Virtual and physical breast phantoms that mimic patients

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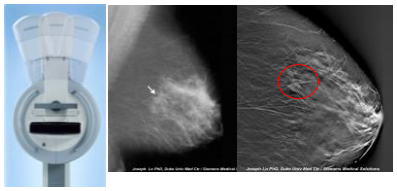
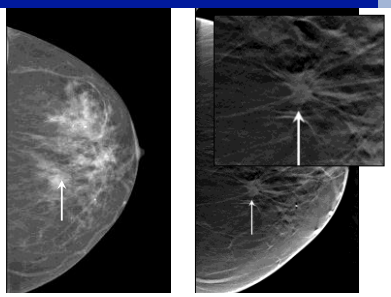
Background | From 2D to 3D Mammo

- Digital breast tomosynthesis (DBT) or "3D mammography"
- limited-angle cone beam CT, x-ray tube pivots and takes many shots of compressed breast, reconstruct into quasi-3D volume



Background | Lesion seen better on 3D than 2D



Status quo | Many commercial vendors…

- Current commercial DBT systems:
  - FDA approved (top row): GE, Hologic, Siemens
  - EU approved (bottom row): IMS, FUJIFILM

Status quo | Variability of Systems

	GE SenoClaire	Hologic Selenia Dimensions	Siemens MAMMOMAT Inspiration
target/filter	Rh/Rh	W/Al	W/Rh
detector	indirect CsI	direct a-Se	direct a-Se
pixel pitch (μm)	~100	140	85
scan angle	25°	15°	45°
# projection imgs	9	15	25
mechanism	step-and-shoot	continuous tube	continuous tube
acquisition time (sec)	~15	~5	25
reconstruction	IR	FBP	FBP

Why focus VCT efforts on DBT?

- Misconception: DBT is a "solved problem"
- Facts:
  - Yes, many large trials have shown improvement in sensitivity and specificity vs. mammography, **BUT…**
  - DBT adoption is still early
    - ~30% sites have a system, ~10% total systems
    - Reimbursement still mixed while awaiting definitive trials
  - DBT systems vary greatly in implementation and features
  - DBT protocols are not yet established
  - Many variations still to come

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Why focus VCT efforts on DBT?

- Unanswered questions:
  - Comparing different acquisition geometries:
    - angular range, # projections, dose distribution across angles
  - Radiographic technique and dose
  - Masses vs. calcifications
  - 1 vs 2 views
  - Real vs. synthetic mammogram
  - Full vs. partial compression
  - Reconstruction algorithm or post-processing modes
  - Other emerging technologies:
    - contrast-enhanced mammo/tomo, dedicated breast CT

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What is a virtual 3D phantom?

- Computational model of the breast
- Allows simulation of virtual images with known ground truth under precise control
- No radiation dose!
- Images can be interpreted by human or model observers
- To maximize clinical relevance, new generation of phantoms go beyond uniform or random texture to mimic patients

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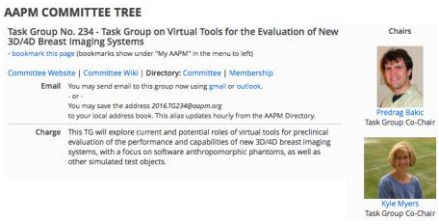
Virtual tools | AAPM TG 234

- Work in progress: AAPM TG 234 on virtual tools…



AAPM COMMITTEE TREE

Task Group No. 234 - Task Group on Virtual Tools for the Evaluation of New 3D/4D Breast Imaging Systems

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Charge This TG will explore current and potential roles of virtual tools for preclinical evaluation of the performance and capabilities of new 3D/4D breast imaging systems, with a focus on software anthropomorphic phantoms, as well as other simulated test objects.

Chairs

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Virtual phantoms: Penn VCTworld

- Penn VCTworld environment

Andrew Maidment & Predrag Bakic, Univ of Penn

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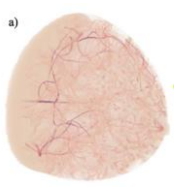
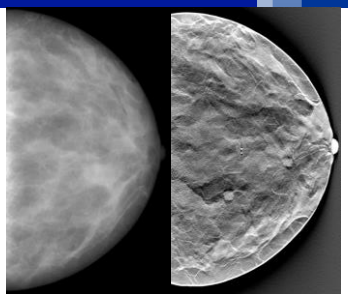
Virtual phantoms: FDA Graff / VICTRE

