Slide 1

July 11, 2022
2022 AAPM Annual Meeting

UF FLORIDA

3D Mammography

Justin Brown, Ph.D.
Diagnostic Imaging Medical Physics Resident

Slide 2

University of Florida Medical Physics

3D Mammography
Disclosures

None

2

Slide 3

University of Florida Medical Physics

3D Mammography
Outline

1) Introduction digital breast tomosynthesis (DBT)
2) Tomosynthesis basics
3) System design
4) Image reconstruction
5) Dosimetry in DBT
6) Artifacts in DBT
7) Synthetic mammograms
8) QC in DBT
9) Other 3D methods
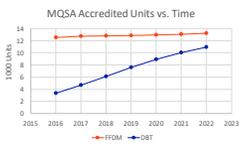
3

Slide 4

Introduction

1

4

Slide 5

University of Florida Medical Physics

Introduction
Rise of Digital Breast Tomosynthesis

- What is it?
  - 3D imaging of breast
  - Acquisitions over many angles
  - Reconstructed to form "slices" through breast
- FDA Approval
  - FFDM January 2000
  - DBT February 2011
- Steady increase in DBT units over time
  - Data from MQSA National Statistics

MQSA Accredited Units vs. Time

(graph: 1000 Units vs. years 2015–2023, lines for FFDM and DBT)

5

Slide 6

University of Florida Medical Physics

Introduction
Why Add Another Dimension?

- Projection imaging limitation:
  - Tissue superposition
    - Hides pathology
    - Mimics pathology
- Tomographic advantages
  - Reduces superposition
  - Clearer images
  - Growing evidence supports improvement in cancer rate detection
  - Reduce call-back rates
    - Recall rate was 10.6% for FFDM and 8.0% for DBT (p < 0.001)[1]

[1]Amir T, Ambinder EB, Harvey SC, et al. Benefits of digital breast tomosynthesis: A lesion-level analysis. Journal of Medical Screening. 2021;28(3):311-317. doi:10.1177/0969141320978267

6

Slide 7

Tomosynthesis Basics

Slide 8

Tomosynthesis Basics

History – Early Tomographic Techniques

- Conventional Tomography: Integrated data over entire exposure
  - Uses planar sections(slices) to blur out of plane tissues with source and detector motion
  - Early implementations used linear translations i.e. linear tomography
    - Tube moves above patient
    - Detector moves opposite direction below
    - Final single image in focal plane
- Tomosynthesis: Sampled at discrete intervals
  - Plane of focus determined during reconstruction
  - Non-focused planes are still present (unlike CT)

Slide 9

Tomosynthesis Basics

Linear Tomosynthesis – Reconstruction

- Series of images with shifted objects dependent on depth
- Objects in focal plane will be clear
- Further from focal plane/fulcrum the greater the blurring
  - Blur is also varies as a function of projection angle
- "Shift-and-add" or simple back projection reconstruction

Plane

Plane

Slide 10

System Design

Slide 11

System Design

Modern System Design

- Similar design to FFDM systems
- Translating source
- Detector
  - May slightly angulate
  - Pixels may be binned
  - 85-150 microns
- Acquisition may be continuous or step and shoot
- Grid may be in place or removed
- Tube typically between 15-50 degrees
- 9-25 projections
- 3-25 second scan times

FIG. 1. Schematic of breast tomosynthesis acquisition, in which a number of projection images is acquired of the compressed breast, while the x-ray source rotates around a center of rotation close or on the detector surface while the detector is either static or rotates, depending on the system design.

Sechopoulos. A review of breast tomosynthesis. Part I. The image acquisition process. *Med Phys*. 2013 Jan; 40(1): 014301.

Slide 12

*System Design*

Modern System Design: Vendor Implementations

Parameter	Hologic	GE	Siemens	Fujifilm
Target	W	Mo/Rh	W	W
Filter(s)	Al	Mo/Rh	Rh	Al/Rh
Tube motion	Continuous	Step and shoot	Continuous	Continuous
Detector	Direct (a-Se)	Indirect (CsI)	Direct (a-Se)	Direct (a-Se)
Pixel size (micron)	140(2x2 bin)	100	85	150(2x1 bin)/100(HR)
Grid	No	Yes	No	No
Arc (Degrees)	15	25	50	15/40(HR)
# Projections	15	9	25	15
Scan time(s)	3.7	10	25	7/9(HR)
Reconstruction Algorithm	FBP	FBP/ASiR	FBP	FBP

