Mammography: Dosimetry
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Why Measure Dose?

- Evaluation of Risk to the Patient
  - Benefit - Risk Calculation
- Comparison of Techniques
  - Screen/Film
  - New Image Receptors
- Equipment Performance Evaluation
- Information to Patient
- Regulations and Guidelines
NCRP Report No. 149

A GUIDE TO MAMMOGRAPHY AND OTHER BREAST IMAGING PROCEDURES

Replaced

MAMMOGRAPHY — A USER’S GUIDE

www.ncrponline.org
<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Other Title</th>
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</thead>
<tbody>
<tr>
<td>Stephen A. Feig, M.D.</td>
<td></td>
<td>(R)</td>
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<tr>
<td>Arthur G. Haus</td>
<td>(P)</td>
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<td>R. Edward Hendrick, Ph.D.</td>
<td>(P)</td>
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<td>Geoffrey R. Howe, Ph.D.</td>
<td>(E)</td>
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<td>Wende W. Logan-Young, M.D.</td>
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<td>John L. McCrohan, M.S.</td>
<td>(P)</td>
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<td>Edward A. Sickles, M.D.</td>
<td>(R)</td>
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<td>Martin Yaffe, Ph.D.</td>
<td>(P)</td>
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<tr>
<td>William Beckner</td>
<td>(S)</td>
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<tr>
<td>James A. Spahn</td>
<td>(S)</td>
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</table>

E = Epidemiologist, P = Physicist, R = Radiologist, S = NCRP Staff
What to Measure?

What to Report?
Dose Parameters

- In-air Surface Exposure, $X_a$
- Surface Dose, $D_s$
- Midline Dose, $D_{\text{mid}}$
- Mean Glandular Dose, $(D_g)_{av}$
In-air Surface Exposure

- Easy to measure
- Useful for quick comparisons
- Non-additive
- Not representative of risk
- Not representative of relative risk - beam quality changes
NCRP 149
Lateral View of Breast
Mean Glandular Dose

- Can not be measured directly
- Most representative of risk
- Calculated from simple measurements and lookup tables
Assumptions: Dose Calculation

- Firm Compression
- Uniform Cross Section
- 0.5 cm Adipose Layer - Top & Bottom
- Adipose / Gland Mix:
  - 100% / 0%
  - 50% / 50% (discussion later about appropriateness of 50/50)
  - 0% / 100%
Compression (NCRP 149)
NCRP 149 Compression
NCRP 149 Dose Model
D = f \ast X
f - Factors

Adipose: 5.4 mGy/R

Glandular: 7.9 mGy/R
Dose and Exposure vs Thickness

The graph illustrates the relationship between relative depth dose and the thickness of adipose tissue. The y-axis represents the relative depth dose, while the x-axis shows the thickness in centimeters. The graph includes curves for Adipose, Adipose-Gland Mix, and the exposure (free-in-air) (R) or air kerma (mGy). The curves are labeled with $D_g (\text{mGy})$ and $D_{ad} (\text{mGy})$. The y-axis values range from 0.0 to 1.0.
Units

- Exposure: C/kg* or R
- Dose: Gy* or rad

*SI Units
Factors Affecting Dose

- For a properly exposed film
- Assume only mAs changes, not kVp changes
  - Some AEC modes may raise or lower kVp as well as mAs
Exposure Time

INCREASE TIME, INCREASE DOSE
Peak Tube Potential - kVp

INCREASE kVp (& decrease mAs),
DECREASE DOSE (and Contrast)
Voltage Waveform

- Constant Potential - High or Medium Frequency
- Three - Phase
- Single - Phase

INCREASE CONSTANCY, DECREASE DOSE
X-Ray Tube Target

- Molybdenum (Mo)
- Rhodium (Rh)
- Tungsten (W)
- Others for Digital (?)

