Medical Physics 2.0
Mammography 2.0

Andrew Karellas, PhD
Srinivasan Vedantham, PhD

Department of Radiology
University of Massachusetts Medical School
Worcester, MA

Andrew.Karellas@umassmed.edu

AAPM 2014, Austin, TX

- NIH NCI grant R21 CA 134128  (A. Karellas, UMass)
- NIH NCI grant R21 CA176470  (S. Vedantham, UMass)
- R01 CA139449-01 (K. Paulsen-PI, Dartmouth, A. Karellas UMass sub-award)

The contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH or the NCI.

Disclosures: None

Acknowledgements

Collaborators and team members

University of Massachusetts Medical School
- Srinivasan Vedantham, PhD
- Linxi Shi, MS
- Stephen Glick, PhD
- Gopal Vijayaraghavan, MD

University of Rochester
- Avice O’Connell, MD
Objectives

2. Accomplishments and problems in current practice.
3. It is more than mammography, it is Breast Imaging.
4. Evolution of mammography: tomosynthesis and other techniques.
5. Responsibilities beyond equipment surveys.
7. Operationally engaged.

Historical note

- The Mammography Quality Standards Act and Program (MQSA) was enacted by the United States Congress in 1992 to regulate the quality of care in mammography. The act was officially effective in 1994, and was extended in 2004. The U.S. Food and Drug Administration (FDA) began inspections of mammography facilities to ensure compliance in 1995. In 1997, more comprehensive regulation was added and became effective in 1999.1

- Prior to MQSA the American College of Radiology (ACR) had established a rigorous mammography accreditation program.


Historical note

- ACR and MQSA requirements represent landmark initiatives defining the role and responsibilities of the Medical Physicist at the national level.
- Some local jurisdictions had certain requirements for medical physics services prior to ACR and MQSA.
Developments since MQSA implementation

FDA Approved

- Digital mammography
  - Flat panel
  - Computed radiography
  - Photon counting
  - Digital stereotactic imaging
- Digital readout of “dose”
- Computer assisted diagnosis and detection
- Quantitative density evaluation
- Digital Breast Tomosynthesis
- Reconstruction of planar view from tomosynthesis acquisition.
- Contrast mammography
- MRI
- Whole breast ultrasound

Under development (not FDA approved)

- Dedicated breast CT (CE Mark approval in Europe and approved in Canada)
- Contrast tomosynthesis
- Nuclear medicine imaging (breast specific gamma imaging)

Tomographic Imaging of the Breast
Tomosynthesis vs. Dedicated Breast CT

Tomosynthesis
- Moving x-ray source
- Breast
- Detector

Dedicated breast CT
- Moving x-ray source
- Breast
- Detector

From lab notes on file dated 3-6-1996
Andrew Karellas
The medical physicist is largely viewed as a person who conducts QA on equipment.

Many medical physicists are not afforded the opportunity to spend enough time with technologists and radiologists.

Phantom images are very useful but they may not represent all aspects of image quality.

The medical physicist rarely deals with dose issues relating to a specific patient. Frequently patients who inquire about radiation dose and risk may not be given factual information.

In spite of the recognized need for medical physics expertise in breast imaging, advances in professional medical physics services tend to lag the technology.

Technologies may be deployed in the clinic but medical physicists have limited information on initial acceptance and periodic QA (rely mostly on manufacturer’s QA recommendations).

### Current status - Confidence in medical physics support *

<table>
<thead>
<tr>
<th>Modality</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Digital mammography</td>
<td>High</td>
</tr>
<tr>
<td>- Flat panel</td>
<td>High</td>
</tr>
<tr>
<td>- Computed radiography</td>
<td>High</td>
</tr>
<tr>
<td>- Digital stereotactic imaging</td>
<td>Low</td>
</tr>
<tr>
<td>- Photon counting</td>
<td>Low</td>
</tr>
<tr>
<td>✓ Digital readout of &quot;dose&quot;</td>
<td></td>
</tr>
<tr>
<td>✓ Computer assisted diagnosis and detection</td>
<td></td>
</tr>
<tr>
<td>✓ Quantitative density evaluation</td>
<td></td>
</tr>
<tr>
<td>✓ Digital Breast Tomosynthesis</td>
<td></td>
</tr>
<tr>
<td>✓ Reconstruction of planar view from</td>
<td></td>
</tr>
<tr>
<td>tomosynthesis</td>
<td></td>
</tr>
<tr>
<td>✓ Contrast mammography</td>
<td>Low</td>
</tr>
<tr>
<td>✓ MRI</td>
<td>Low</td>
</tr>
<tr>
<td>✓ Whole breast ultrasound</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

*All FDA approved modalities*
Questions we need to ask and our vision for the role of the Medical Physicist

• Is what we measure all we should be measuring in routine QA?
• How does a small drift in kVp can affect the AEC?
• Are x-ray spectra important and under what circumstances?
• Is “disk” contrast or contrast-to-noise a sufficient measurement?
• Does anyone measure radiation waveform?
• Is the dose we measure with the phantom in place meaningful for patient dosimetry?

