Breast dosimetry in digital mammography and tomosynthesis

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Outline

• Essentials of breast dosimetry in 2D
  - quantities
  - formalism
  - breast/PMMA equivalence
  - practical dosimetry using PMMA
  - practical patient dosimetry

• Extension for dosimetry for tomosynthesis (work in progress)
UK DOSE SURVEY 1981

- 5CM PHANTOM
- Entrance surface dose - TLD
- Dose range 0.9 to 45 mGy (!)

- kV range 24- 49 kV
- HVL range 0.2 mm Al to 1.7 mm Al
Transmission through 5 cm breast

Transmission

Energy keV
In 1987 the ICRP 1987 recommended the use of

**Average glandular dose (AGD)**
(also known as mean glandular dose)

for breast dosimetry

**Why?**
Because it is these tissues that have the highest risk of radiation induced carcinogenesis.
Average glandular dose

- Cannot measure AGD on patients
- Incident air kerma $K$ (without backscatter) can be measured or estimated
- Need conversion coefficients which relate $K$ to AGD

\[ \text{AGD} = K \text{ g} \]

Calculation of $g$ using Monte Carlo model

(Dance 1990)

Focal spot

Calculate energy deposited in breast tissues

Compression plate
Simple breast phantom
Breast support etc
Simple breast model

CC projection

Hammerstein et al 1979

- 5 mm adipose shield region
- Central region with mixture of glandular and adipose tissues
- Fraction by weight of glandular tissue in central region is known as the glandularity

Hammerstein et al suggested the use of 50% glandularity for dosimetry
g-factors \quad (AGD = Kg)

- g-factor is for 50% glandularity and varies with breast thickness.
- g-factors depend upon kV, anode material and filtration.

Simplification

- Tables of g-factor just based on HVL & breast thickness
- For spectra in use in 1990 worked within ± 5%
$g$-factors

Breast thickness cm

$g$-factor mGy/mGy

HVL 0.3 mm

HVL 0.6 mm
Improved formulation in 2000
Dance et al 2000

- Real breasts don’t all have 50% glandularity – factors calculated for 0.1-100%
- Wider range of spectra used

$$\text{AGD} = K_{gcs}$$
C-factors
Tabulated against HVL, breast thickness and glandularity

But what glandularity should be used?
Breast glandularity

Breast thickness cm

Glandularity %

Ages 50-64

Breast thickness cm
## S-factors

<table>
<thead>
<tr>
<th></th>
<th>$S$</th>
<th>Max Error</th>
</tr>
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<tbody>
<tr>
<td>Mo/Mo</td>
<td>1.000</td>
<td>3.1%</td>
</tr>
<tr>
<td>Mo/Rh</td>
<td>1.017</td>
<td>2.2%</td>
</tr>
<tr>
<td>Rh/Rh</td>
<td>1.061</td>
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<tr>
<td>Rh/Al</td>
<td>1.044</td>
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</tr>
<tr>
<td>W/Rh</td>
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<tr>
<td>W/Ag</td>
<td>1.042</td>
<td>4.6%</td>
</tr>
</tbody>
</table>
“Standard breasts”

- For quality control and inter-system comparison need a simple phantom or phantoms
- Cheap and easily reproducible (PMMA)
- Should be approximately equivalent to typical compressed breast(s)
PMMA equivalence age 50-64
Dance et al, 2000

![Graph showing PMMA equivalence](image-url)
Practical dosimetry using blocks of PMMA

- Objective is to simulate exposure of ‘standard breasts’

- **Stage 1:** determine exposure settings using blocks of PMMA
- **Stage 2:** determine incident air kerma from output measurement
- **Stage 3:** measure HVL
- **Stage 3:** calculate AGD
- **Stage 4:** review results
European guidelines

AGD = Kgcs

Tables A5.1 & A5.2 give g and c vs PMMA cm & HVL

Table A5.4 gives s
Stage 4: review results

The diagram shows the relationship between PMMA thickness (cm) and AGD (mGy). The graph indicates that as PMMA thickness increases, AGD also increases. The chart distinguishes between acceptable and achievable levels, with red bars representing acceptable and green bars representing achievable values.
Patient dosimetry

