Considerations and strategies for setting target exposure indicator (EI₁) in digital radiography

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Disclosures

• None

“The nice thing about standards is that you have so many to choose from”

-Andrew S. Tanenbaum
Outline

1. Why use DI and EI_T?
   i. Pros/Cons
   ii. Manufacturer presets
2. Necessary steps
   i. EI Accuracy
   ii. AEC calibration
   iii. Processing
3. Set and review

---

Why use DI and EI_T?

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

**PROS**
- Do not need to worry about different EI implementations
- One number for technologist/radiologist
Why use DI and EI\(_T\)?

### PROS
- Do not need to worry about different EI implementations
- One number for technologist/radiologist

### CONS
- Does not necessarily point to over/under-exposure
- Can be mis-used for repeat imaging

\[
DI = 10 \log_{10}\left(\frac{EI}{EI_r}\right)
\]

Manufacturer EI\(_T\) presets

<table>
<thead>
<tr>
<th>Exam</th>
<th>DR 1</th>
<th>DR 2</th>
<th>DR 3</th>
<th>DR 4</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest PA</td>
<td>250</td>
<td>206</td>
<td>175</td>
<td>236</td>
<td>1.4X</td>
</tr>
<tr>
<td>Humerus</td>
<td>250</td>
<td>N/A</td>
<td>245</td>
<td>150</td>
<td>1.7X</td>
</tr>
<tr>
<td>Abd Supine</td>
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Manufacturer EI\(_T\) presets

<table>
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<tr>
<th>Exam (Abdomen)</th>
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<tr>
<td>KUB</td>
<td>595</td>
<td>250</td>
</tr>
<tr>
<td>AP</td>
<td>595</td>
<td>250</td>
</tr>
<tr>
<td>Bladder</td>
<td>175</td>
<td>250</td>
</tr>
<tr>
<td>Supine</td>
<td>315</td>
<td>250</td>
</tr>
<tr>
<td>Lateral</td>
<td>1050</td>
<td>250</td>
</tr>
<tr>
<td>Upright</td>
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Outline

1. Why use DI and EI-?
   i. Pros/Cons
   ii. Manufacturer presets

2. Necessary steps
   i. EI Accuracy
   ii. AEC calibration
   iii. Understand VOI

3. Set and review
### Step 1: EI Accuracy

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EI Sensitivity = 200

i.e. 1000/200 = 5 uGy, EI = 500

*Not internally consistent*

### Step 2: AEC Calibration

-2.5 uGy +/- 0.5

### Step 2: AEC Calibration

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Step 3: Understand VOI

- Field and Central Value
- Could be DICOM overlays/tags

Example VOI:
- Bone: 25%
- Lung: 90%

Method 1: Exam (anatomy) – specific VOI

EI = 817
EI = 263

EI based on Image Quality (SNR) in VOI

Image Courtesy of Stefan Specht, Philips Healthcare
Method 2: Central tendency of histogram

- Defined by IEC
- Requires wider range of exam-specific EI_T

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Step 3: Set and review

- Perfect is the enemy of good!
- Start somewhere
  - e.g. Abdomen (300), Chest (400), Extremity (700)
- Select subset (e.g. one room)
  - ensure correct collimation VOI/processing
- Radiologist review
  - bookend image noise using outliers
BCH Values

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</tr>
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</tr>
<tr>
<td>Chest PA</td>
<td>400</td>
</tr>
<tr>
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<td>700</td>
</tr>
</tbody>
</table>

Ongoing Review

• Hawthorne effect:
  - “productivity gain occurred as a result of…interest being shown to them”

• i.e. the act of reviewing data drives quality improvement more than the reporting results
Considerations and *strategies* for setting target exposure indicator (EI<sub>T</sub>) in digital radiography

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**Disclosures**

- Member of X-Ray Medical Advisory Board GEMS

**Introduction**

- EI target values were deliberately avoided by AAPM TG 116.
- Too broad scope for the TG.
- State of practice largely unknown but expected to be widely variable.
- Expectation that manufacturers should be able to define appropriate target values for their specific technologies – like screen/film speed classes.
- AAPM TG 232 survey data confirmed state of practice was highly variable.
- Leads to question of how to establish target EI values.
II. Preconditions

- DR system properly calibrated for EI
- Consistent configuration management
- Operator compliance with
  - technique guides,
  - patient positioning,
  - collimation,
  - SID,
  - use of grids,
  - patient size estimation and size/technique selections.

III. Three Approaches for discussion

- Statistical approach
- Deterministic approach
- Experimental approach

Statistical approach
aka laissez-faire approach

- Collect data to determine state of practice
- Set the EI target to the median of the histogram of the EI observed for each view
- Not unlike method of TG 232
- Remember that EI distributions are log-normal
**Example of Statistical Approach**

**Deterministic approach \(aka\) AEC approach**

- Set the \(E_I\) to some value of air kerma that you expect to produce an acceptable image by the technology used.
- What TG 116 expected that the manufacturers would do.