Adapted from: Tirada, N., Li, G., Dreizin, D., Robinson, L., Khorjekar, G., Dromi, S., & Ernst, T. (2019). Digital Breast Tomosynthesis: Physics, artifacts, and quality-control considerations. *RadioGraphics*, 39(2), 413–426. https://doi.org/10.1148/rg.2019180046
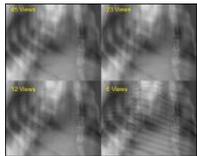
University of Florida Medical Physics

System Design
Parameter Trade-Offs: Tube Motion

- Tube motion
  - Continuous
    - Faster imaging times
    - More focal spot motion blur
      - Steered focal spot can reduce this
    - Less patient motion blur
  - Step-and-shoot
    - Slower imaging time
    - Less focal spot motion blur
    - More likely patient motion blur
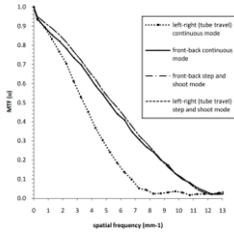
Eman Shaheen, Nicholas Marshall, Hilde Bosmans, "Investigation of the effect of tube motion in breast tomosynthesis: continuous or step and shoot?," Proc. SPIE 7961, Medical Imaging 2011: Physics of Medical Imaging, 79611E (16 March 2011); https://doi.org/10.1117/12.877348

13

University of Florida Medical Physics

System Design
Parameter Trade-Offs: Arc Size

- Anisotropic spatial resolution
  - Due to limited projection angle/arc size
- Given same dose and # of projections
  - Large angle
    - More blurring of out of plane objects
    - **Increase in "z" resolution[1]**
    - **Longer imaging time[1]**
  - Small angle
    - Better in plane resolution and visualization of microcalcifications
    - Better for larger breasts
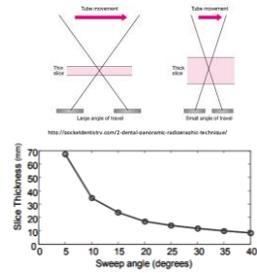
http://pocketdentistry.com/2-dental-panoramic-radiographic-technique/

Trada, N., Li, G., Dreizin, D., Robinson, L., Khorjekar, G., Dromi, S., & Ernst, T. (2019). Digital Breast Tomosynthesis: Physics, artifacts, and quality control considerations. RadioGraphics, 39(2), 413–426. https://doi.org/10.1148/rg.2019180046

[1]Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., & Boone, J. M. (2021). Breast Imaging: Mammography. In The Essential Physics of Medical Imaging (pp. 284–288).

14

University of Florida Medical Physics

System Design
Parameter Trade-Offs: Number of Projections

- The more projections the better?
  - Increased in plane resolution
  - Decreased out of plane blurring of low contrast structures
  - **Reduced ripple artifacts[1]**
- Dose constraints in DBT
  - Given maximum dose → more projections = less dose per projection
  - **More projections → more noise[2]**
- Increased scan time
  - Detector electronic limitations
    - Pixel binning helps
  - Thermal limitation of tube
  - **Motion artifacts more likely[3]**

Property of Andrew Maidment, University of Pennsylvania
http://www.aapm.org/meetings/amos2/pdf/59-17209-49161-396.pdf

[1]Machida H, Yuhara T, Mori T, Ueno E, Moribe Y, Sabol JM. Optimizing parameters for flat-panel detector digital tomosynthesis. Radiographics. 2010;30(2):549-562. doi:10.1148/rg.30209509
[2]Sechopoulos, I. (2013). A review of breast tomosynthesis. Part I. The image acquisition process. Med. Phys., 40: 014301. https://doi.org/10.1118/1.4770279 Digital Breast Tomosynthesis: Physics, Artifacts, and Quality Control Considerations
[3]Nikki Tirada, Guang Li, David Dreizin, Luke Robinson, Gauri Khorjekar, Sergio Dromi, and Thomas Ernst RadioGraphics 2019 39:2, 413-426

15

University of Florida Medical Physics

System Design
Parameter Trade-Offs: Number of Projections

- "The upper limit in vertical resolution is given by the angular range, and the number of projections for a specific angular range should be that which just meets the required "threshold" number to obtain the best possible ASF [artifact spread function], with no benefit in a further increase."
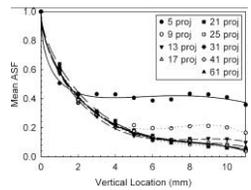
Artifact spread function from simulated DBT images acquired with a 60° angular range and varying number of projections. Reprinted with permission from I. Sechopoulos and C. Ghetti, "Optimization of the acquisition geometry in digital tomosynthesis of the breast," Med. Phys. 36(4), 1199–1207 (2009). Copyright © 2009, American Association of Physicists in Medicine (AAPM).