HIGHER Z, DECREASE DOSE (and Contrast)
X-Ray Tube Filter

- Molybdenum (Mo)
- Rhodium (Rh)
- Aluminum (Al)

- Thickness

INCREASE HVL, DECREASE DOSE (& Contrast)
Breast Size

INCREASE THICKNESS, INCREASE DOSE
Breast Composition

- More Adipose, Lower Dose
- More Glandular, Higher Dose
Compression

- Material
- Thickness
- Pressure

INCREASE COMPRESSION, DECREASE DOSE
Grid

- Ratio
- Transmission (Bucky Factor)

REMOVE SCATTER, INCREASE DOSE
Distances

- Source-Image Distance (SID)
- Source-Object Distance (SOD)
- Object-Image Distance (OID)
- Magnification (M)

\[ M = \frac{\text{SID}}{\text{SOD}} = 1 + \frac{\text{OID}}{\text{SOD}} \]

INCREASE M, INCREASE DOSE
(Unless air-gap w M allows removal of grid)
Image Receptor

INCREASE SPEED, DECREASE DOSE

- (May increase quantum mottle)
- (What is correct dose for digital imaging?)
Processing

- Chemicals
- Development Time
- Development Temperature

INCREASE SPEED, DECREASE DOSE
X-Ray Tube Focal Spot

NO EFFECT ON DOSE

- Assume proper calibration
- Assume no Reciprocity Failure
Measurement Instruments

- Ionization Chamber
- Electrometer
- Aluminum Filters
Ionization Chamber

- Collection Volume
- Energy Response
- Wall Material
Mammography Ionization Chamber

Thin Aluminized Mylar Entrance Window
Mammo Ion Chamber Energy Response

![Graph showing correction factor vs. HVL (mm Al)](image)

- **Mammography**
- **General Diagnostic**
Aluminum Filters

- Thickness
- Uniformity
- Purity
Ring Badge with TLD Chip
Thermoluminescent Dosimeters (TLD)

- Patient Surface Measurements
- Care in Selection of Chips
- Care in Handling and Annealing
- Energy Corrections
- Fading Corrections
TLD Energy Response

![Graph showing TLD Relative sensitivity vs. First HVL (mm Al)]
Dose Phantoms

- For AEC Dose Evaluation
- Materials - Composition
- Tissue Equivalence
  - Adipose-Glandular Mix
- Thickness Range: 2 to 8 cm
Dose Phantoms

- ACR Phantom
- 0.5 and 1.0 cm slabs of
  - Acrylic
  - BR-12
ACR-MAP Mammography Phantom
ACR Exposure Set Up
\[(D_g)_{av} = (D_{gN})_{av} \ast X_a\]
<table>
<thead>
<tr>
<th></th>
<th>kVp</th>
<th>HVL</th>
<th>4 cm</th>
<th>5 cm</th>
<th>6 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo Target</td>
<td>29</td>
<td>0.30</td>
<td>1.64</td>
<td>1.32</td>
<td>1.09</td>
</tr>
<tr>
<td>Mo Filter</td>
<td></td>
<td>0.32</td>
<td>1.73</td>
<td>1.39</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.34</td>
<td>1.82</td>
<td>1.46</td>
<td>1.21</td>
</tr>
<tr>
<td>50% Adipose</td>
<td></td>
<td>0.36</td>
<td>1.91</td>
<td>1.54</td>
<td>1.27</td>
</tr>
<tr>
<td>50% Glandular</td>
<td>31</td>
<td>0.31</td>
<td>1.71</td>
<td>1.37</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.33</td>
<td>1.80</td>
<td>1.45</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.35</td>
<td>1.89</td>
<td>1.52</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.37</td>
<td>1.97</td>
<td>1.59</td>
<td>1.32</td>
</tr>
</tbody>
</table>

Other $D_{gN}$ References

- **Mo/Rh and Rh/Rh:**

- **Magnification Mammography:**

- **Mo/Mo and W/Al:**
  NCRP Reports No. 85 and 149
What to Measure

- Exposure In-air at Breast Surface
- Half-value Layer
- Compressed Breast Thickness
- Estimate of Tissue Composition
Steps: Dose Calculation

- Measure $X_a$, Exposure In-Air at Surface
- Determine $kV_p$ & Target Material
- Determine Compressed Breast Thickness
- Measure HVL (Type 1145 Aluminum)
- Estimate Adipose / Glandular Mix
- Look Up $(D_{gN})_{ave}$ in Table
- Calculate $(D_g)_{ave} = (D_{gN})_{ave} \times X_a$
**10. Breast Entrance Exposure, AEC Reproducibility, Average Glandular Dose, and Radiation Output Rate**

<table>
<thead>
<tr>
<th>Imaging mode:</th>
<th>SD (cm):</th>
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<tbody>
<tr>
<td>Source-detector distance (cm):</td>
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<tr>
<td>Firm type:</td>
<td></td>
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<td>Cassette size (cm):</td>
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<td>Field Restriction:</td>
<td></td>
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<tr>
<td>Energy correction factor:</td>
<td></td>
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</table>