**Example of a Deterministic Approach**

- Assume SNR = 30 desired.
- For quantum-limited system, about 1000 photons contribute per pixel.
- Only about 1 incident photon contributes, so need 2000 incident.
- Detector element is about \(2 \times 10^{-8} \text{ cm}^2\).
- The energy fluence would be \(5 \times 10^{11} \text{ eV} \times 1 \times 10^{9} \text{ photons per cm}^2\) or \(5 \times 10^{-3} \text{ eV/cm}^2\). We have to know the conversion factor for the charge on an electron is \(1.6 \times 10^{-19} \text{ C} \approx 1.6 \times 10^{-19} \text{ J/eV}\) to get angstroms. \(1 \text{ J} = 1 \text{ J} \times 10^{-19} \text{ C} = 6.24 \times 10^{-19} \text{ J} \approx 1 \text{ eV}\).
- To get the air KERMA from the energy fluence, multiply times the ratio of the linear attenuation coefficient for air divided by the density of air. At 50 keV, it's 40 cm\(^2\)/kg.
- Multiply this times the energy fluence and you get \(3 \times 10^{-7} \text{ J/kg}\). One Gy is \(1 \text{ J/kg}\), so the air KERMA is \(3 \times 10^{-7} \text{ Gy}\) or 3 mGy.
- 3 mGy times 100 mGy/yield E\(_I\) of 300.
Another Example of Deterministic Approach: Speed Class

<table>
<thead>
<tr>
<th>Speed Class</th>
<th>Receptor Exposure (mR)</th>
<th>Receptor Exposure (µGy)</th>
<th>IEC EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>5.0</td>
<td>8.76</td>
<td>876</td>
</tr>
<tr>
<td>200</td>
<td>0.5</td>
<td>4.38</td>
<td>438</td>
</tr>
<tr>
<td>250</td>
<td>0.4</td>
<td>3.50</td>
<td>350</td>
</tr>
<tr>
<td>350</td>
<td>0.3</td>
<td>2.50</td>
<td>250</td>
</tr>
<tr>
<td>400</td>
<td>0.25</td>
<td>2.82</td>
<td>282</td>
</tr>
<tr>
<td>500</td>
<td>0.2</td>
<td>2.45</td>
<td>245</td>
</tr>
<tr>
<td>600</td>
<td>0.125</td>
<td>0.71</td>
<td>71</td>
</tr>
</tbody>
</table>

Caveats: Neither of these deterministic approaches really dealt with secondary photons. The detector doesn’t distinguish between primary or secondary photons. In a bedside chest examination the SPR is at least 1 without a grid and likely 0.5 even with a grid, so EI may need to be adjusted upward accordingly to compensate. This is just the median – what about the tail of the exposure distribution? 1/10 SNR\text{median}? 

Experimental approach

\textit{aka} Phantom approach

- Use geometric or anthropomorphic phantoms to simulate the anatomy of interest
- Set the EI target for what is observed when reasonable radiographic techniques or AEC is used and acceptable quality metrics are obtained
- Adjust EI target based on clinical results

Experimental Approach: Choice of patient-equivalent phantom

- Anthropomorphic phantom
  - Potential difficulties with positioning, segmentation, image processing
- Geometric phantom
  - PMMA
  - ANSI/AAPM phantoms (configurable to Chest, ABD, Skull, extremity)
  - LucAl phantoms (Chest, Abdomen, Pedi Chest/Abd)
  - ACR RF phantom (configurable to Chest, ABD, Skull, extremity)

May also measure entrance skin exposure (ESE) for comparison to Reference Values or Regulatory Limits.
Example of Experimental Approach

- Five mobile DR systems (5/2014: we were pretty ignorant about EI)
- LucAl Chest phantom followed by clinical demo
- 100 kVp, 1.6 mAs, 50° SID, no grid

<table>
<thead>
<tr>
<th>Vendor</th>
<th>EI_T</th>
<th>EI_ave</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>787</td>
<td>856</td>
</tr>
<tr>
<td>Carestream</td>
<td>850</td>
<td>562</td>
</tr>
<tr>
<td>Philips</td>
<td>586</td>
<td>621</td>
</tr>
<tr>
<td>Siemens</td>
<td>560</td>
<td>703</td>
</tr>
<tr>
<td>Fuji</td>
<td>876</td>
<td>2127</td>
</tr>
<tr>
<td>average</td>
<td>731.8</td>
<td>973.8</td>
</tr>
<tr>
<td>w/o Fuji</td>
<td>695.8</td>
<td>685.5</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>21%</td>
<td>19%</td>
</tr>
</tbody>
</table>

Adjusting technique for thickness: expecting too much?

<table>
<thead>
<tr>
<th>Image</th>
<th>kVp</th>
<th>mA</th>
<th>Raw PV</th>
<th>Raw SD</th>
<th>Raw SNR</th>
<th>DI</th>
<th>EI</th>
<th>(+) PMMA</th>
<th>(c) PMMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>100</td>
<td>0.0</td>
<td>1375.9</td>
<td>5.9</td>
<td>237.0</td>
<td>2.4</td>
<td>856.9</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>15</td>
<td>110</td>
<td>0.0</td>
<td>1335.6</td>
<td>4.6</td>
<td>235.6</td>
<td>2.7</td>
<td>842.9</td>
<td>2 cm</td>
<td>2 cm</td>
</tr>
<tr>
<td>17</td>
<td>120</td>
<td>0.0</td>
<td>1295.6</td>
<td>4.1</td>
<td>234.6</td>
<td>2.0</td>
<td>842.9</td>
<td>4 cm</td>
<td>4 cm</td>
</tr>
<tr>
<td>Average</td>
<td>136.3</td>
<td>6.7</td>
<td>229.6</td>
<td>5.8</td>
<td>835.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

COV < 10%: PASS | FAIL

COV < 10%: PASS | FAIL

COV < 10%: PASS | FAIL

IV. Conclusions and caveats

- Three approaches for setting $EI_T$
  - Statistical
  - Deterministic
  - Experimental
- Calibration of detectors is critical
- Collimation is critical for segmentation and calibration
- Beam quality, (kVp, HVL) and SPR is critical
- EI is only accurate to ± 20%
- Your mileage may vary