16

**University of Florida Medical Physics**

System Design
Example implementations

17

Image Reconstruction

18

Slide 19

Image Reconstruction
Various Methods

- Filtered Back Projection
  - Fourier based method
  - Computationally fast
  - Artifacts due to incomplete sampling
- Iterative Reconstruction
  - Statistical
  - Algebraic
  - Computational expensive
    - Longer reconstruction times
  - Likely better image quality with less dose
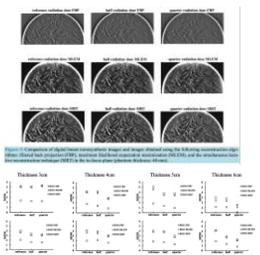
Gomi, T. (2015). Comparison of different reconstruction algorithms for decreasing the exposure dose during Digital Breast Tomosynthesis: A phantom study. *Journal of Biomedical Science and Engineering, 08*(08), 471–478. https://doi.org/10.4236/jbise.2015.88044

19

Slide 20

Image Reconstruction
FBP

- Projection data as function of angle
  - Fourier slice theorem
- Incomplete sampling
  - Farfalle(bowtie pasta) sampling
  - Low pass/apodizing filters to suppress high frequency data artifacts
  - Imaging parameters such as arc size and number of projections modify sparsity and angular density

https://thefonandalo.com/archaeology-pasta-farfalle/

Property of Andrew Maidment, University of Pennsylvania http://www.aapm.org/meetings/amos2/pdf/59-17209-49161-396.pdf

20

Slide 21
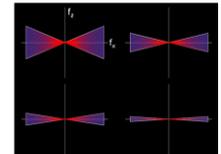
Image Reconstruction
Iterative

(a) (b) (c) (d)

- Iterative: Start with initial guess (can be FBP)
- Iterate on solution
- Statistical IR
  - Look at projection data as an observation given from some (Poisson) distributions in the sample
  - What intensities/attenuation values in each pixel given projection trajectory maximize the likelihood of the observed projection data
- Algebraic IR
  - Look at projection data as a result of a system of equations (line integral) received by each detector per projection angle
  - Find the least squares solution to minimize error to the observed projection data
- Recent AI method show promise
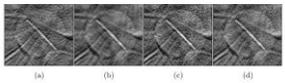
Fig. 9. Comparison of fibrils in mass reconstructed by different methods. (a) FBP, (b) SIR-ρ-OT, (c) OS-EM, (d) SART.
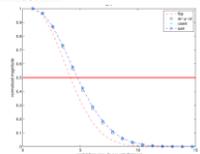
Fig. 12. In-plane MTF measured along microcalcification on a focus plane reconstructed by SIR-ρ-OT, FBP, SART, and OS-EM.

Xu, S., Lu, J., Zhou, O., & Chen, Y. (2015). Statistical Iterative Reconstruction to improve image quality for digital breast tomosynthesis. *Medical Physics, 42*(9), 5377–5390. https://doi.org/10.1118/1.4928603

21

Slide 22

Dosimetry

22

Slide 23

Dosimetry
AAPM TG 223

- Similar to normal mammography dose calculation
- Compute normal kerma to dose conversion factor
  - ACR: g*c*s
- Correct for geometric difference in acquisition
  - Uses Relative Glandular Dose (RGD)
  - Ratio of dose at angle alpha relative to 0 degrees
  - Compute RGD mean factor
- Scale standard mammography dose factor by RGD mean
- Multiply by reference air kerma

$$RGD\,(\alpha) = \frac{D_g N(\alpha)}{D_g N(0^\circ)},$$

$$D_g N_{TOMO} = D_g N_{MAMMO} \left(\frac{\sum_{\alpha=0}^{N_p} RGD(\alpha)}{N_p} \right)$$

$$D_g N_{TOMO} = D_g N_{MAMMO} \times \overline{RGD},$$

$$D_{g,TOMO} = D_g N_{TOMO} \times AK_{REF}.$$
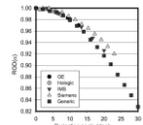
1. Determine technique for which dose estimate is needed?
2. Place dosimeter in field of view and collimate to only illuminate dosimeter
3. Position compression paddle at max height, place load on support plate
4. Set acquisition for static tomosynthesis mode, if possible
5. Record air kerma during exposure with same total mAs as complete tomosynthesis acquisition
6. Correct air kerma to height at breast entrance surface
7. Look up appropriate $D_g N_{(MAMMO)}$ from existing sources
8. Modify $D_g N_{(MAMMO)}$ to $D_g N_{(TOMO)}$ using Equations 2-4 and Tables 3-7, as appropriate?
9. Compute mean glandular dose $D_g = D_g N_{TOMO} * air\ kerma$

