AAPM 2014 innovation

innovation

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Innovations in Clinical Breast Imaging

Dedicated breast CT

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Contributors

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- Srinivasan Vedantham, Ph.D., UMass Medical School.
- Peymon Gazi, M.S., University of California, Davis.

Disclaimer

- Mention of any company or product does not constitute as endorsement.
- Dedicated breast CT has not been U.S. FDA approved for clinical use.

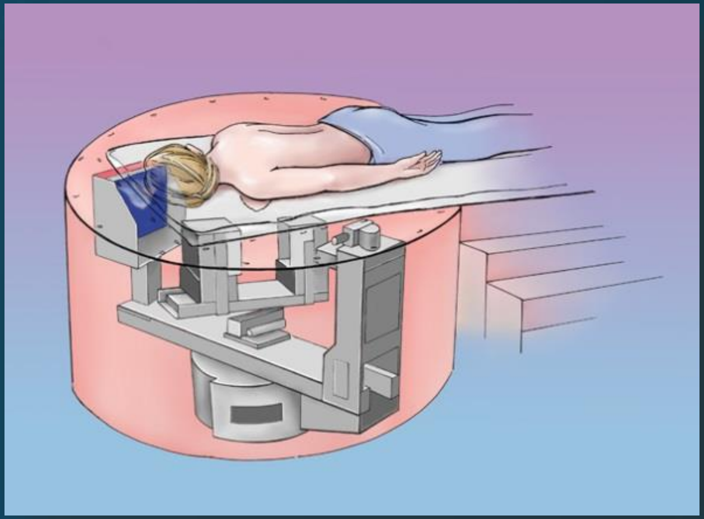
Learning objectives

To understand the following topics after this talk:

- Rationale for dedicated breast CT
- Current development and clinical studies of breast CT
- Challenges for dedicated breast CT
- Considerations on quality assurance

Breast CT (bCT)

- Introduction
- Development of bCT
- Patient imaging / clinical studies
- Challenges for bCT
- Quality assurance for bCT
- Summary



Breast cancer facts and figures

About 40,000 deaths from breast cancer in 2011.

About 288,000 women diagnosed with breast cancer in 2011.

12.2% of women will get breast cancer sometime during their lifetime.

Table 1. Estimated New Female Breast Cancer Cases and Deaths by Age, US, 2011*

Age	In Situ Cases	Invasive Cases	Deaths
Under 40	1,780	11,330	1,160
Under 50	14,240	50,430	5,240
50-64	23,360	81,970	11,620
65+	20,050	98,080	22,660
All ages	**57,650**	**230,480**	**39,520**

*Rounded to the nearest 10.

Source: Total estimated cases are based on 1995-2007 incidence rates from 46 states as reported by the North American Association for Central Cancer Registries. Total estimated deaths are based on data from US Mortality Data, 1969-2007, National Center for Health Statistics, Centers for Disease Control and Prevention.

American Cancer Society, Surveillance Research, 2011

Table 5. Age-specific Probabilities of Developing Invasive Female Breast Cancer*

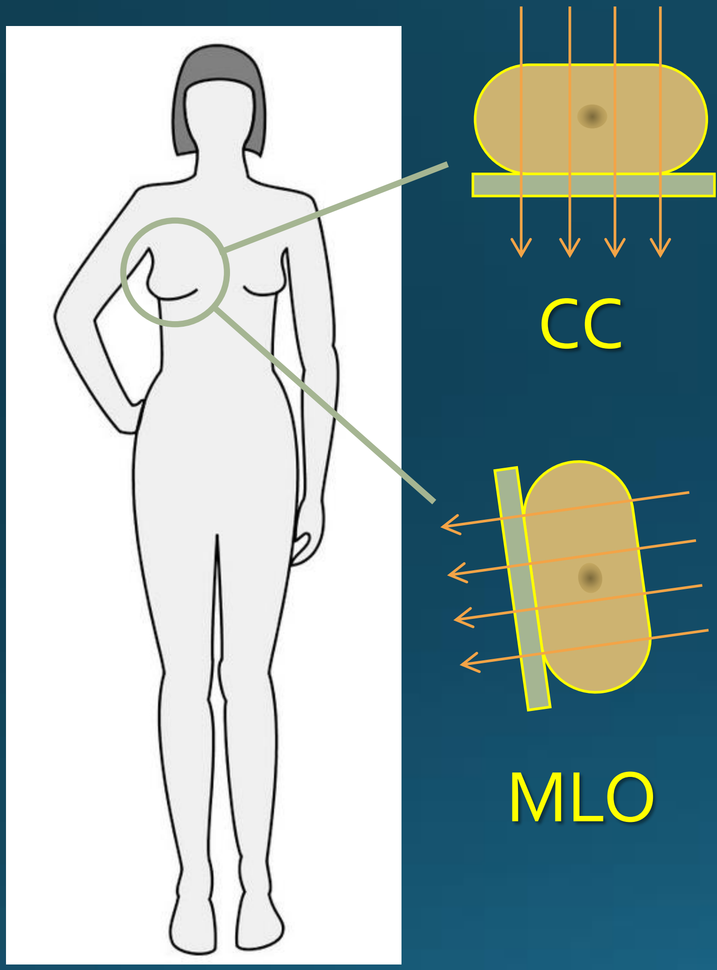
If current age is ...	The probability of devloping breast cancer in the next 10 years is:	or 1 in:
20	0.06%	1,681
30	0.43%	232
40	1.45%	69
50	2.38%	42
60	3.45%	29
70	3.74%	27
Lifetime risk	12.15%	8

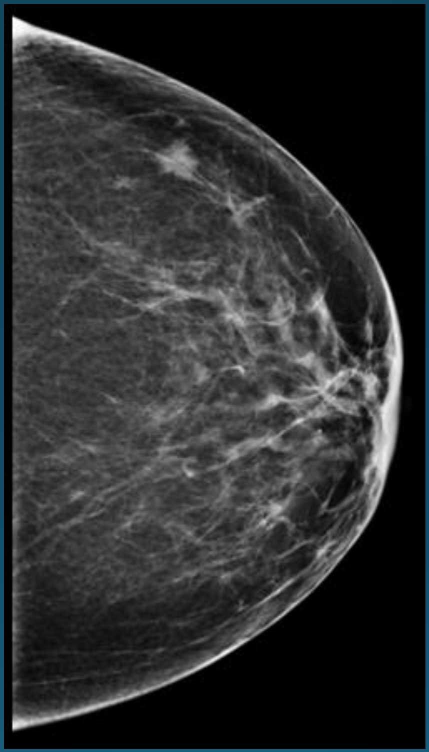
*Among those free of cancer at beginning of age interval. Based on cases diagnosed 2005-2007. Percentages and "1 in" numbers may not be numerically equivalent due to rounding.

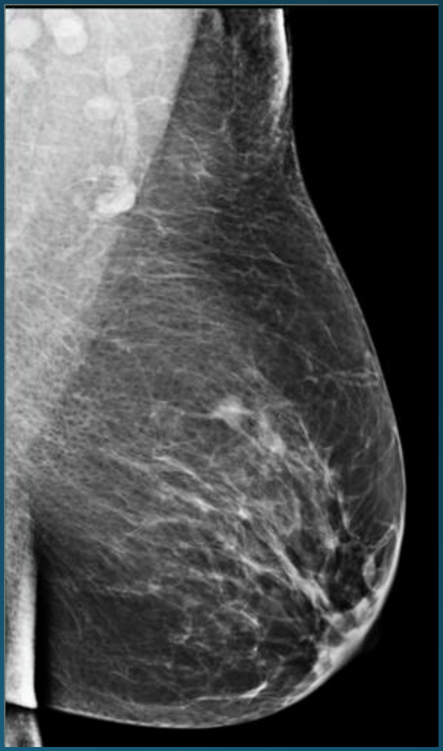
Probability derived using NCI DevCan Software, Version 6.5.0.

