**Contrast-Enhanced Mammography: Physics and QC Testing**

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**Disclosures**
- OSU has research agreements with Siemens Healthineers and Qaelum NV (unrelated to talk).
- Most of the QC I will discuss is for Hologic units because that is what we have at OSU.

**X-ray Energy**
- Contrast is important
- Attenuation coefficients ($\mu$) of breast cancer are very close to that of normal tissue
- Low kVp (23-32 kVp) gives increased contrast

**Leaky Vessels**
- Normal vessels
- Tumor vessels

**Iodine $k$-edge**
- Photoelectric effect
- Enough energy to get free from innermost shell

**Iodine $k$-edge**
- Mass attenuation coefficient
**X-ray Spectra**

To maximize iodine contrast:
- Higher kVp: 45-49 kVp
- Filtration: ~0.3 mm copper (GE, Hologic) or 1 mm titanium (Siemens)

![Graph showing X-ray spectra](image)

**Image Acquisition**

- Low E = 30 kVp with Ag filter
- High E = 49 kVp with Cu filter

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**Dual-energy subtraction**

\[
\ln \frac{\text{High E}}{\text{Low E}} = \ln - k \cdot \ln
\]

**“Breast-in-Breast” or Rim Artifact**

- On subtraction images, band at the periphery
- From scatter distribution differences between high- and low-energy images
- Also occurs at the chest wall
- You will most likely see this on artifact evaluation images

**CEM QC**

Additional tests required:
- Artifact Evaluation/Flat-field Uniformity with Cu filter
- Half-value layer (HVL) for copper filter and high kV
- Entrance exposure, AEC reproducibility, and average glandular dose (AGD) for high- and low-energy subtraction acquisition

- GE-specific automated tests:
  - Flat field test with copper filter
  - AOP & SNR tests with copper filter
CEM QC

2018 ACR QC Manual FAQ: Use manufacturer’s QC manual for CEM

Q. Our facility has a digital mammography unit that performs 2D and/or DBT imaging and contrast enhancement (imaging of an iodinated contrast agent using mammography equipment). Will we be allowed to use the ACR Digital Mammography QC Manual instead of our manufacturer’s manual for QC of the 2D and DBT applications of our digital mammography unit and then follow our manufacturer’s QC manual for contrast enhancement?

A. Yes. The FDA has determined that facilities may use the manual for QC of the 2D and DBT applications of these units, and recommends that facilities follow manufacturer QC procedures for contrast enhancement applications.

Artifact Evaluation

- Hologic QC manual revision 010: must use Manual mode for CEM, unlike other target/filter combos, which use Auto-Time mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>kVp</th>
<th>mAs</th>
<th>Filter</th>
<th>Focal Spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>28</td>
<td>100</td>
<td>Rh</td>
<td>Large</td>
</tr>
</tbody>
</table>

Note: The Cu filter is only compatible with manual and Auto-Time mode images.

- Hologic QC manual revision <010: Auto-Time mode instructed

Artifact Evaluation

Hologic:
- Add View
- QC tab
- Flat Field CEDM
- Add

CEM QC

Hologic: Viewing CEM images
- Contrast tab
- Low-energy image
- Subtraction image
- Split screen

Half-value layer (HVL)

Note
Use the Conventional modality and select the Cu filter to measure the HVL for the CE2D high energy exposure. Adjust the kVp accordingly (i.e., 45 kVp) when using the Cu filter (CE2D Option). Use two to four aluminum 1145 or 1100 alloy sheets of 1 mm thickness for HVL measurements.
HVL

<table>
<thead>
<tr>
<th>Nominal kVp setting</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Material</td>
<td>W</td>
</tr>
<tr>
<td>Filter</td>
<td>Cu</td>
</tr>
<tr>
<td>mAs</td>
<td>100</td>
</tr>
<tr>
<td>Exposure measurements (mR)</td>
<td>73.045</td>
</tr>
<tr>
<td>No aluminum filtration, E(0)</td>
<td>73.11</td>
</tr>
<tr>
<td>0.2 mm of added Al, E(x)</td>
<td>72.93</td>
</tr>
<tr>
<td>0.5 mm of added Al, E(x)</td>
<td>72.83</td>
</tr>
<tr>
<td>0.4 mm of added Al, E(x)</td>
<td>72.81</td>
</tr>
<tr>
<td>0.6 mm of added Al, E(x)</td>
<td>72.80</td>
</tr>
<tr>
<td>Upper exposure value (E0)</td>
<td>72.80</td>
</tr>
<tr>
<td>Corresponding Al thickness (x)</td>
<td>0.5</td>
</tr>
<tr>
<td>Lower exposure value (E1)</td>
<td>70.24</td>
</tr>
<tr>
<td>Corresponding Al thickness (x1)</td>
<td>0.5</td>
</tr>
<tr>
<td>E0 = E(0)x2</td>
<td>36.52</td>
</tr>
<tr>
<td>Calculated HVL (mm Al)</td>
<td>3.19</td>
</tr>
</tbody>
</table>

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Entrance exposure, reproducibility, and AGD

- Each acquisition will have a low- and high-energy exposure
- Set your meter’s calculation/stop delay to the minimum, putting the dose from the three separate exposures (AEC pre-pulse, low energy, high energy) into the correct category.

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Alternatively, if your meter is not that accurate, you can use the average R/mAs from your conventional exposure measurements and the mAs of each low-energy exposure to distribute the total exposure.

Note

An AEC Phantom CEM view includes both a low and high-energy exposure. If the measuring equipment does not allow for separating the low from the high exposure, then you can use the average R/mAs computed from form 8a and the mAs of the low energy exposure to distribute the accumulated exposure between the low and the high energy exposures.
Entrance exposure, reproducibility, and AGD

Average R/mAs from the conventional exposure measurements:

<table>
<thead>
<tr>
<th>Mean value</th>
<th>R</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.480</td>
<td>112.8</td>
</tr>
</tbody>
</table>

$\Rightarrow 0.004258 \text{ R/mAs}$

<table>
<thead>
<tr>
<th>Total R</th>
<th>mAs</th>
<th>R</th>
<th>mAs</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5148</td>
<td>112</td>
<td>0.4769</td>
<td>52</td>
<td>0.0379</td>
</tr>
<tr>
<td>0.5185</td>
<td>112</td>
<td>0.4769</td>
<td>52</td>
<td>0.0415</td>
</tr>
<tr>
<td>0.5124</td>
<td>112</td>
<td>0.4769</td>
<td>52</td>
<td>0.0355</td>
</tr>
<tr>
<td>0.5125</td>
<td>112</td>
<td>0.4769</td>
<td>52</td>
<td>0.0356</td>
</tr>
</tbody>
</table>

Example comparison:

<table>
<thead>
<tr>
<th>Individual Exposures</th>
<th>Average R/mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed average glandular dose (mrad)</td>
<td></td>
</tr>
<tr>
<td>Low E</td>
<td>High E</td>
</tr>
<tr>
<td>126.8</td>
<td>30.6</td>
</tr>
</tbody>
</table>

Total average glandular dose (mrad) 157.4 157.7

Exporting data

- Go to Admin > Archive
- Search for study you wish to export
- Select acquisitions you wish to export
- Click the down arrow to move them into the export queue

Exporting data

- In the export window, make sure to check "Advanced"
- Make sure high and low unprocessed energy images are checked to see pre-subtraction images
- For patient images, be aware that "Anonymize" does not produced completely de-identified data

Dual-energy subtraction

Resources