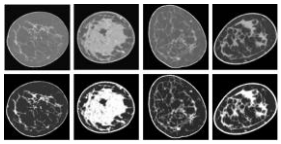




Christian Graff, FDA

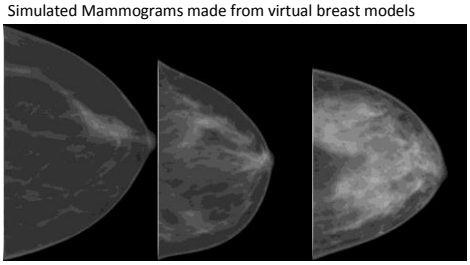
Virtual phantoms: Duke XCAT

- Duke XCAT virtual phantom:
  - "Patient-based" – from breast CT scans of actual human subjects
  - Multi-step process of artifact removal, denoising, and segmentation
  - Voxelized result can be assigned values corresponding to modality, e.g., attenuation coefficients for x-ray
  - PRO: Realistic in appearance
  - CON: (initially) limited in number of cases and resolution



Virtual phantoms: Duke XCAT

Simulated Mammograms made from virtual breast models



Erickson et al, Med Phys 2016

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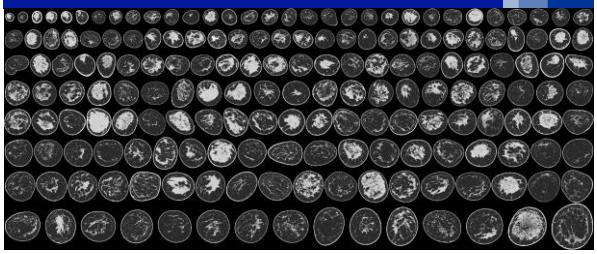
Virtual phantoms: Duke XCAT



Greg Sturgeon, Duke RAILabs

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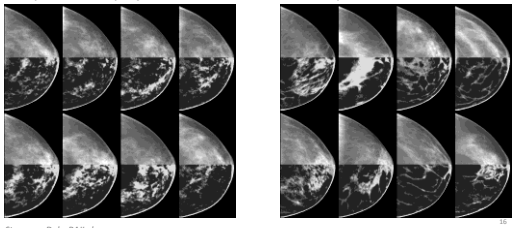
Virtual phantoms: Improving numbers

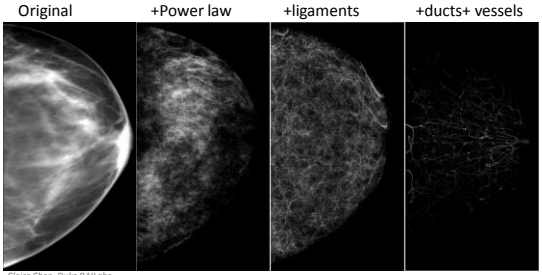
- Synthesized (left) vs. original (right) phantoms
- Top: mammo projection, bottom: central 250 µm slice



Greg Sturgeon, Duke RAILabs

Virtual phantoms: Improving resolution

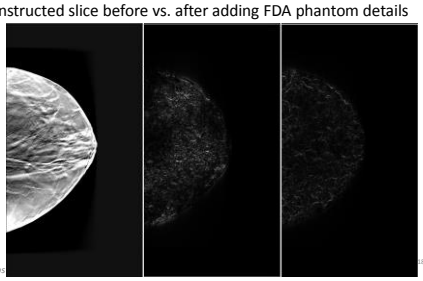
Original +Power law +ligaments +ducts+ vessels



Claire Chen, Duke RAILabs

Virtual phantoms: Improving resolution

Tomo reconstructed slice before vs. after adding FDA phantom details



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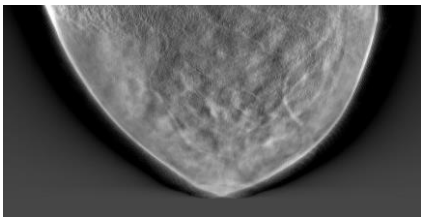

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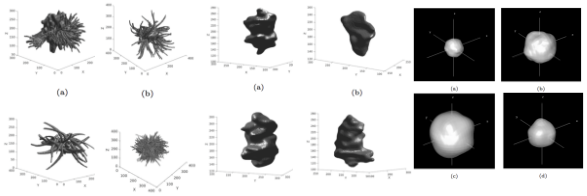
Virtual phantoms: Virtual lesions

Spiculated
Hilde Bosmans

Irregular
Kevin Wells

Circumscribed
Justin Solomon



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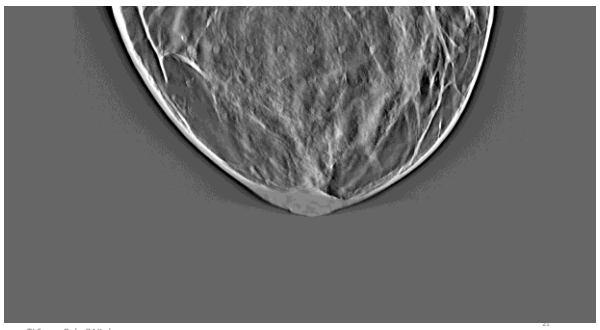