23

Slide 24

Artifacts

24

University of Florida Medical Physics
Artifacts
Slinky/Out of Plane/Truncation

25

University of Florida Medical Physics
Artifacts
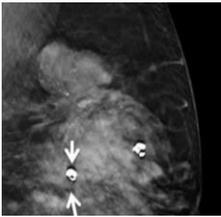**Dead Pixel**

26
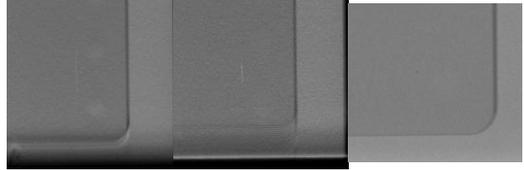
University of Florida Medical Physics
Artifacts
Halo

Rangarajan and Hari. Artifacts in Digital Breast Tomosynthesis. Poster presented at ECR 2013.

27

Synthetic Mammograms

28

University of Florida Medical Physics
Synthetic Mammograms
What is a "Synthetic Mammogram"

- Replacement for the standard FFDM 2D image
- Generated using the tomosynthesis (3D) dataset
  - Varies by vendor, similar to a MIP

Advantages	Disadvantages
Decreased radiation dose[1]	**Pseudo-calcification or disappearing calcifications[1]**
Decreased acquisition time	Foreign body artifacts
Maintained or reduced recall rates	Decreased resolution of axilla and subcutaneous tissue
Maintained or improved cancer detection rates	Decreased visualization of asymmetries
Improved visualization of architectural distortion and calcifications	Lower breast density by visual BI-RADS density assessment

Adapted from: Sona Chikarmane, MD, FSBI, Synthetic Mammography: Review of Benefits and Drawbacks in Clinical Use, *Journal of Breast Imaging*, Volume 4, Issue 2, March/April 2022, Pages 124–134, https://doi.org/10.1093/jbi/wbac008
[1]Ratanaprasatporn L, Chikarmane SA, Giess CS. Strengths and Weaknesses of Synthetic Mammography in Screening. Radiographics. 2017;37(7):1913-1927. doi:10.1148/rg.2017170032

29

University of Florida Medical Physics
Synthetic Mammograms
FFDM vs. Synthetic Mammogram
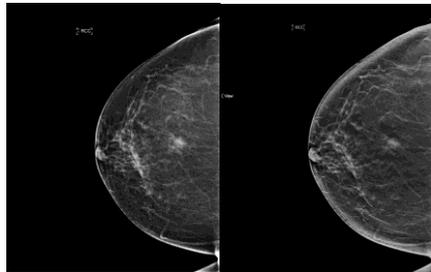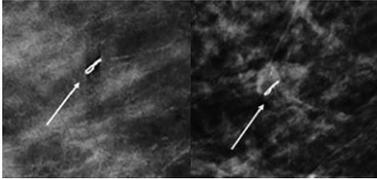
30

5

Synthetic Mammograms
Artifacts in Synthetic Mammograms

31

Synthetic Mammograms
Artifacts in Synthetic Mammograms

32

Synthetic Mammograms
Artifacts in Synthetic Mammograms

C-View

Tomo slice 17/17

33

QC for DBT

34
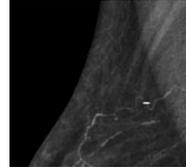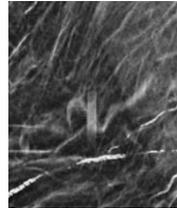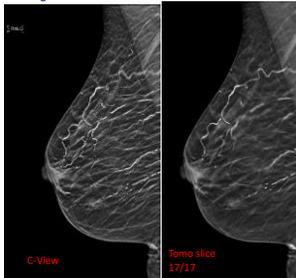
Quality Control for DBT
ACR DBT QC

- Vendor agnostic
- Must use ACR DM Phantom
- Unique tests:
  - DBT spatial resolution
    - >=2 lp/mm
  - DBT Z resolution
    - Compute FWHM
    - Must be within 30% of baseline
  - DBT Volume Coverage
  - DBT image quality
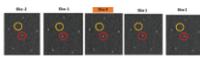
Figure 20. Images of the 5 different slice locations for Z-resolution measurements with ROI placement locations.
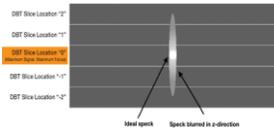
DBT Slice Location "2"

