Standardized Exposure Index for Digital Radiography – Technical Issues

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The Issues

• CR & DR systems have variable speed, wide dynamic range, and internal signal scaling

• Consistent (and often inconsistent) image appearance eliminates exposure feedback loop

• There is no direct link between image appearance and detector “speed class”

• Overexposures can easily be unnoticed, resulting in needless overexposure to the patient

• Underexposures have increased image noise that can reduce diagnostic accuracy
Screen-Film system indicators

Traditional screen-film systems use overall film density as an exposure indicator

Direct feedback to the technologist regarding exposure
CR & DR system indicators

CR & DR systems use image processing to align the grayscale with the signals

Direct visual cues (dark/light) are lost regarding exposure
Noise

The image processing adjusts the grayscale, however;

- Images with low signals are noisy and
- Images with high signal are associated with high dose

Exposure Indicators describe image quality in terms of the signal to noise ratio (SNR)

Underexposed, low SNR  Overexposed?, high SNR
Exposure Indicators

CR and DR systems assess the recorded signal to indicate whether the radiographic technique used is appropriate

- Tests with defined beam conditions are used to verify that correct indicators are being reported
- Recommended exposure indicator ranges are used by technologists to check each radiographic exposure
Systems vary in the region used to assess the signal for an image.

- Full Image
- Regular regions
- Anatomic regions
Region to assess signal indicator

**IEC 62494-1**

- Gray histogram for the entire image
- Black histogram for the anatomic region (relevant region)
Computation of an exposure indicator

.... typically computed from the probability distribution of signal values that are determined in the relevant image region, using a recognized statistical method (e.g., median)

Manufacturers have adopted *proprietary* methods

- Algorithms, values, and calibration methods are widely different, leading to confusion amongst users
- Inappropriate image segmentation or histogram ‘values of interest’ range can produce inaccuracies
# Summary of manufacturer Exposure Indices

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Indicator Name</th>
<th>Symbol</th>
<th>Units</th>
<th>Exposure Dependence</th>
<th>Calibration Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fujifilm</td>
<td>S Value</td>
<td>S</td>
<td>Unitless</td>
<td>$200/S \propto X \text{ (mR)}$</td>
<td>$80 \text{ kVp, 3 mm Al &quot;total filtration&quot; S=200 @ 1 mR}$</td>
</tr>
<tr>
<td>Kodak</td>
<td>Exposure Index</td>
<td>EI</td>
<td>mbels</td>
<td>$\text{EI + 300} = 2X$</td>
<td>$80 \text{ kVp + 1.0 mm Al + 0.5 mm Cu EI = 2000 @ 1 mR}$</td>
</tr>
<tr>
<td>Agfa</td>
<td>Log of Median of histogram</td>
<td>lgM</td>
<td>bels</td>
<td>$\text{lgM + 0.3} = 2X$</td>
<td>$\text{for 400 Speed Class, 75 kVp + 1.5 mm Cu lgM=1.96 at 2.5 \mu Gy}$</td>
</tr>
<tr>
<td>Konica</td>
<td>Sensitivity Number</td>
<td>S</td>
<td>Unitless</td>
<td>$200/S \propto X \text{ (mR)}$</td>
<td>$\text{for QR=200, 80 kVP S=200 @ 1 mR}$</td>
</tr>
<tr>
<td>Canon</td>
<td>Reached Exposure Value</td>
<td>REX</td>
<td>Unitless</td>
<td>$\text{Brightness} = c_1, \text{ Contrast} = c_2, REX \propto X^1$</td>
<td>$\text{for Brightness = 16, Contrast = 10, REX} \approx 106 @ 1 \text{ mR}^1$</td>
</tr>
<tr>
<td>Canon</td>
<td>EXP</td>
<td>EXP</td>
<td>Unitless</td>
<td>$\text{EXP \propto X}$</td>
<td>$80 \text{ kVp, 26 mm Al HVL = 8.2 mm Al DFEI = 1.5 EXP = 2000 @ 1 mR}$</td>
</tr>
</tbody>
</table>