Questions we need to ask and our vision for the role of the Medical Physicist

• Can we provide the average glandular dose for a given patient?
• How do we know the selected mammographic technique is optimal for a given breast size and composition? How do we evaluate this?
• Are we prepared to discuss radiation risks in view of the potential benefit from mammography (screening or diagnostic) with an inquiring physician or with a concerned patient?
• Do all medical physicists fully appreciate the difference between screening and diagnostic mammography?

Radiation dose

Medical physicists must:

✓ Become familiar with emerging developments in patient specific dosimetry in mammography. New models are emerging on dose estimation in mammography and tomosynthesis. These new models take into account the size and revised composition of the breast.

✓ Investigate methods for testing the accuracy and reproducibility of dose estimation models.

✓ Expand the dose reporting from simple phantom to various scenarios of breast size and composition.
Radiation dose

✓ Provide input on the dose from diagnostic mammography.

✓ Be prepared to answer questions about the radiation dose to other parts of the body from mammography or digital breast tomosynthesis.

✓ Be prepared to answer questions about radiation and allay any fears in situations where the risk is very small in view of the potential benefit.

✓ Adapt to translating this knowledge to emerging imaging approaches such as dedicated breast CT*.

* Not FDA approved in the US. CE Mark approval in Europe and approved in Canada.

---

Radiation dose

Knowledge learned from emerging modalities that is applicable to mammography and digital breast tomosynthesis dosimetry

---

Personalized estimates of radiation dose from dedicated breast CT in a diagnostic population and comparison with diagnostic mammography

Srikumar Valsangkar1,*, Lim-Lim1, Tahseen Kandil1, Joyce M.O’Connor1 and David L. Coon1

1 Department of Radiology, University of Arizona Health Sciences, Tucson, AZ, USA

E-mail: srikumar.valsangkar@email.arizona.edu

Received 15 May 2013; revised June 18 August 2013

Published 31 May 2013

Online at dx.doi.org/10.1016/j.ijrobp.2013.05.039

Abstract

This study retrospectively analyzed the mean glandular dose (MGD) in 134 women from 13 California, US, hospitals, who participated in a clinical trial of dedicated breast CT (CBCT) and digital breast tomosynthesis. The individual MGD of dedicated breast CT was compared to the median and mean MGD of the diagnostic population of women who underwent digital mammography by the same breast imaging groups. The results show that the mean MGD of dedicated breast CT was similar to the median MGD of diagnostic mammography.

---

Dedicated breast CT

---

The median Mean Glandular Dose from dedicated breast CT was equivalent to 4–5 diagnostic mammography views...
Average Glandular Dose ~ 1.2 mGy (2D mode)

Average Glandular Dose ~ 1.4 mGy (Tomosynthesis mode)

With ACR recommended accreditation phantom. For individual breasts, the radiation dose will vary depending on compressed breast thickness, selected technique factors and breast composition.

- Measure exposure (air kerma) at skin entrance
- Measure kVp / HVL
- Use DgN conversion factors that were derived from Monte Carlo simulations
  - Monte Carlo simulations assumed 4 mm thick skin and 50% fibroglandular breast

Subcutaneous fat may provide additional shielding, its thickness affects the dose calculation.

More importantly, radiosensitive ductal epithelium and fibrous attachment are present within subcutaneous fat\(^1\)

Should we use 1.45 mm skin layer for estimating DgN coefficients to provide a more accurate estimate of radiation risk?

Breast skin thickness

Determination of the mean and range of location-averaged breast skin thickness for use in Monte Carlo-based estimation of normalized glandular dose coefficients. The study found that 1.45 mm thick skin layer comprising the epidermis and the dermis for breast dosimetry is appropriate.

Shi et al., Med Phys 2013, 40(3): 031913

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of breasts</th>
<th>Mean ± Inter-breast SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shi et al(^1)</td>
<td>137</td>
<td>1.44 ± 0.25 mm</td>
<td>0.9 – 2.3 mm</td>
</tr>
<tr>
<td>Huang et al(^2)</td>
<td>100</td>
<td>1.45 ± 0.3 mm</td>
<td>0.9 – 2.3 mm</td>
</tr>
</tbody>
</table>

Measured skin thickness corresponds to the combined thickness of epidermis and dermis

\(^1\) Shi et al., Med Phys 2013, 40(3): 031913
\(^2\) Huang et al., Med Phys 2013, 40(3): 031913

Fibroglandular fraction

- Should we use 15% fibroglandular breast instead of 50% fibroglandular breast for estimating dose?
- Should we calculate the fibroglandular fraction for each breast (Quantra, Volpara, Cumulus, etc.) and use appropriate DgN coefficients?
- How do we determine if the fibroglandular fraction provided by these tools are accurate?
- Need for structured phantoms with different compositions.
Mean and range of volumetric glandular fraction (VGF) of the breast in a diagnostic population using a high-resolution flat-panel cone-beam dedicated breast CT system. Important for Monte Carlo-based estimation of normalized glandular dose coefficients and for investigating the dependence of VGF.