American Cancer Society, Surveillance Research, 2011

Mammography: standard of care

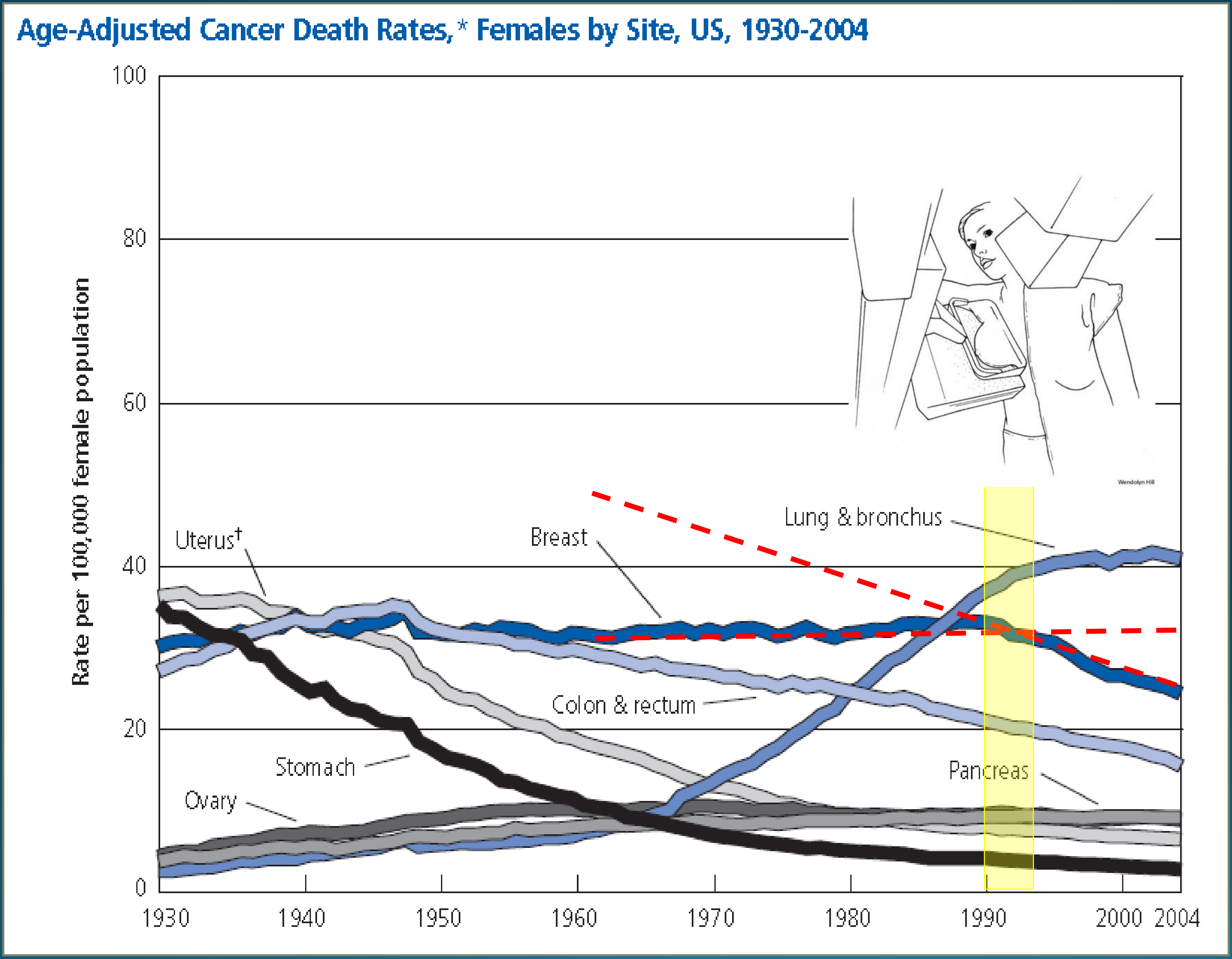






CC MLO

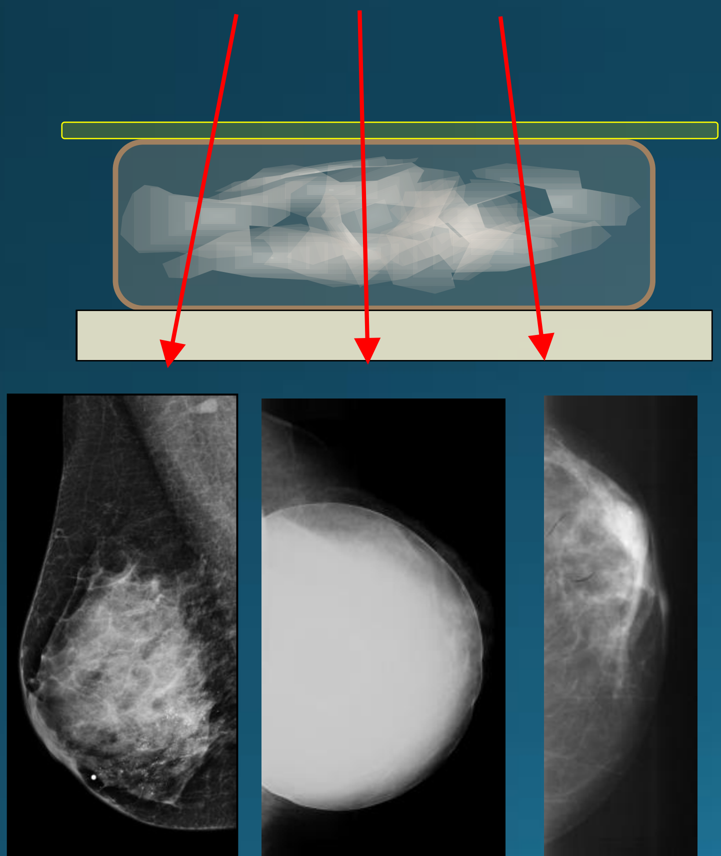
Cancer prognosis and screening



Jemal A, *et al.*, Cancer Statistics 2006

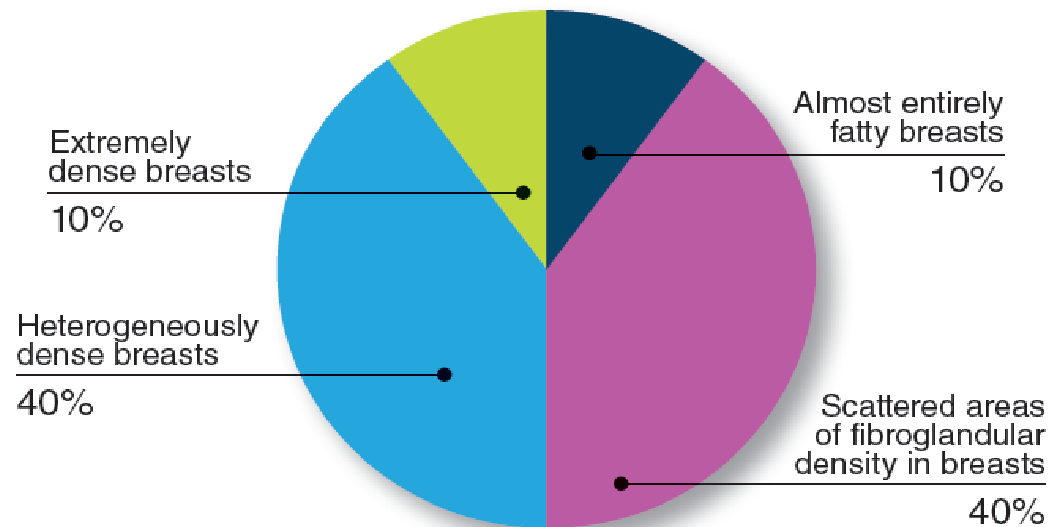
Major limitation of mammography

Tissue overlapping – “Anatomical noise” especially for dense breasts



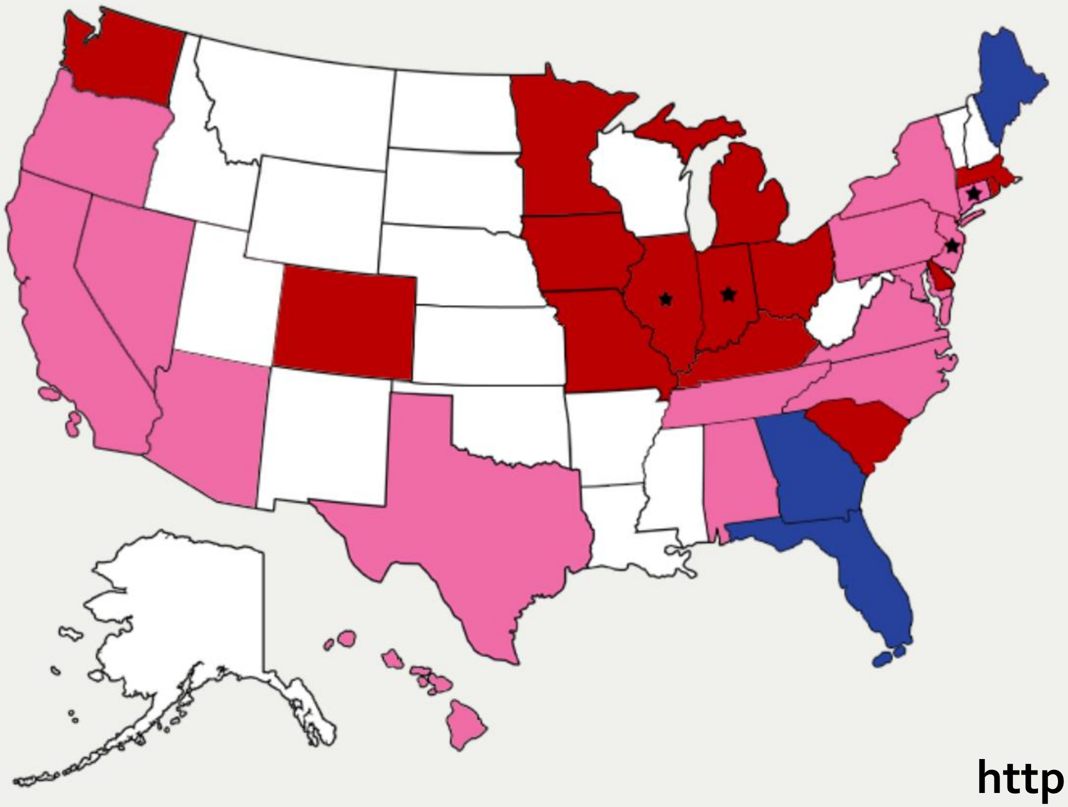
Breast density in the U.S. (See pie chart)