$^1$ From empirical data
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Indicator Name</th>
<th>Symbol</th>
<th>Units</th>
<th>Exposure Dependence</th>
<th>Calibration Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>Uncompensated Detector Exposure</td>
<td>UDExp</td>
<td>μGy Air KERMA</td>
<td>UDExp (\propto X) (μGy)</td>
<td>80 kVp, standard filtration, no grid</td>
</tr>
<tr>
<td>GE</td>
<td>Compensated Detector Exposure</td>
<td>CDExp</td>
<td>μGy Air KERMA</td>
<td>CDExp (\propto X) (μGy)</td>
<td></td>
</tr>
<tr>
<td>GE</td>
<td>Detector Exposure Index</td>
<td>DEI</td>
<td>Unitless</td>
<td>DEI (\approx 2.4X) (mR) (^1)</td>
<td>Not available</td>
</tr>
<tr>
<td>Swissray</td>
<td>Dose Indicator</td>
<td>DI</td>
<td>Unitless</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td>Imaging Dynamics Company</td>
<td>Accutech</td>
<td>f#</td>
<td>Unitless</td>
<td>(2^f(X(mR))/X_{tgt}(mR))</td>
<td>80 kVp + 1 mm Cu</td>
</tr>
<tr>
<td>Philips</td>
<td>Exposure Index</td>
<td>EI</td>
<td>Unitless</td>
<td>(100/S \propto X) (mR)</td>
<td>RQA5, 70 kV, +21 mm Al, HVL=7.1 mm Al</td>
</tr>
<tr>
<td>Siemens Medical Systems</td>
<td>Exposure Index</td>
<td>EXI</td>
<td>μGy Air KERMA</td>
<td>(X(\muGy)=EI/100)</td>
<td>RQA5, 70 kV +0.6 mm Cu, HVL=6.8 mm Al</td>
</tr>
<tr>
<td>Alara CR</td>
<td>Exposure Indicator Value</td>
<td>EIV</td>
<td>mbels</td>
<td>(EIV + 300 = 2X)</td>
<td>1 mR at RQA5, 70 kV, +21 mm Al, HVL=7.1 mm Al =&gt; EIV=2000</td>
</tr>
<tr>
<td>iCRco</td>
<td>Exposure Index</td>
<td>none</td>
<td>Unitless</td>
<td>Exposure Index (\propto \log [X (mR)])</td>
<td>1 mR at 80 kVp + 1.5 mm Cu =&gt; =0</td>
</tr>
</tbody>
</table>
Approximate EI Values vs. Receptor Exposure

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Symbol</th>
<th>5 µGy</th>
<th>10 µGy</th>
<th>20 µGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canon (Brightness = 16, contrast = 10)</td>
<td>REX</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>IDC (S_T = 200)</td>
<td>F#</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Philips</td>
<td>EI</td>
<td>200</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Fuji, Konica</td>
<td>S</td>
<td>400</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Kodak (CR, STD)</td>
<td>EI</td>
<td>1700</td>
<td>2000</td>
<td>2300</td>
</tr>
<tr>
<td>Siemens</td>
<td>EI</td>
<td>500</td>
<td>1000</td>
<td>2000</td>
</tr>
</tbody>
</table>

..... The need for a standard clearly evident
Standardization

• American Association of Physicists in Medicine Task Group 116 and International Electrotechnical Commission (IEC)

• Collaborative effort
  • Physicists
  • Manufacturers/Vendors representatives
  • MITA (Medical Imaging and Technology Alliance)

• Develop common “Exposure Indices” and “Deviation Indices” across detectors and manufacturers/vendors

• Provide means for placing data in DICOM metadata
AAPM TG 116

The AAPM TG 116 report on exposure indicators was published in July of 2009

An exposure indicator for digital radiography: AAPM Task Group 116 (Executive Summary)

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IEC Standard

IEC published a standard for Exposure Index definitions in August of 2008

IEC 62494-1

INTERNATIONAL STANDARD

Medical electrical equipment – Exposure index of digital X-ray imaging systems – Part 1: Definitions and requirements for general radiography
# Description of Exposure Indices Parameters

|---------------------|---------------------------------------------------------------------------------------------|-------------------------|
| **Exposure Index**  | Air-kerma at the receptor

\[ K_{\text{IND}} = K_{\text{CAL}} (\mu \text{Gy}) \]

|                     | **Calibration Energy**

- RQA-5
  - 66 - 74 kVp

|                     | **Calibration Filtration**

- RQA-5 Equivalent
  - 0.5 mm Cu (+ 0-3 mm Al)
  - or 21 mm Al
  - 6.8 ± 0.2 mm Al HVL

|                     | **Deviation Index**

\[ DI = 10 \times \log_{10} \left( \frac{K_{\text{IND}}}{K_{\text{TGT}}} \right) \]

|                     | **DI format**

- Signed decimal string with 1 decimal point

|                     | **Calibration Energy**

- RQA-5
  - 66 - 74 kVp

|                     | **Calibration Filtration**

- RQA-5 Equivalent
  - 0.5 mm Cu + 2 mm Al or
  - 21 mm Al
  - 6.8 ± 0.3 mm Al HVL

|                     | **Deviation Index**

\[ DI = 10 \times \log_{10} \left( \frac{E_{\text{I}}}{E_{\text{T}}} \right) \]

|                     | **DI format**

- Unspecified
Exposure Indices

Deviation Index (DI)

\[ DI = 10 \times \log_{10} \left( \frac{EI}{EI_T(b,v)} \right) \]

- \( EI_T \) is a target index value that is to be determined for each body part \( b \), view \( v \), procedure type, and clinical site.