**Breast thickness (cm):** 4.2

<table>
<thead>
<tr>
<th>Phantom</th>
<th>Nominal kVp setting</th>
<th>Target material</th>
<th>Filter</th>
<th>kVp (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mo</td>
<td>Mo</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>AEC mode</th>
<th>Density control setting</th>
<th>Measured HVL (mm Al)</th>
</tr>
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**Breast Entrance Exposure and AEC Reproducibility:**

<table>
<thead>
<tr>
<th>R</th>
<th>mA s</th>
<th>R</th>
<th>mA s</th>
<th>R</th>
<th>mA s</th>
<th>R</th>
<th>mA s</th>
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</table>

**ACTION LIMIT:** ACR/MQA - If coefficient of variation for either R or mA s exceeds 0.05, seek service.

**Average Glandular Dose:**

<table>
<thead>
<tr>
<th>Inv Sq corrected skin exp</th>
<th>Dose conversion factor from Table 1-3 (mAs/RI)</th>
<th>Computed average glandular dose (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

**ACTION LIMIT:** ACR/MQA - If average glandular dose exceeds 300 mrad (3 mGy) for 4.2 cm effective breast thickness, seek service or technique adjustment. Corrective action must be taken before further examinations are performed if the test results fail MQSA regulations.

**Radiation Output Rate:**

<table>
<thead>
<tr>
<th>3 sec, 4.5 cm above breast support</th>
<th>kVp</th>
<th>Anode</th>
<th>Filter</th>
<th>SD (cm)</th>
<th>Exp (mGy)</th>
<th>mA s</th>
<th>Time (sec)</th>
<th>Rate (mR/RI)</th>
<th>Kema (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

**ACTION LIMIT:** ACR - If output rate is less than 800 mR/RI (7.0 mGy/RI), seek service.

MQSA - If output rate is less than 613 mR/RI (4.5 mGy/RI), seek service. After 10/3/2002, this value changes to 800 mR/RI (7.0 mGy/RI).
10. Breast Entrance Exposure, Average Glandular Dose and Radiation Output Rate

Average glandular dose for average breast is below 3 mGy (300 mrad)
Average glandular dose to a 4.2-cm-thick breast on your unit is
Radiation output rate is ≥ 800 mR/sec (ACR); 513 mR/sec (MQSA)
What to Report

- Mean Glandular Dose
Recommendations: Mean Glandular Dose

- 4.5* cm Compressed Breast
- 50% Adipose / 50% Glandular
- Dose per view

*ACR Phantom is actually more like 4.2 cm
Recommendations:
Screen-Film with Grid

- ACR MAP 3 mGy
- MQSA 3 mGy
- NY, RI 3 mGy
- CA 3 mGy (was 2 mGy)
- NCRP SC-72 3 mGy
Full Field Digital Mammography (FFDM)

- Currently no new recommendations
- Calculate dose with ACR $D_{gN}$ Tables for screen/film imaging
- Continue to use 3 mGy per view recommendation
- Required dose is determined by quantum mottle-image quality considerations rather than film O.D.
Stereotactic Breast Biopsy (SBB) Units

- Chamber positioned in air
  - Not enough room in field for phantom
  - Assure that entire chamber is irradiated
  - Use typical patient technique for 4.5 cm
- Use ACR $D_{gN}$ Tables for Full Breast Screen/Film Imaging to Calculate Dose
- 3 mGy Recommendation Applies to both Digital and Screen/Film SBB systems
ACR MAP Dose

- 5 Groups of 3 TLD Chips - 4 with Al
- Mean Glandular Dose from
  - Compressed Breast Thickness
  - Breast Surface Exposure In-air
  - HVL
  - Published Tables
Published Dose Surveys-ACR Phantom

All Facilities Screen Film with Grid

- **ACR-MAP:** 6265 Facilities
  - 1992 1.27 mGy

- **CDRH / MQSA:** 4172 Facilities
  - First Inspection 1.5 mGy
  - Second Inspection 1.6 mGy
## Mammography in U.S. 1988 - 1997

