Dosimetry in digital breast tomosynthesis and CEDM

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Outline

• 3D formalism
  \(t\)-factors & \(T\)-factors
• Values of \(t\) & \(T\)-factors
• Use of PMMA
• Measurement results
• Conclusions for DBT dosimetry
• Recent work on CEDM dosimetry
3D formalism
Protocol objectives

- Easy to implement
- Consistent with methodology used for projection (2D) mammography
European 2D formalism

\[ \text{AGD} = K \cdot g \cdot c \cdot s \]

- **K** incident air kerma
  - \textit{(in contact with compression paddle)}

- **g** conversion factor for 50:50 breast (function of HVL, thickness)

- **c** corrects for actual breast glandularity

- **s** corrects for X-ray spectrum
Suggested formalism for tomo:

\[ AGD = K \ gcs \ T \]
\[ T = \Sigma a_i \ t(\Theta_i) \]
Suggested formalism for tomo:

\[ t(\Theta) = \frac{MC[AGD(\Theta)]}{MC[AGD(2D)]]} \]

AGD(\Theta) and AGD(2D) calculated for the same tube loading

For full-field irradiation: \( t(0) = 1 \)
Incident air kerma

\[ AGD = K \, gcs \, T \]

Air kerma is for a 2D geometry (zero degree projection) and for the total mAs from all projections.
Air kerma measurement

• For full field systems, measure for zero degree position

• Procedure is the same as 2D
  – Correct for ISL and to total mAs

• For slit scanning geometry, measure for a whole scan
  – It is then mandatory to make the measurement with the dosimeter resting on the breast support
T and t(θ) will depend on:

- Radiation quality
- Breast thickness, shape and glandularity and position
- Tomographic motion:
  - projection angles
  - position of rotation axis
  - FID
  - Field size
Full-field geometry

- Fixed detector: whole detector irradiated at each angle
- FID 660 mm
- Rotation axis 40 mm above image plane
- Angular range $\theta = -30$ to $+30$ degrees
- MC calcs of AGD for a wide range of spectra, breast sizes and compositions in CC view

ALSO:
Results available for scanning geometry (not shown today)
Values of t- and T-factors
Monte Carlo calculations of $t(\theta)$

Spectra:
- Mo/Mo, Mo/Rh, Rh/Rh,
- W/Rh, W/Ag, W/Al
- 25-49 kV (depending on spectrum)

Breast thicknesses
- 2-11 cm

Breast glandularities
- 0.1 – 100%
  (variation ±1.6% or less)
Dependence of $t(\Theta)$ on projection angle

Tomo factor $t$

- 5 cm
- 2 cm

W/Rh 30kV
glandularity 50%

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

- 0 degrees
- 15 degrees
- 30 degrees

30kV W/Rh

glandularity 50%

Breast thickness (cm)
Dependence of $t(\Theta)$ on X-ray spectrum

- 25 kV Mo/Mo
- 35 kV W/Rh
- Sechopoulos

5cm thick breast
Glandularity 50%

Tomo factor $t$

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

All spectra, thicknesses and glandularities

Tomo factor $t$

Projection angle (degrees)

Lowest value

Highest value
Overall variation of $t(\Theta)$ (CC view)

Projection angle (degrees)

- Tomo factor $t$
- Hologic

- Lowest value
- Highest value
Overall variation of $t(\Theta)$ (CC view)

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

- **Tomo factor** $t$
- **Projection angle (degrees)**

Graph showing the variation of $t(\Theta)$ with projection angle for Siemens with the following lines:
- **Lowest value**
- **Highest value**
Overall variation of $t(\Theta)$ (CC view)

Max variation $\pm 9\%$

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

Max variation ±5%
if thickness results are not lumped

Projection angle (degrees)
Calculation of $T$ from $t(\Theta)$

$$T = \sum a_i \ t(\Theta_i)$$

If same tube loading for each projection:

$$T = \frac{1}{N} \sum t(\Theta_i)$$
Overall variation of $T$ with angular range (CC view)

Projection angle (degrees)

Tomo factor $T$
Overall variation of T with angular range (CC view)

Tomo factor T

Projection angle (degrees)

Max error %
Overall tomo factor T

Breast thickness mm

T-factor

T Hologic

T Siemens
Conclusions for dosimetry for tomosynthesis (full field case)

1. Data for both $t(\theta)$ and $T$ can be specified in very compact tabulations (vs angle and breast thickness), to be used for all spectra and breast glandularities.

