Radiation Dosimetry in Digital Breast Tomosynthesis

March, 2015

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Imagination at work.
Syllabus

1. Introduction
2. Dosimetry in Mammography
3. Dosimetry in Digital Breast Tomosynthesis
4. Methodology
5. Conclusion
Introduction
Introduction

Radiation dosimetry in digital breast tomosynthesis:
Report of AAPM Tomosynthesis Subcommittee Task Group 223
(2014)

- Ioannis Sechopoulos
- John M. Sabol
- Johan Berglund
- Wesley E. Bloch
- Libby Brateman
- Emmanuel Christodoulou
- Michael Flynn
- William Geiser
- Michael Goodsitt
- A. Kyle Jones
- Joseph Y. Lo
- Andrew D.A. Maidment
- Kazuyoshi Nishino
- Anita Nosratieh
- Baorui Ren
- W. Paul Segars
- Miriam Von Tiedemann
Introduction

• Over a lifetime, 1 in 8 women will develop breast cancer

• Annual mammography for women age 40 and older*

• Complimentary imaging procedures (MRI, US, NUC) used at increasing frequency
Introduction
**Introduction**

**1950’s**
- no-screen
- direct exposure film
- high dose
- clinical benefits?

**1960’s**
- Xeroradiography
- better resolution
- contrast/dose WIP

**1985**
- NEXT Survey
- poor IQ in 36% of mammograms

**1992**
- MQSA

**1992**
- MQSA

**2000**
- FFDM

**History of X-Ray Breast Imaging**

**DBT**
Introduction

- Digital Breast Tomosynthesis (DBT) is a new screening tool
- Need to understand, estimate and communicate patient dose
- Radiation dose to glandular tissue is primary consideration in x-ray based breast imaging
- Cancer risk to adipose tissue is considered minimal
Introduction

Image Quality Requirements:

- Masses with irregular or spiculated borders
- Clusters of micro-calcifications
- Architectural distortions of breast structures
Introduction
Introduction

high % adipose tissue  →  high % glandular tissue
Introduction

• Small attenuation differences between normal and cancerous tissue

• Low energy x-rays can help to highlight the difference
Introduction

μ

kV

glandular

fat

tumor
Introduction

\[ Ca_5(PO_4)_3 \text{ OH (0.1 mm)} \]

contrast vs. kV

- glandular

- \[ Ca_5(PO_4)_3 \text{ OH (0.1 mm)} \]
Dosimetry in Mammography
Dose in Mammography

- focal spot
- diaphragm
- compression paddle
- supporting table grid
- screen - film
**Entrance Skin Exposure**

*Entrance Skin Exposure (X\textsubscript{ESE})*

free-in-air ionization chamber measurement at the point where the x-ray beam first interacts with the skin

Typical $X\textsubscript{ESE}$ values for a 4.5 cm breast are in the range of 500-1,000 mR
Dose in Mammography

Entrance dose

1 cm ≈ 50%

2 cm ≈ 25%

3 cm ≈ 10%
Mean Glandular Dose

Mean Glandular Dose ($D_g$)

preferred dose index

glandular tissue is the most probable site of carcinogenesis

Difficult to calculate $D_g$ since doses vary by depth below skin

$D_g$ does not represent individual patient dose
Mean Glandular Dose

$D_g$ is dependent upon:

- composition of the breast
- breast thickness
- Half value layer
- kVp
Normalized Mean Glandular Dose

\[ D_g = D_{gN} \times X_{\text{ESE}} \]

**Normalized Mean Glandular Dose (\( D_{gN} \))**

- relates \( X_{\text{ESE}} \) to \( D_g \)
- \( D_{gN} \) provides a conversion factor in units of \( \text{mGy/}R \)
- \( D_{gN} \) depends on kVp, HVL, target material, filter material, breast thickness, and tissue composition
Mean Glandular Dose

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mGy/R (for Mo/Mo and 4 cm compressed 50/50 breast)
## Mean Glandular Dose

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For 28 kVp, 0.35 mm HVL

\[ X_{ESE} = 1.231 \text{ R} \]

\[ D_g = 1.68 \text{ mGy/R} \times 1.231 \text{ R} \]

\[ D_g = 2.07 \text{ mGy} \]

mGy/R (for Mo/Mo and 4 cm compressed 50/50 breast)
Factors Affecting Breast Dose

<table>
<thead>
<tr>
<th>Comp Breast</th>
<th>ESE (mR)</th>
<th>MGD (mGy)</th>
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</thead>
<tbody>
<tr>
<td>2 cm</td>
<td>250</td>
<td>0.7</td>
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<tr>
<td>4 cm</td>
<td>1,000</td>
<td>1.8</td>
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<tr>
<td>6 cm</td>
<td>1,500</td>
<td>2.4</td>
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</table>

- Increased breast thickness requires increased dose
- Compression lowers breast dose by reducing breast thickness
- Higher kVp lowers $X_{ESE}$ and $D_g$ (decreases contrast)
Factors Affecting Breast Dose