- 10% of women have almost entirely fatty breasts
- 10% have extremely dense breasts
- 80% are classified into one of two middle categories



http://www.breastdensity.info

Breast density notification/reporting law



PINK: Enacted Law
RED: Introduced Bill
BLUE: Working on Bill
WHITE: No Action
BLACK : Insurance Coverage Law

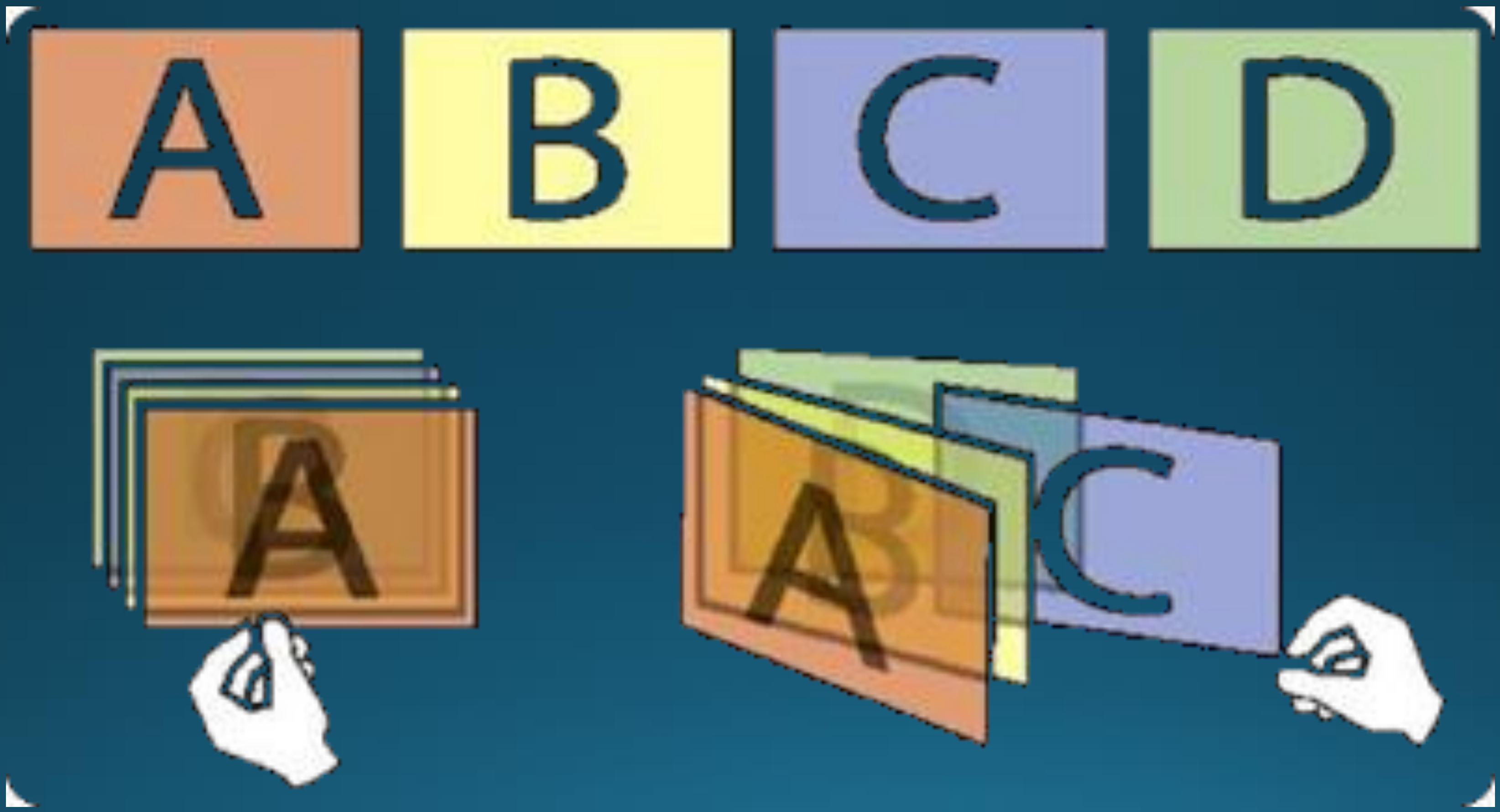
http://www.areyoudenseadvocacy.org/

"If you have dense breast tissue, the odds of finding a cancer on your mammogram are about equal to a coin toss."