DBT Slice Location "1"

DBT Slice Location "0"

DBT Slice Location "-1"

DBT Slice Location "-2"

Ideal speck   Speck blurred in z-direction

35

Quality Control for DBT
ACR DBT QC

- Vendor agnostic
- Must use ACR DM Phantom
- Unique tests:
  - DBT spatial resolution
    - >=2 lp/mm
  - DBT Z resolution
    - Compute FWHM
    - Must be within 30% of baseline
  - DBT Volume Coverage
    - Each sheet must be in focus in one reconstructed slice
  - DBT image quality

36

Slide 37

University of Florida Medical Physics

Quality Control for DBT
ACR DBT QC

- Vendor agnostic
- Must use ACR DM Phantom
- Unique tests:
  - DBT spatial resolution
    - >=2 lp/mm
  - DBT Z resolution
    - Compute FWHM
    - Must be within 30% of baseline
  - DBT Volume Coverage
    - Each sheet must be in focus in one reconstructed sli
  - DBT image quality
  - DBT Dosimetry
    - AGD= K*g*c*s
    - [1]Each view must be less than 3.0 mGy separately even in "Combo" mode
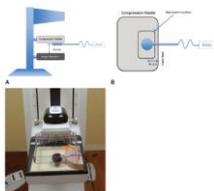
https://www.acr.org/-/media/ACR/Files/Clinical-Resources/QC-Manuals/Mammo_QCManual.pdf

37

Slide 38

University of Florida Medical Physics

Quality Control for DBT
ACR DBT Summary

Table 2. Required Tests for Imaging Modes Used on 2D and DBT Systems

38

Slide 39

University of Florida Medical Physics

*Quality Control for DBT*

Table 2: Typical DBT Quality Control

Digital Breast Tomosynthesis: Physics, Artifacts, and Quality Control Considerations Nikki Tirada, Guang Li, David Dreizin, Luke Robinson, Gauri Khorjekar, Sergio Dromi, and Thomas Ernst RadioGraphics 2019 39:2, 413-426

39

Slide 40

Alternative 3D Acquisitions

40

Slide 41

University of Florida Medical Physics

Alternative 3D Acquisitions
MRI

- Typically reserved for high risk patients
- In addition to screening mammograms
- Pros:
  - High specificity
  - Non ionizing radiation
  - No compression
  - High spatial resolution
  - Larger anatomical coverage
- Pre and post GD contrast acquisitions
  - Uptake curves for suspicious areas
- Cons:
  - Expensive
  - Time consuming
  - Sensitive to patient movement
 - Positioning may be uncomfortable

https://radiopaedia.org/cases/normal-breast-mri-in-dense-breasts-1

41

Slide 42
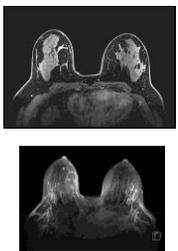
University of Florida Medical Physics

Alternative 3D Acquisitions
Breast CT

- Pros:
  - Eliminates tissue superposition
  - Comfortable for patient
  - Better for dense breasts
  - Cheaper than MRI
  - Contrast
  - Fusion with PET
- Cons:
  - Dose concerns
    - 4-5x dose than single view mammographic view
      - Better reconstruction and system design can further reduce dose
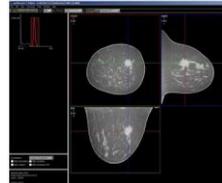
Lindfors KK, Boone JM, Newell MS, D'Orsi CJ. Dedicated breast computed tomography: the optimal cross-sectional imaging solution? Radiol Clin North Am. 2010 Sep;48(5):1043-54. doi: 10.1016/j.rcl.2010.06.001. PMID: 20868893; PMCID: PMC2972197.

42

Summary

Summary

Closing Remarks

- DBT is an evolution of conventional tomographic techniques applied to breast imaging
- Image quality depends on many factors:
  - Angular range
  - Number of projections
  - Reconstruction algorithm
- DBT adds additional QC tests
- Awareness of artifacts and their causes are paramount in triaging issues
- Synthetic mammograms have potential to significantly reduce dose with minimal diagnostic impact
- Synthetic mammograms are susceptible to artifacts not present in FFDM
- Alternative 3D methods show promise and are most beneficial for high risk populations

44

UF | Medical Physics
COLLEGE *of* MEDICINE

Thank you

https://medphysics.med.ufl.edu/

jbro0020@radiology.ufl.edu

45