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</thead>
<tbody>
<tr>
<td><strong>MGD (mGy)</strong></td>
<td>1.33</td>
<td>1.49</td>
<td>1.50</td>
<td>1.56</td>
<td>1.60</td>
</tr>
<tr>
<td><strong>ESE (mR)</strong></td>
<td>683</td>
<td>NA</td>
<td>910</td>
<td>943</td>
<td>965</td>
</tr>
<tr>
<td><strong>HVL (mmAl)</strong></td>
<td>0.38</td>
<td>0.35</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
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<tr>
<td><strong>Optical Density</strong></td>
<td>0.96</td>
<td>1.18</td>
<td>1.43</td>
<td>1.48</td>
<td>1.52</td>
</tr>
<tr>
<td><strong>Phant Score</strong></td>
<td>10.3</td>
<td>11.2</td>
<td>11.9</td>
<td>12.0</td>
<td>12.2</td>
</tr>
</tbody>
</table>

From Suleiman, Spelic, McCrohan, Symonds, Houn
Radiology 1999;210:345-351
Dose for Digital Mammography

- Preliminary ACRIN Values - RSNA 2001
  E. Berns & R.E.Hendrick
  Dose to ACR/MQSA Accreditation Phantom

- Fischer SenoScan - 1.37 mGy
- GE Senographe 2000D - 1.50 mGy
- Screen-Film - 1.68 mGy
ACRIN-DMIST MGD Results 2006

- Five types of FFDM Units:
  - Range: 1.31 – 1.98 mGy, Average: 1.62 mGy

- DMIST Screen-Film Units:
  - Average: 1.90 mGy

Bloomquist et al. Med Phys 2006; 33 (3) 719 - 736
Comparison of dose and image quality for four FDA Approved FFDM Units (Added 5th Unit-GE Essential in talk)

For ACR Phantom:
- MGD Range: 0.9 – 2.3 mGy
- Factor of 2.5

Variations of image quality did not strictly track with dose
ACR MAP Phantom Failures vs. Dose

- MGD vs Phantom Failure Rates for 31,535 mammography units from 1993 - 99
- Failure Rate 11% over all doses
- Failure Rate 43% for doses from 0.26 - 0.5 mGy
- Failure Rate 6% for doses from 1.5 - 2.0 mGy
- Increasing failure rate from 2.0 - 6.0 mGy

“A phantom composed of 30% glandular and 70% adipose tissue allows closer simulation of the phototimer response of the mammographic x-ray unit for the average breast. The phantom currently used contains 16% more glandular tissue than the average breast.”

Published Dose Survey - Patients

Mayo Clinic - Screen Film with Grid

- 6,006 Women - 24,471 Mammograms
- Median MGD: 2.6 mGy
- Median Breast Glandular Tissue: 28%
- Median Compressed Breast Thickness: 5.1 cm

Assumptions: Dose Calculation

- Firm Compression
- Uniform Cross Section
- 0.5 cm Adipose Layer - Top & Bottom
- Adipose / Gland Mix:
  - 100% / 0%
  - 70%/30%*
  - 50% / 50%
  - 0% / 100%

*Tables for 70%/30% from X. Wu included in NCRP 149
Risk Negligible for Diagnostic Exam of a Given Woman

Benefits and Risks Must Be Known for Screening of Asymptomatic Women
Mammographic equipment should be chosen to provide acceptable image quality at a typical mean glandular dose (for a two-view examination) of 6 mGy, or less for screen-film image receptor with grid for a patient having 4.5 cm thick compressed breasts of 50 percent adipose and 50 percent glandular tissue composition.
NCRP 149 Conclusions

- Annual mammographic screening examinations appear to provide favorable benefit/risk ratios in terms of breast cancer mortality in women age 50 or above, if acceptable image quality and dose are maintained.
NCRP 149 Conclusions

- Results of randomized clinical trials of screening mammography for women age 40 to 49, for which 10 or more years of follow-up is available, have shown evidence of a substantial benefit in reducing mortality which exceeds any risk of radiation-induced breast cancer.
Take Home Points - Mammo Dose

- Measure Exposure - Calculate Mean Gland Dose
- Required Dose Depends on Target/Filter, kVp, HVL, Breast Thickness and Composition
- For ACR Phantom S-F: Typical Doses are 1.5 - 2.0 mGy/view with a maximum of 3 mGy
- Lowest ACR Phantom Failures for 1.5 - 2.0 mGy
- Average Patient doses may be somewhat higher
- Minimal Benefit will outweigh any risk (NCRP)
- No specific recommendations yet for FFDM
Thank You!

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