Dr. Stacey Vitiello

Rationale for a tomographic modality

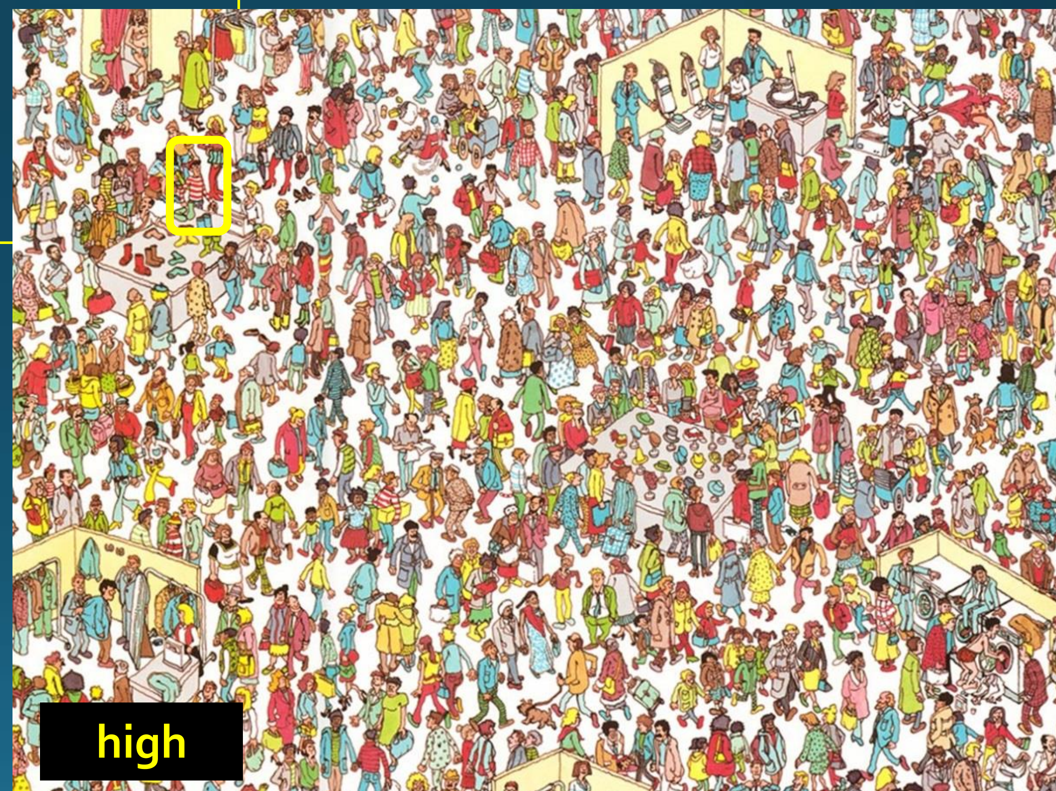
2D vs. 3D

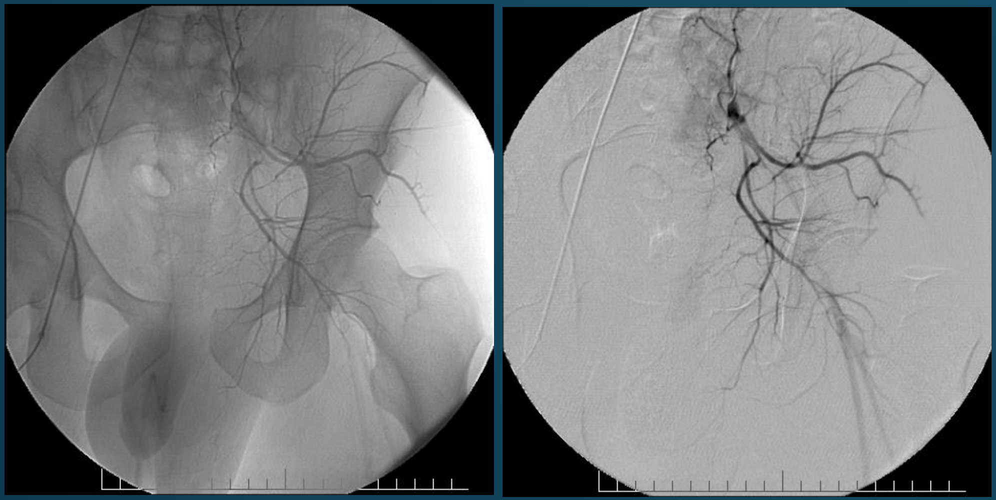


Background Noise

Anatomical Noise

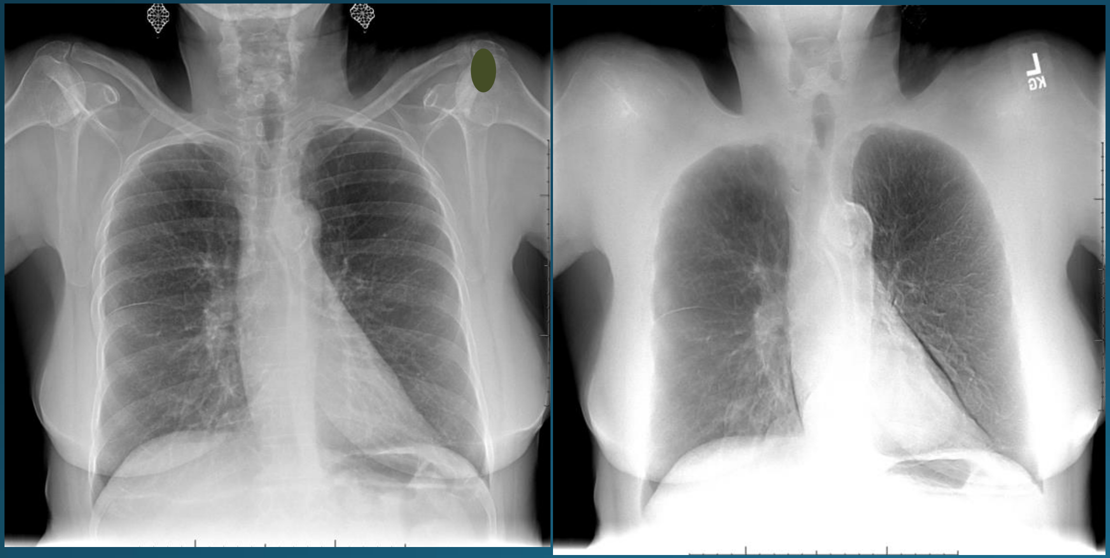
low





Digital Subtraction Angiography (Temporal Subtraction)

Reduces Anatomical Noise

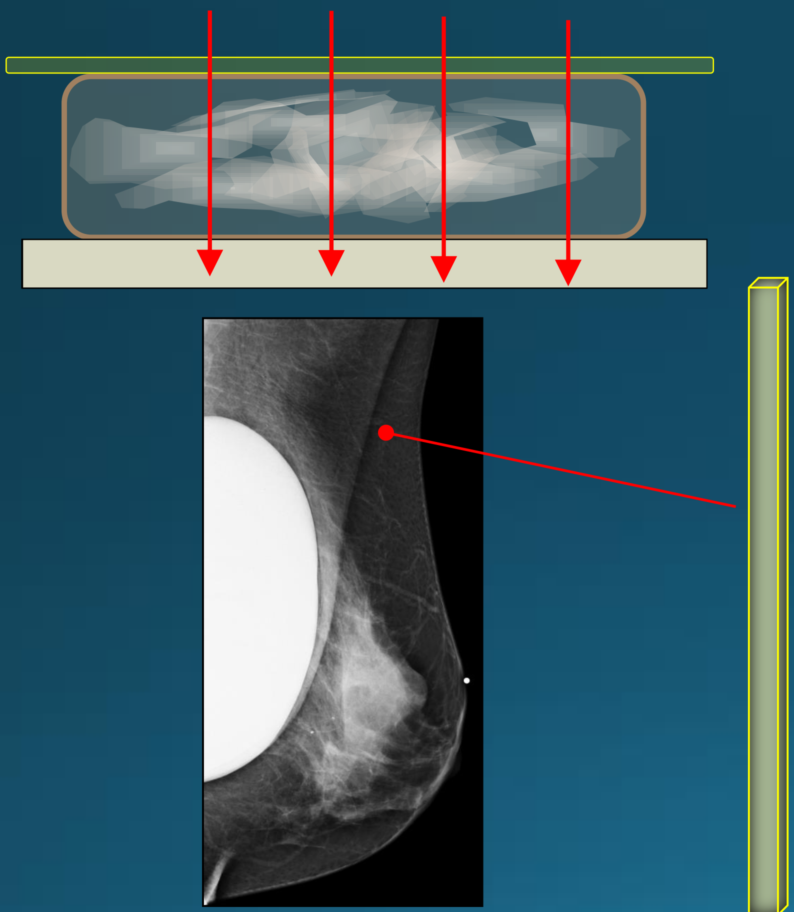


Dual Energy Chest Radiography (Energy Subtraction)

