector, and imaging plate size can affect the accuracy of EI as well.1 In these cases, the technologist may need to evaluate the presence of increased (underexposure) or decreased (overexposure) noise in the image. It is important that technologists understand what EI is and how it is used to set target exposures and calculate deviations for these targets.

**Target Exposure Index**

EI_T is the target reference exposure obtained when the image receptor is exposed properly. The values may differ for each body part and projection (eg, chest, abdomen, and foot), and may vary by the sensitivity of the detector in each examination room (depending on factors such as filtration or sensitivity of detector plate).16 EI_T values may be best managed by a database of appropriate, examination-specific EI_T values for individual digital acquisition systems.17

The EI_T should provide the exposure that produces a balance between image quality and noise level acceptable to the radiologists. The EI_T may be set by the manufacturer or imaging facility as determined by statistical averaging of a series of exposures for any body part and imaging system.16 Currently, little information exists about establishing EI_T values. A unique value may be needed for each detector type and each body part. However, similar body parts (eg, abdomen and pelvis, hands and feet) may use similar values of EI_T, provided the image processing by the vendor and kVp on the x-ray machine are similar.

**Deviation Index**

DI measures how far the actual EI value deviates from the projection-specific EI_T following the formula.
The technologist must specify the correct body part and radiographic projection, so the correct EIT value is used for calculation of the DI value. The clinical use of DI is as an indicator of proper radiographic exposure. The DI provides immediate feedback to the technologist of the appropriateness of the selected radiographic technique. The technologist can reflect on the calculated metrics and understand exposure changes that should be made in the future.

Irrespective of the body part or the imaging room, the DI reflects a fixed standard method of showing how much the actual exposure was above or below the ideal value (see Table 2). The DI provides a negative (-) value, zero (0), or a positive (+) value on the workstation when an underexposure, ideal, or overexposure, respectively, occurred. One deviation unit equals 26% increase (+1) or 20% decrease (-1) in exposure relative to the target; 3 deviation units equal 2× target exposure or half target exposure (+3 or -3). Plus or minus 1 DI is approximately 1 mAs step change on a standard generator. Overall, the use of the DI is important in the effort to optimize radiographic studies in an attempt to lower dose, especially for children. Each department should ensure that the DI is displayed on every image in the facilities’ picture archiving and communications system so the radiologist can determine inappropriate exposures quickly.

Despite following the proper actions for digital imaging, acceptable DI values may not guarantee good image quality. The DI value is simply a number to indicate whether the exposure was appropriate, underexposed, or overexposed. Each radiograph must still be evaluated on an individual basis. Images should not be repeated based on the EI if they are of diagnostic quality because this will result in unnecessary patient radiation exposure.

### Standardized Terminology and Quality Assurance

Although it is important to monitor the quality of every image, quality assurance (QA) programs that review performance targets on a periodic basis are needed. The 2004 ALARA conference advocated this. With advances in standardized terminology, QA processes can be automated using digital imaging and communications in medicine structured reports and Integrating the Healthcare Enterprise Radiation Exposure Monitoring program. This should make it easier and less time-intensive to identify image quality issues. Ultimately, national programs based on detector type and examination could be instituted to provide reference levels.

Exposure creep in digital imaging that has been reported for more than a decade provides rationale for QA programs. Exposure creep is the gradual increase over time of the radiologic technologist’s selected exposures for a radiographic anatomical projection. Lower doses in CR and DR increase quantum mottle in the image, which creates a less aesthetically pleasing image to the radiologist. Technologists quickly learn that complaints received from radiologists can be decreased by increasing the exposure settings to reduce the quantum mottle. As a result, patient dose has a tendency to increase gradually over time after a department converts from film-screen imaging to digital radiographic imaging.

Establishing initiatives that monitor EI and DI can help identify exposure issues and corrective action prior to issues becoming clinically significant. The IEC standard will help standardize terminology for ease of QA. Tracking and evaluating the EI and DI values to ensure correct equipment use and radiation exposure management on an exam-by-exam basis cannot be underestimated, especially regarding infants whose condition requires frequent radiographic imaging. When purchasing new CR and DR equipment,

<table>
<thead>
<tr>
<th>Deviation Index</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-1</td>
<td>-20</td>
</tr>
<tr>
<td>-2</td>
<td>-40</td>
</tr>
<tr>
<td>-3</td>
<td>-50</td>
</tr>
<tr>
<td>-4</td>
<td>-60</td>
</tr>
</tbody>
</table>

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Table 2

### Deviation Index Varies by Fixed Percentage for Exposure Factor Changes

<table>
<thead>
<tr>
<th>Deviation Index</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
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<tr>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-1</td>
<td>-20</td>
</tr>
<tr>
<td>-2</td>
<td>-40</td>
</tr>
<tr>
<td>-3</td>
<td>-50</td>
</tr>
<tr>
<td>-4</td>
<td>-60</td>
</tr>
</tbody>
</table>
technologists should insist on the implementation of the IEC 62494-1 standard.5

Quality Improvement

Quality improvement projects centered on the IEC 62494-1 standard should be initiated to monitor changes in exposure over time.4 Deviation indices that vary by ±3, double or half of EI relative to EIT, should be investigated for educational and training purposes.21 Further, the QA system allows radiologic technologists to cross-check their own tendencies toward underexposure or overexposure, providing better quality of patient care.20

Conclusion

Overall, the objective is to ensure a standardized approach to the management of the radiation dose to pediatric patients that results in appropriate image quality for the clinical question. As technologists go “back to the basics” and monitor exposure as a standard of practice using the IEC standardization terminology, exposure to pediatric patients will be reduced while ensuring diagnostic-quality images.

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References


Watch a short video from coauthor and ASRT Chief Operating Officer Greg Morrison, MA, R.T.(R), CNMT, CAE, concerning this issue’s special reports in the digital edition at www.asrt.org/publications.

For additional information regarding digital radiography, see “Best Practices in Digital Radiography” on Page 83.