- Measure tube output and HVL with paddle in place
- Record exposure parameters for patient series (50 or more)
  - kV & target/filter
  - mAs
  - compressed breast thickness
- Calculate AGD
Dosimetry for breast tomosynthesis

- Work in progress
- Results from
  - Dance et al
  - Sechopoulos et al

- There are presently no European guidelines for dosimetry for breast tomosynthesis
Dose will depend on:

- Breast thickness, shape and glandularity
- Breast position in relation to edge of detector
- Central projection used: MLO or CC
- Radiation quality
- Tomographic motion:
  - projection angles
  - position of rotation axis
  - FFD
Possible methodology and formalism:

- Determine AGD for zero degree position using standard method for 2D imaging
- Apply formula to calculate dose for tomosynthesis.

\[ AGD = K(0)gcs \, T \]
Possible formalism:

\[ \text{AGD} = K(O)gcsT \]

\[ T = \sum \tau(\Theta) \]

\[ \tau(\Theta) = \frac{\text{AGD}(\Theta)}{\text{AGD}(0)} \]

BUT how does \( \tau(\Theta) \) vary with all the various parameters?
Dependence of $t(\Theta)$ on projection angle (CC view)

Tomo factor $t$

- 5 cm
- 2 cm

W/Rh 30kV

glandularity 50%

Projection angle (degrees)
Dependence of $t(\Theta)$ on breast thickness (CC view)

30kV W/Rh

glandularity 50%

Breast thickness (cm)

Tomo factor $t$

15 degrees

30 degrees
Dependence of $t(\Theta)$ on X-ray spectrum (CC view)

5cm thick breast, glandularity 50%

- 25 kV Mo/Mo
- 35 kV W/Rh
Overall variation of $t(\Theta)$ (CC view)

Mo/Mo, Mo/Rh, Rh/Rh and W/Rh spectra, 2-11 cm thick breasts
glandularity 50%

Tomo factor $t$

Projection angle (degrees)
Overall variation of $t(\Theta)$ (CC view)

Projection angle (degrees)

Tomo factor $t$

- Lowest value
- Highest value

Hologic
Overall variation of $t(\Theta)$ (CC view)

Projection angle (degrees)

Tomo factor $t$

- Red: Lowest value
- Blue: Highest value

Sectra
Overall variation of $t(\Theta)$ (CC view)

Graph showing the variation of Tomo factor $t$ with projection angle (degrees) for Siemens. The graph includes a line for the lowest value and another for the highest value, indicating the range of Tomo factor for different projection angles.
Overall variation of $t(\Theta)$ (CC view)

Projection angle (degrees)

Tomo factor $t$

Max variation $\pm 7\%$
Overall variation of T with angular range (CC view)

![Bar chart showing the variation of T with projection angle.](chart.png)
Overall variation of T with angular range (CC view)

Projection angle (degrees)

Tomo factor T / No of projections

Max error %

-10 to +10 -15 to +15 -20 to +20 -25 to +25 -30 to +30
Dependence of $t(\Theta)$ on projection angle (MLO view)

Data from Sechopoulos

Tomo factor $t$

Projection angle (degrees)

Data from Sechopoulos
glandularity 50%
Overall variation of T with angular range (MLO view)
Conclusions for dosimetry for tomosynthesis

1. The formalism for 2D can be extended to tomosynthesis by the use of a further factor $T$, which can be tabulated against the angular range used. $T$ is close to 1.

2. If different weights are given for each angle, individual factors $t(\Theta)$ must be used.

3. Different factors may be needed for breasts of different compressed areas and for different projections.

4. The dose is affected by the position of the breast on the breast support plate.
What is the dose for breast tomosynthesis?

\[ \text{AGD} = K(0)gcs \times T \]

1. The value of $T$ is close to 1

2. The AGD will thus be similar to that for digital mammography if the same total mAs is used.

3. Actual values of AGD depend upon the exposure parameters chosen by the manufacturer, and these vary.

4. Can expect the total dose for the examination to be similar to that for standard digital mammography
Finally...

- Breast dosimetry important part QC

- Careful measurement is essential in accordance with procedures in the European Guidelines.

- Remember that all dosimetry is for very simple models of the breast. In real breasts, the distribution of glandular tissue will be different as will the AGD.
Acknowledgements

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