Reduces Anatomical Noise

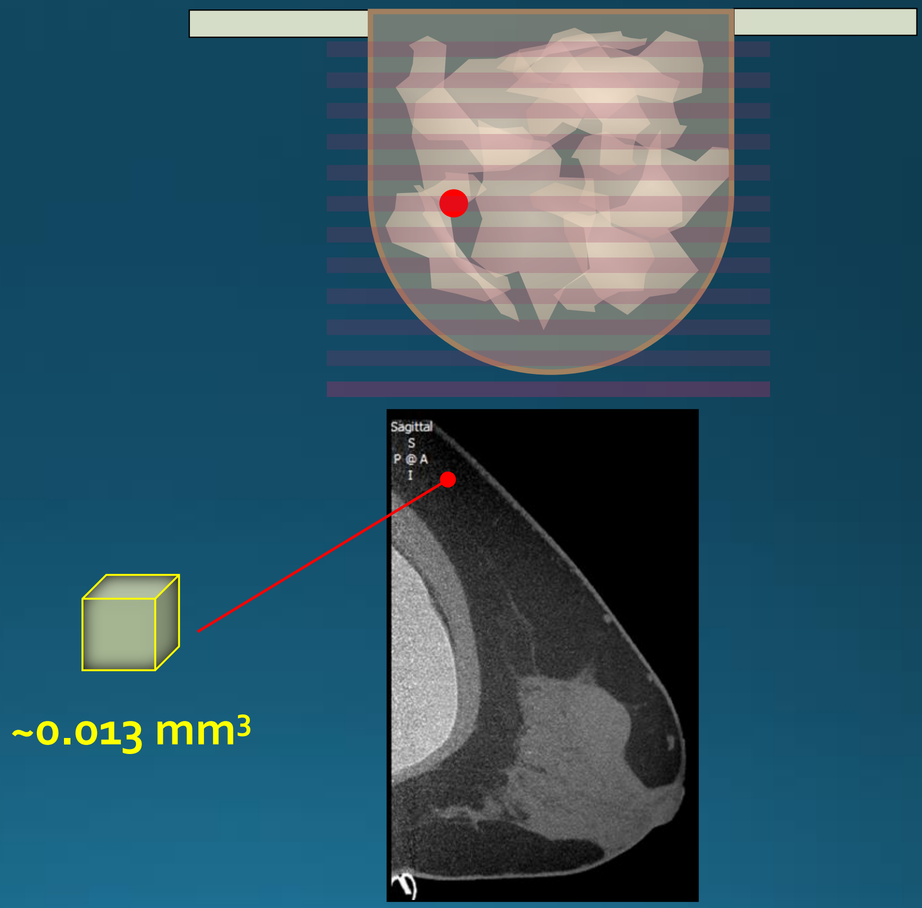
Rationale for a tomographic modality

Mammography



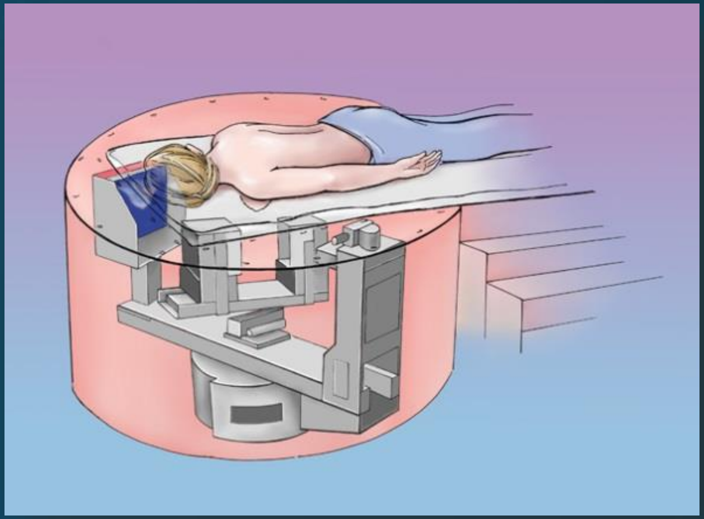
70 μm × 70 μm × 50,000 μm ~0.25 mm^3

Breast CT (bCT)



230 μm × 230 μm × 250 μm

Breast CT (bCT)



Introduction

➡ Development of bCT

Patient imaging / clinical studies

Challenges for bCT

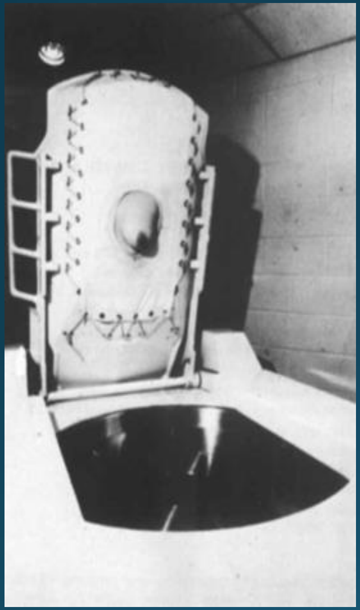
Quality assurance for bCT

Summary

Dedicated breast CT - Timeline

1970's-80's

Chang et al., Univ. of Kansas Med Ctr.



127 Xe detectors
1.56 x 1.56 x 10 mm
127 x 127 reconstruction
CT #: -127 to 128 HU

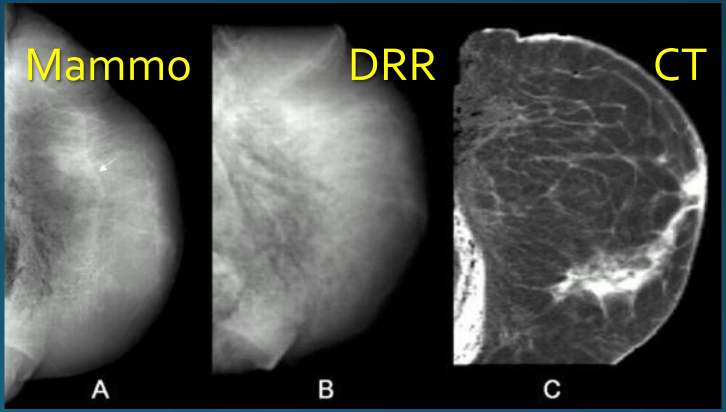
1625 patients (78 cancers)
IV contrast media
94% detection rate vs.
77% for mammography

Chang et al., Cancer 46:939-946, 1980.

2000 onwards

Boone et al., Radiology 221: 657-67, 2001.

Reported on glandular dose estimates with dedicated breast CT



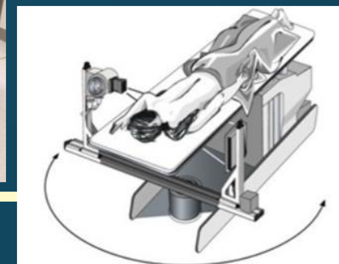
Boone et al., Radiology 221: 657-67, 2001

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass

Dedicated breast CT- an ongoing research

- UC Davis

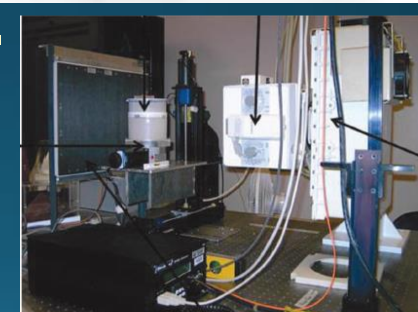
- U Mass Worcester



- U Nurnberg

- U Rochester

- MD Anderson



- Duke

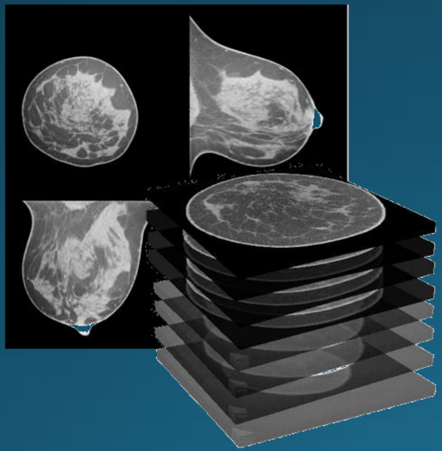
- Louisiana State University
- Universita di Napoli

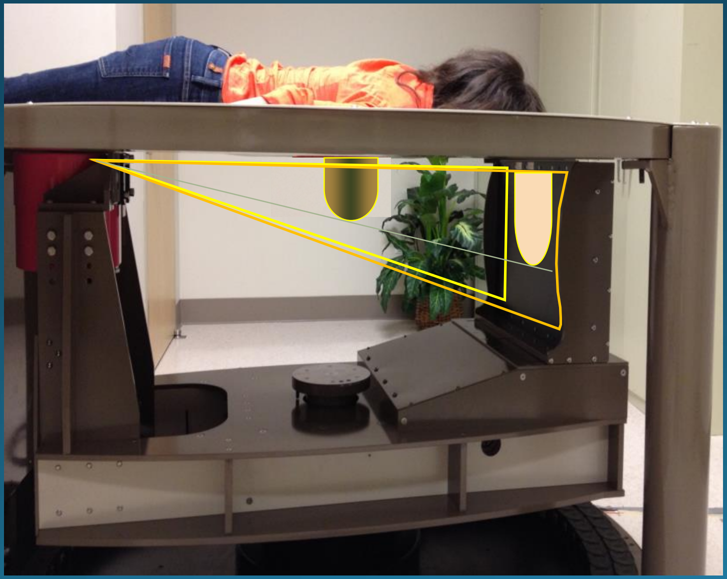
- Universitia di Bologna
- UC Irvine

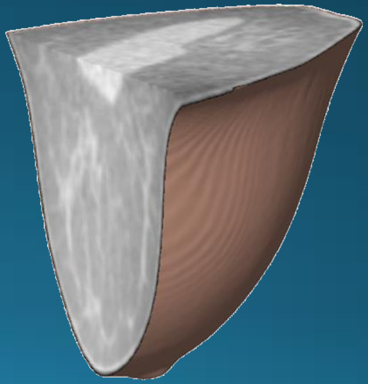
Current <u>clinical</u> breast CT imaging