2. $T$ close to 1

(range 0.99-0.93)
Where to find the $t$ and $T$ factors and the protocol?

- Dance et al
  - PMB 56 453–471 (2011)
  - Tables of $t$ and $T$ vs angle and thickness
  - Tables of $T$ for Hologic, Siemens and Phillips (Sectra) prototype

- Draft EUREF tomo QC protocol
  - As above plus tables for Fuji, GE, IMS Giotto, Planmed Nuance Excel

- Use $T$ for both CC and MLO projections
Use of PMMA
PMMA for standard breast dosimetry

<table>
<thead>
<tr>
<th>PMMA mm</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast mm</td>
<td>21</td>
<td>32</td>
<td>45</td>
<td>53</td>
<td>60</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Gland'y %</td>
<td>97</td>
<td>67</td>
<td>41</td>
<td>29</td>
<td>20</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>

But are these appropriate for tomo?
- Angled beams, no anti-scatter grid
Work of Bouwman et al (PMB 2013)

- Comparison of PMMA – breast equivalence for FFDM and DBT
  - Based on Monte Carlo simulations and analytical calculations
- Found that 2D PMMA thicknesses could be used for DBT with acceptable errors
  - 1%, 5%, 10% for breast thicknesses 30, 70, 100 mm
- Designed dosimetric phantoms of polyethylene and PMMA which matched breast thickness
Measurement results
AGD for Hologic DBT system

- Patient dose
- PMMA dose

AGD (mGy) vs. breast thickness (mm)
AGD for Siemens DBT system

(b)

Patient dose
PMMA dose

AGD (mGy)

breast thickness (mm)
AGD summary

- **PMMA dose is on average about 8% less than patient dose**
  - (much less than variation between patients for fixed breast thickness)
  - Same PMMA blocks can be used as in 2D

- **For Hologic**
  - DBT dose is $\approx 1.2 \times 2D$ dose

- **For Siemens**
  - DBT dose is $\approx 1.5 \times 2D$ dose
Conclusions for DBT dosimetry

- 2D formalism can be extended to tomo by using tables of factors $t$ (individual projection) and $T$ (whole exam)
  - $T$ generally close to 1 (fixed detector)
- For same total mAs dose quite similar to 2D mammography
- Same PMMA blocks can be used for dosimetry QC as for 2D FFDM
- Actual dose depends on manufacturer's choice of imaging parameters.
  - Our results show AGD for DBT is 1.2-1.5x AGD for 2D
Dosimetry for contrast enhanced digital mammography (CEDM)
European 2D formalism

$$\text{AGD} = K \ gcs$$

g Available up to HVL 2.0 mm Al

c available up to HVL 0.8 mm Al

s available for Mo/Mo, Mo/Rh, Rh/Rh, Rh/Al & W/Al

Higher energy spectrum for CEDM:
W/Cu or Mo/Cu or Rh/Cu (all 0.3 mm Cu)

40-49 kV, HVL 2.5 – 3.5 mm Al

New factors needed
CEDM spectra

- MC Calculations made for:
  - W with 0.28, 0.30 or 0.32 mm Cu
  - Mo with 0.30 mm Cu
  - Rh with 0.30 mm Cu
  - 40 – 50 kV
  - Breast thicknesses 20-110 mm
  - Glandularities 0.1% - 100%
CEDM spectra, matched HVL, kV
CEDM spectra matched HVL, kV
All three Cu thicknesses for W/Cu fit on the same curve
True for each breast thickness
Mo/Cu and Rh/Cu fit on the WCu curve
True for each breast thickness
CEDM $g$-factors

W/Cu, Mo/Cu and Rh/Cu fit same curve
True for each breast thickness
$g$ can be tabulated against HVL
$s=1$ for all spectra considered

DO NOT EXTRAPOLATE EARLIER DATA!!
CEDM $c$-factors

W/Cu, Mo/Cu and Rh/Cu fit same curve
True for each glandular/breast thickness
$c$ can be tabulated against HVL

DO NOT EXTRAPOLATE EARLIER DATA!!
Where to find CEDM factors

Data in:
Dance & Young, PMB 59 2127 (2014)

Soon to be at:
medphys.royalsurrey.nhs.uk/nccpm
Acknowledgements

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