- When \( EI \) equals \( EI_T \), \( DI = 0 \)
  - \( DI = +3.0 \) for 2x target exposures
  - \( DI = -3.0 \) for \( \frac{1}{2} \) target exposure
  - \( \pm 1 \) is one step on a standard generator mAs control or AEC compensation (ISO R5 scale)
Need to have robust methods of determining DI

What about VOI modification by the technologist?

\[ EI = EI_T \]
\[ DI = 0.0 \]

EI and DI calculated from this pixel value

Values of Interest
Need robust methods of determining EI & DI

VOI recognition algorithm fails
• Gonadal shields, prosthetics, etc.
• False DI reported

\[
\begin{align*}
&\text{Correct Values of Interest} \\
&\text{EI} = EI_T \\
&\text{DI} = 0.0
\end{align*}
\]

\[
\begin{align*}
&\text{Incorrect Values of Interest} \\
&\text{EI} \neq EI_T \\
&\text{DI} = -1.3
\end{align*}
\]
Need robust methods of determining EI & DI

Tech adjusts VOI for proper grayscale rendition manually, and DI returns to zero

EI $= E_{I_{TGT}}$

DI $= 0.0$

EI and DI correctly calculated from this pixel value

EI and DI incorrectly calculated from this pixel value

Correct Values of Interest

Incorrect Values of Interest

Pixel Value

Number of pixels
Need to determine recommendations for repeats

• DI target is -2.0 to +2.0

• Check for noise. Consult with radiologist on need for repeat if EI is ≤ 63% of target (DI≤ -2)

• Investigate cause (do not repeat) if EI is between 160% and 200% of target (+2.0 ≤ DI ≤ +3.0)

• Consult with radiologist (check for saturation) on need for repeat and counsel of technologist if EI is ≥200% of target (DI ≥ +3.0)
IEC 62494-1: Target Exposure Index $EI_T$

- $EI_T$ may depend on detector type, examination type, diagnostic question and other parameters

- Establishing target exposure index values needs medical knowledge – may be done by professional societies

- $EI_T$ values should be provided as a data base in the digital imaging system

Ulrich Neitzel
Project Leader,
Convenor IEC SC62B WG 43
Caveats

• The EI does not describe patient dose
  • EI is derived from detector signal (dose at the detector)

• The EI is not a dose measurement tool
  • Dose calibration only valid at one radiation quality

• Images with same EI obtained on different digital systems might not have similar image quality
  • Influence of detector DQE, scattered radiation, beam quality differences

Ulrich Neitzel
Project Leader,
Convenor IEC SC62B WG 43
Exposure Index & Deviation Index monitoring

- Collect EI and DI for every image and analyze
  - By technologist
  - Technique factors
  - X-ray system
  - Plate scanning unit (CR)
  - Processing unit (CR - DR)
  - Anatomical view

- Longitudinal studies
  - Track performance over time
  - Mean and Standard Deviation of EI and DI
  - Watch for trends upward (Dose Creep)
Consensus goals

• To adopt IEC standard 62494-1

• To determine “appropriate” EI<sub>T</sub> values for pediatric exams as correlated to digital detector types and optimized SNR.... How?

• To set “allowable” DI range as suggestions for “appropriate” exposure

• To mandate methods for capturing and tracking EI and DI values for trend analysis
Consensus goals

• To address AEC calibration for procedures and patient attributes amenable to AEC use

• To acquire kVp, mAs, beam filtration (HVL), and tube output data per study, for patient dosimetry evaluation when possible

• To request manufacturers to provide on-line training and continuing education materials regarding the practical use of EI & DI
Calculation of Patient Dose

- Technique factors
  - kV, mA, time, added filtration
- Calibration factors
  - HVL at kV, output (mGy/100 mAs), focal spot
- Geometric factors
  - SID, OID, collimation,
- Anatomic factors
  - Area irradiated, patient attributes, shielding
Dose estimation

- Entrance skin air kerma
  - Reference point AK, KAP
  - Tube output determination
- Monte Carlo photon transport
  - PCXMC or similar program
  - Area, beam HVL, kV, mAs
Radiography DICOM RDSR

• New radiography efforts
Example calculation and reference to exposure index
American College of Radiology Dose Index Registry

• CT is now underway……..

• Radiography is the next input
  • Reference doses
  • Comparative data
Conclusions

• Digital radiography devices have enabled robust patient dose tracking
• Active acquisition technologies provide technical factors for the study
• Patient size and habitus metrics are needed as input for dose estimates
• Exposure indices assist the radiographer in ensuring proper techniques with feedback
• Radiation dose levels appropriate for the exam enhance patient safety and care