- Tungsten anode x-ray tube
- Cone beam geometry with flat panel detectors (CsI:Tl + a:Si)
- 10~20 seconds scanning time
- 300~512 images across the breast in 360 degrees
- FDK or iterative reconstruction

- Prone patient position
- Breast pendant through a hole
- No compression
- Equal radiation dose to 2-view mammography







BCT Specs – Representative Systems

Parameter	UC Davis (Doheny)	Koning Standard(UMass†)	Duke/Zumatek
X-ray tube	Varian M-1500	Varian Rad 71SP(M-1500)	Varian (Rad 94)
Focal spot (mm)	0.3	0.1/0.3 (0.3)	0.4
kVp/Filtration	60 kVp / Cu	49-60 kVp / Al	65 kVp / Ce
1^{st} HVL (mm of Al)	~4.15	~1.4@49 kV	~3.0
X-ray pulsing	Pulsed (3~8 ms)	Pulsed (8 ms)	Pulsed (25 ms)
No. of projections	500~800	300	300
Magnification factor	1.39	1.42	1.63
Detector	Dexela 2923M	Varian PaxScan 4030 CB (4030 MCT‡)	Varian PaxScan 2520
Detector type	CMOS+ CsI:Tl	a-Si + CsI:Tl	a-Si + CsI:Tl
Detector‡ pixel size/FPS	75 µm x 2 / 50	194 µm x 2 / 30	127 µm x 2 / 5
Reconstruction / voxel (mm)	FBP / 110-200	FBP / 155 or 273	OSTR / 254 or 508

† Built to specific request by UMass

‡ Reduced dead-space at chest-wall

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass

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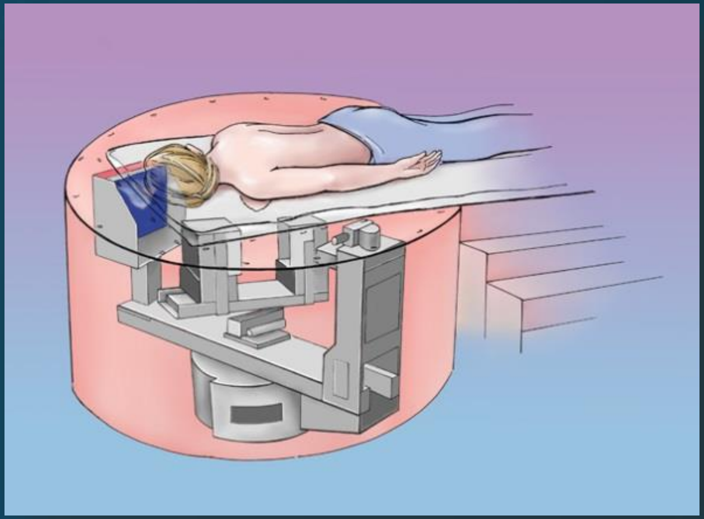
Challenges for bCT

Quality assurance for bCT

Summary



Ongoing clinical studies <u>(Partial list)</u>

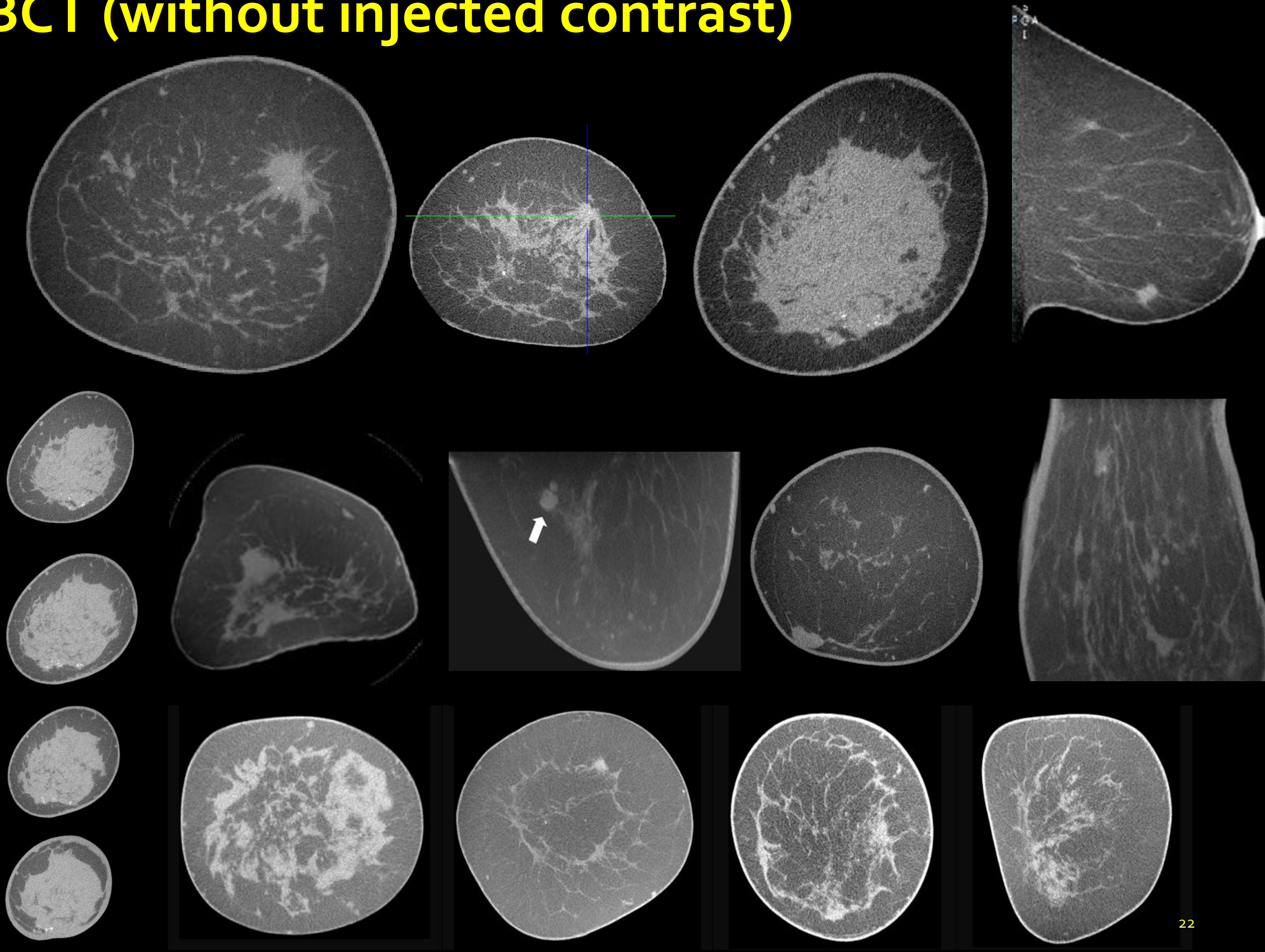
Locations:

- Univ. of California, Davis
- Univ. of Pittsburgh Medical Center
- Univ. of Rochester Medical Center
- UMass Medical School
- M.D. Anderson Cancer Center
- Medical University of South Carolina
- Duke University
- Emory University
- Elizabeth Wende Breast Care

Studies:

- Non-contrast breast CT
- Contrast-enhanced breast CT
- Dedicated breast CT with PET
- Dedicated breast CT with SPECT

BCT (without injected contrast)