Several studies have reported on the fibroglandular fraction:

<table>
<thead>
<tr>
<th>Study</th>
<th>Modality</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vedantham et al\textsuperscript{1}</td>
<td>BCT</td>
<td>15.8 ± 13%</td>
</tr>
<tr>
<td>Yaffe et al\textsuperscript{2}</td>
<td>BCT</td>
<td>14.3 ± 10%</td>
</tr>
<tr>
<td>Nelson et al\textsuperscript{3}</td>
<td>BCT + Mammography</td>
<td>14.3 ± 11%</td>
</tr>
<tr>
<td>Nelson et al\textsuperscript{4}</td>
<td>BCT</td>
<td>17.1 ± 15%</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Vedantham et al., Med Phys 2012; 39:7317-7328
\textsuperscript{2} Yaffe et al., Med Phys 2009; 36:5437-5443
\textsuperscript{3} Nelson et al., Med Phys 2008; 35:1078-1086

Radiation dose (the physicist’s role)

The Medical Physicist’s input must be expanded in:

- Dealing with dose issues in tomographic imaging of the breast (tomo-synthesis at present and eventually in dedicated breast CT).
- Optimization of acquisition protocols (tomo-synthesis with planar views combination versus synthesized planar view from tomo-synthesis projections). Image quality and dose considerations. Radiation dose optimization in tomographic imaging of the breast presents significant challenges.
Operationally engaged to meet future challenges

Stationary Digital Breast Tomosynthesis

LEFT: Hologic Selenia Dimensions Unit. Digital Breast Tomosynthesis system with single rotating x-ray source.
RIGHT: Stationary digital breast tomosynthesis system with integrated CNT x-ray source array (XinRay Systems Inc., Research Triangle Park, NC). There are 31 x-ray generating focal spots; each x-ray beam can be electronically controlled to turn on/off instantaneously.


Investigational device. Limited by Federal law to investigational use. Not FDA approved

Stationary Digital Breast Tomosynthesis

Courtesy of Dr. Otto Zhou, University of North Carolina
Investigational device. Limited by Federal law to investigational use. Not FDA approved
Digital Breast Tomosynthesis (moving versus stationary x-ray sources)


Dedicated Breast CT

Source: Gazi et al., Proc. SPIE 2014; 9033: 903348-3

Current system
John Boone group
UC Davis

Experimental
Otto Zhou group
Univ. of North Carolina

Clinical
(moving source)

System MTF obtained after reconstruction

Manufacturer: Koning Corporation
Investigational device. Limited by Federal law to investigational use. Not FDA approved

Dedicated Breast CT
At the University of Massachusetts Medical School

Digital MLO

University of Massachusetts Medical School – University of Rochester study
A dedicated breast CT QC with calcification phantom - UMass prototype

- 13 cm diameter phantom
- 15% fibroglandular (fg) composition
- Ramp-filtered FBP
- Voxel size: 0.155 mm
- AGD: matched to diagnostic mammography (4.5 views, 12 mGy)
- CaCO$_3$ specks

Note: ACR mammography accreditation phantom uses Al$_2$O$_3$ specks. For CT, this phantom may not represent the best choice for image quality evaluation.

CaCO$_3$ specks size in microns

Vedantham et al., Phys Med Biol 2013; 58:7921-7936

Neoadjuvant treatment
Monitoring response

Before treatment
After treatment

Tumor regression

Collaboration between Avice O’Connell, MD and UMass Medical School team.
Neoadjuvant treatment: Monitoring response
Before and after treatment: tumor size change

Are we ready for contrast enhancement studies?
Contrast enhanced Breast CT

Index lesion (ILC)
UMass Lobular Carcinoma study (UMLC03)

Algorithms / Segmentation routines.

Segmentation routines/algorithms for tumor volume (size) estimation:
- Should Physicists be involved in verifying its accuracy?
  - Can provide a perspective on issues due to dose, contrast, CNR and artifacts
- Do we have the necessary tools?
Today’s research is tomorrow’s practice
“Operational engagement
in the clinical environment”

✔ Medical physicists are “Scientists in Medicine” and they are expected to function as objective evaluators and innovators.

✔ The evaluation of the performance of imaging equipment and practices must be based on sound scientific principles.

✔ Published research serves as the basis for maintaining the validity of existing tests and for implementing new tests.

Conclusions
Today’s research is tomorrow’s practice
“Operational engagement”

✔ Medical physicists must be willing to discontinue tests that are deemed not helpful and replace them with new more effective tests where appropriate.

✔ Medical physicists must continue to play an important role in the evolution of existing and implementation of new standards. They must continue to present and publish their scientific results.

✔ Medical Physicists must be active as reviewers of journal scientific manuscripts, peer review panels, and as authors in high quality review publications (such as book chapters).

Thank you