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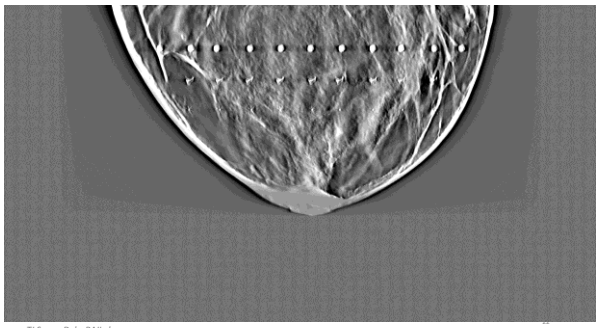

TJ Sauer, Duke RAILabs

Virtual to Physical Phantoms

- Virtual phantoms:
  - Infinite variability and control
  - Cannot reproduce proprietary hardware and software
- Physical phantoms:
  - Limited in number
  - Can reproduce all x-ray physics and acquisition h/w and s/w

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Physical Phantoms | AAPM TG 245

- Work in progress: AAPM TG 245 on tomo QC…

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Task Group No. 245 Tomosynthesis Quality Control

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Charge Develop and recommend QC and Acceptance tests for both radiographic and mammographic diagnostic x-ray tomosynthesis systems. These tests will assess detector, system performance and image reconstructions. Some of these tests may include: planar, spatial and vertical z-axis resolution, SDNR, contrast-details, NPS, uniformity, image lag between projections, artifacts, artifact spread function, line object spread function, cllimation, distance and angle measurements, and slice thickness (slice sensitivity profile). The task group will test physical phantoms for quality assurance and image optimizations with radiation dose. The phantoms can be used for both subjective and objective evaluations. Objective evaluations will evaluate detector and image reconstructions. Subjective evaluations will assess image quality visually and/or with computer scoring.

Chairs

Stephen Glick
Task Group Co-Chair

Wei Zhao
Task Group Co-Chair

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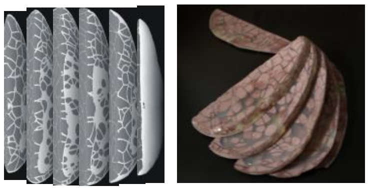
Physical phantom: Penn

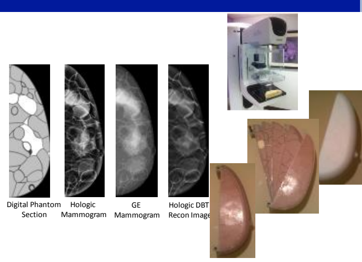
- Anthropomorphic shape and interior:
  - 3D printed glandular/Coopers ligaments
  - filled with adipose-equivalent resin



First generation: Lab prototype
(Carton, Tomo Workshop 2009; SPIE 2010; MedPhys 2011; Brunner, IWDM 2012; Karunamuni, SPIE 2013)

Andrew Maidment & Predrag Bakic, Univ of Penn

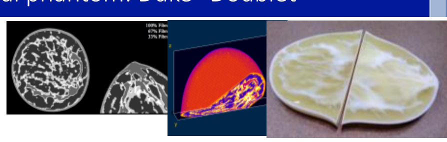
Physical phantom: Penn



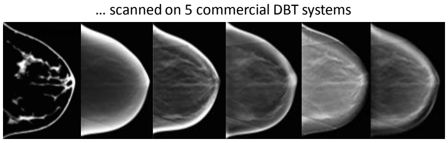
Second generation: Collaboration with CIRS
(Cockmartin, IWDM 2014; Vieira, SPIE 2015; de Oliveira, SPIE 2016)

Andrew Maidment & Predrag Bakic, Univ of Penn

Physical phantom: Duke "Doublet"



... scanned on 5 commercial DBT systems



Conclusions

- DBT shows great clinical promise and is entering clinical practice
- VCTs enable optimization and evaluation of new DBT technologies
- Realistic phantoms should maximize clinical relevance
- Virtual phantoms provide great diversity and computational control
- Physical phantoms directly assess proprietary system h/w and s/w

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Thank You! | Joseph.Lo@duke.edu

Acknowledgments

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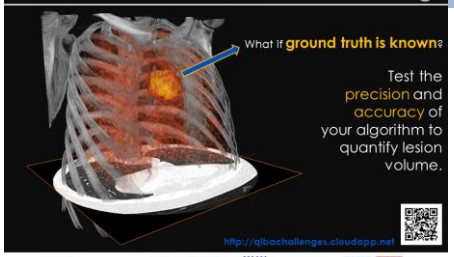
CT Virtual Clinical Trial Grand Challenge



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