Increased breast glandularity requires increased mAs
Conclusion

- Rapid decrease in dose with increase in beam energy.
- Increasing kV from 17.5 to 30 kV lowers $D_g$ by a factor of 30 for 8 cm breast.
- $D_g$ increases by a factor of 17 from 2 cm breast to 8 cm breast.
MQSA

- MQSA limits the average glandular dose to 3 mGy for a compressed breast thickness of 4.2 cm and a breast composition of 50% adipose tissue and 50% glandular tissue (using the MQSA phantom)

- If the average glandular dose for the MQSA phantom exceeds 3 mGy, mammography can not be performed

- The average glandular dose for the MQSA phantom is typically 1.5 to 2.2 mGy per view
Full Field Digital Mammography (FFDM)

The shift from screen film mammography to digital mammography MQSA resulted in improved image quality while providing opportunities for dose reduction.

Acquisition and display can be optimized independently.
Full Field Digital Mammography (FFDM)
Full Field Digital Mammography (FFDM)
Full Field Digital Mammography (FFDM)

Wide dynamic range (1000:1)

*screen film mammography* (40:1)

dynamic image manipulation

post processing

CAD

3D imaging
Full Field Digital Mammography (FFDM)
Full Field Digital Mammography (FFDM)
Full Field Digital Mammography (FFDM)
Dosimetry in Digital Breast Tomosynthesis
Dosimetry in Digital Breast Tomosynthesis
Dosimetry in Digital Breast Tomosynthesis

employ multiple lines of response acquired over various angles

similar acquisition and processing paradigms employed in computed tomography – including iterative reconstruction

dose indices may be different from mammography
Dosimetry in Digital Breast Tomosynthesis
Dosimetry in Digital Breast Tomosynthesis
Dosimetry in Digital Breast Tomosynthesis
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Dosimetry in Digital Breast Tomosynthesis
Dosimetry in Digital Breast Tomosynthesis

A + B = 7
A + C = 6
A + D = 5
B + C = 9
B + D = 8
C + D = 7

Iterative reconstruction

A  B
C  D

2  5
4  3
Dosimetry in Digital Breast Tomosynthesis

• The changing geometry in tomosynthesis may result in variations in dose

• Source to skin distance and $X_{ESE}$ may change as the tube (and possibly the detector) rotate

• *Relative Glandular Dose (RGD)* describes the change in mean glandular dose between the 0° projection (mammography) and a projection acquisition for a non-zero angle
Dosimetry in Digital Breast Tomosynthesis

Relative Glandular Dose is a function of:

• Projection angle
• Breast size
• Breast thickness
Dosimetry in Digital Breast Tomosynthesis

$D_g N (0^\circ)$ is the same as standard mammography.

$D_g N (\alpha)$ for different angulations is a fraction of $D_g N (0^\circ)$

Fraction is described by RGD

Different RGD for each angulation
By convention, MGD (0°) has a value of 1.000.

Assume $D_g N (0°) = 1.68$

Suppose $\alpha = 12.5°$ and $D_g N$ for that angulation is only 1.61

$\text{RGD} (12.5°) = 1.61/1.68$

$\text{RGD} (12.5°) = 0.96$
Dosimetry in Digital Breast Tomosynthesis

Projection angle:

- 0
- 5
- 10
- 15
- 20
- 25
- 30

RGD (\(\alpha\)):

- 1.00
- 0.98
- 0.96
- 0.94
- 0.92
- 0.90
- 0.88
- 0.86
- 0.84
- 0.82

Graph showing the relationship between RGD (\(\alpha\)) and projection angle.
Dosimetry in Digital Breast Tomosynthesis

• Similar to the example in mammography ($D_gN$), the goal is to develop a Roentgen-to-mGy conversion factor for digital breast tomosynthesis

• $D_gN_{TOMO}$ is the Normalized Glandular Dose for a complete tomosynthesis acquisition

• Estimation of the Normalized Glandular Dose requires an RGD correction for every angulation in the tomosynthesis acquisition

• The use of an average RGD value is possible in certain cases.
Methodology
## Methodology

<table>
<thead>
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<th>thickness (cm)</th>
<th>Angle (degree)</th>
<th>RGD</th>
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**RGD and RGD values for GE Healthcare SenoClaire DBT System**
Conclusion
Conclusion

• improved low contrast visibility
• potential for lower dose
• reduced interference from overlapping tissue
• re-evaluate compression requirements
• fewer patient recalls
Conclusion

• Report provides methodology to estimate breast glandular dose in breast tomosynthesis in a manner consistent with established mammography methodology

• For standard breast tomosynthesis acquisition, the normalized glandular dose appears to be in line with values from mammography

• Acquisition protocols with variance in tube current exposure time or with asymmetric tube angulations may not fit the generic model
Conclusion

• Estimated doses are not patient specific

• Patient specific models not possible without knowledge of true distribution of glandular tissue throughout the breast

• Need better accounting for heel effect