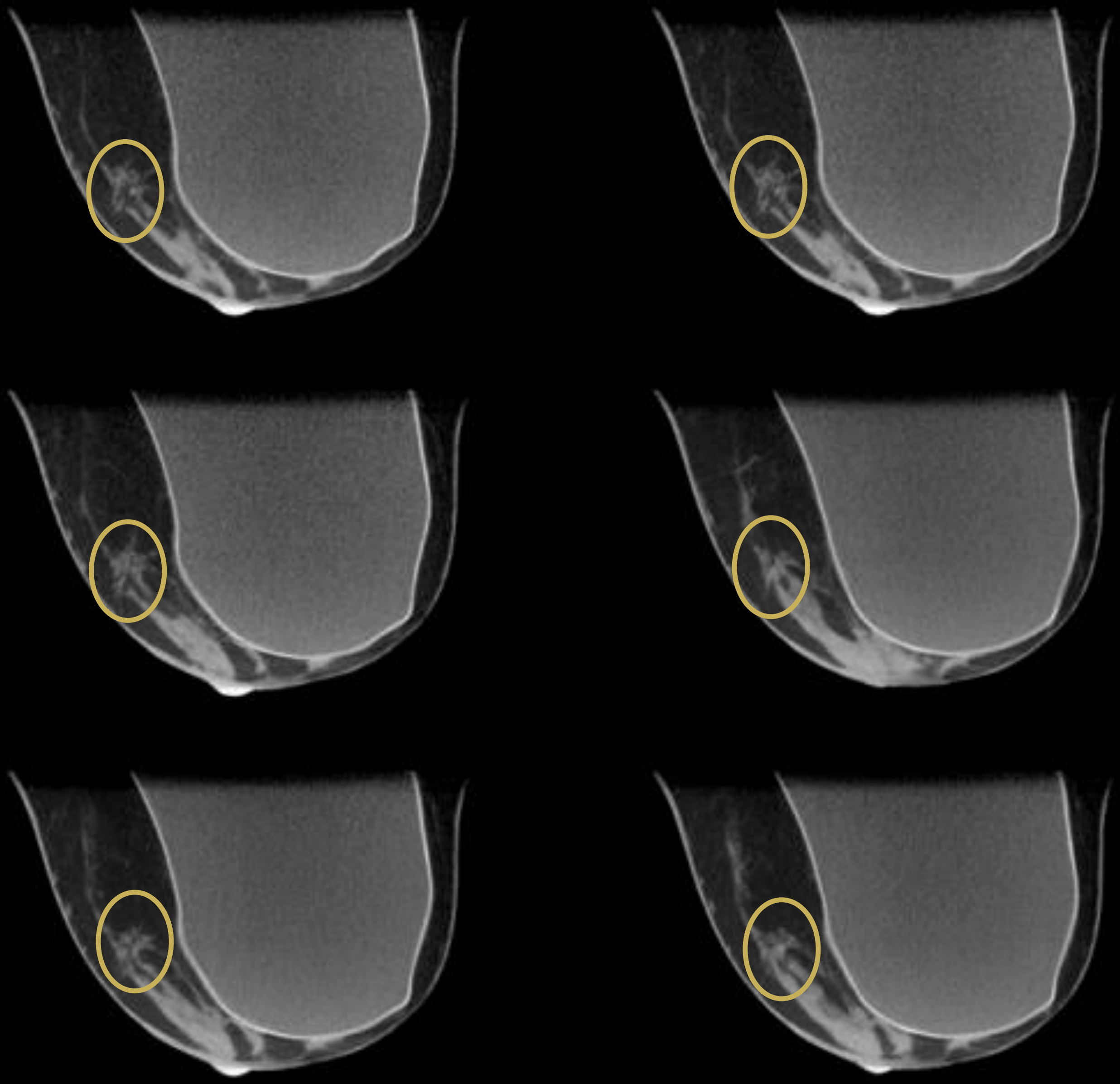


BCT (without injected contrast)

Pre-pectoral Saline Implants

Diagnosis:

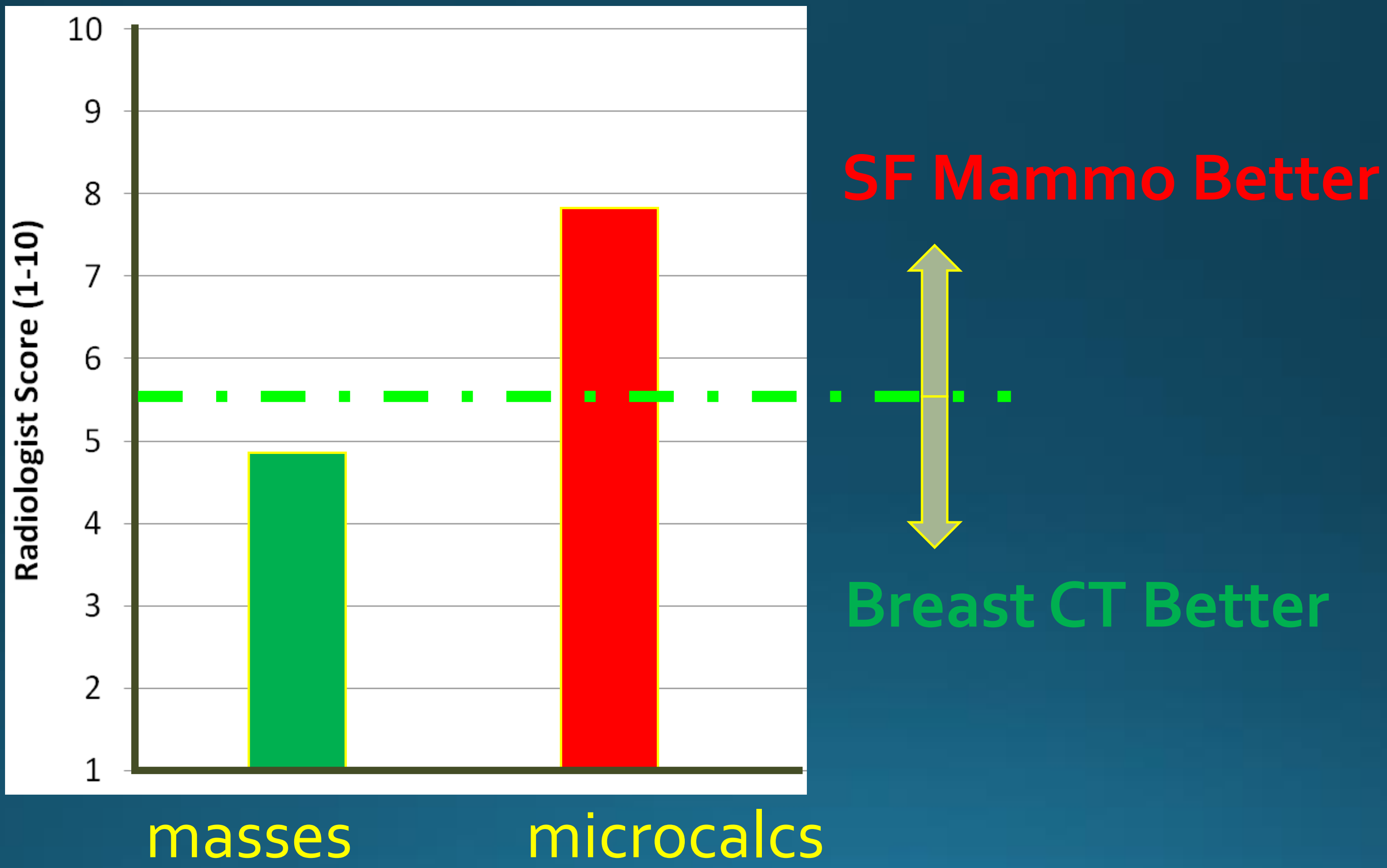
IDC/ILC



UC Davis
January 2005

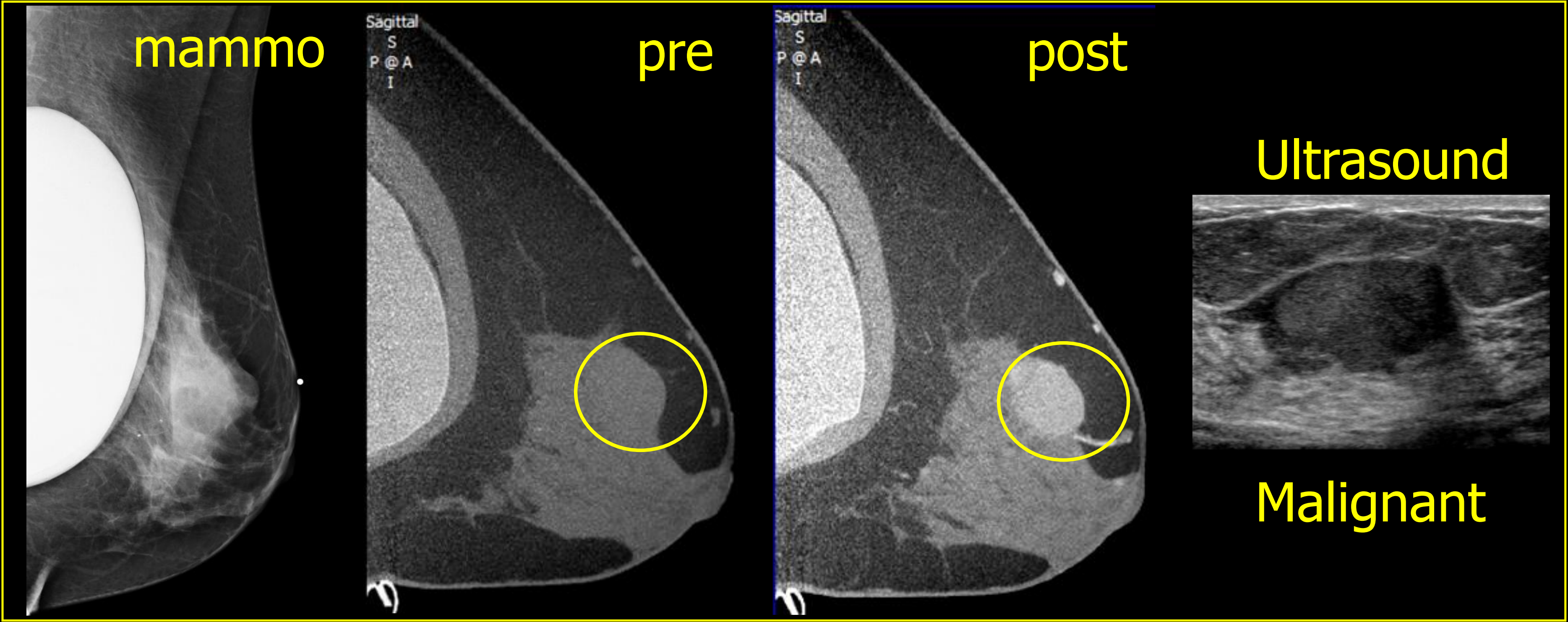
Breast CT clinical studies

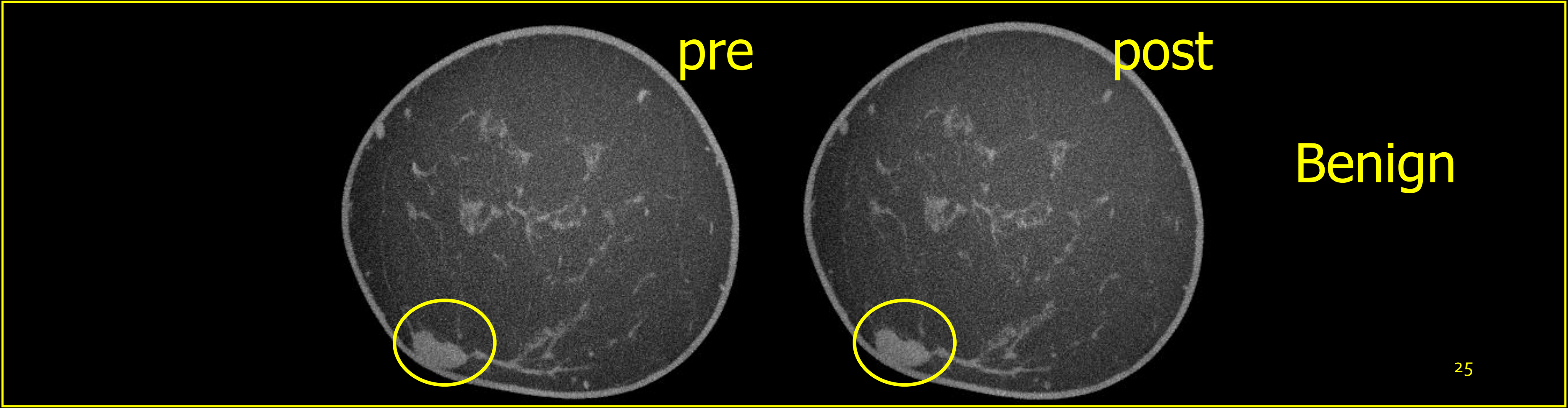
Radiologist Subjective Scoring (N = 69)



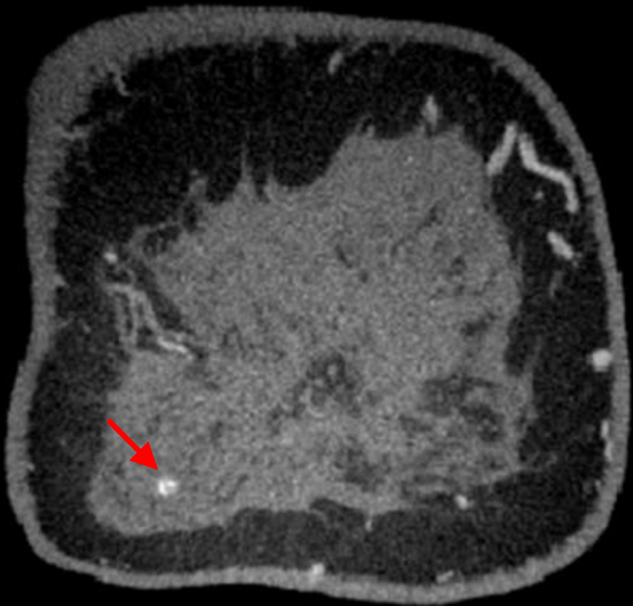
K.K. Lindfors, et al. Radiology 246.3 (2008): 725.

BCT (with contrast injection)

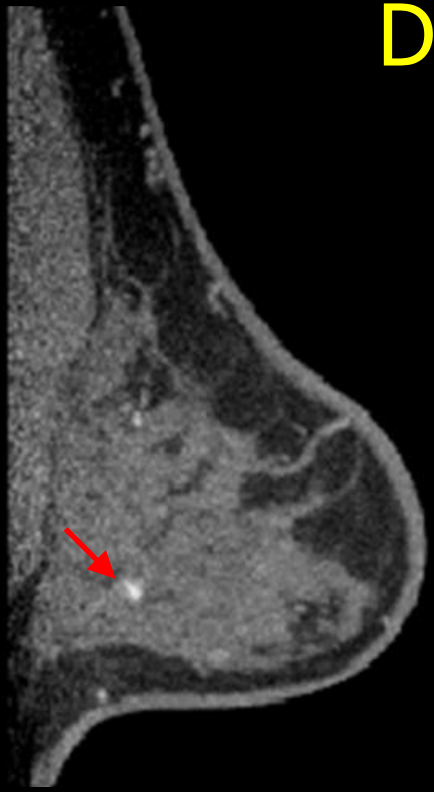




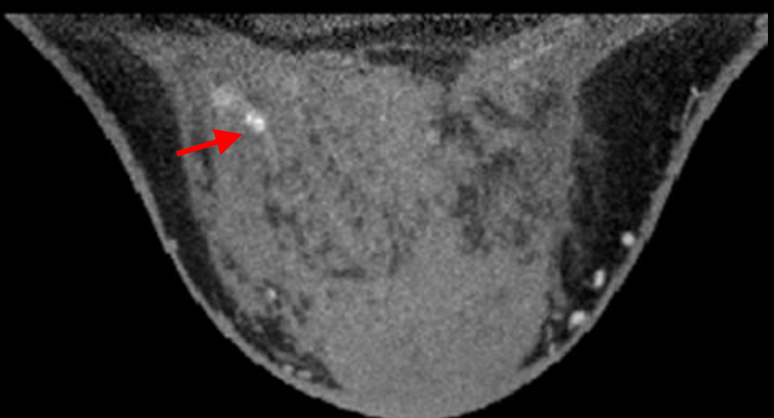
Contrast Enhanced bCT
DCIS



Coronal

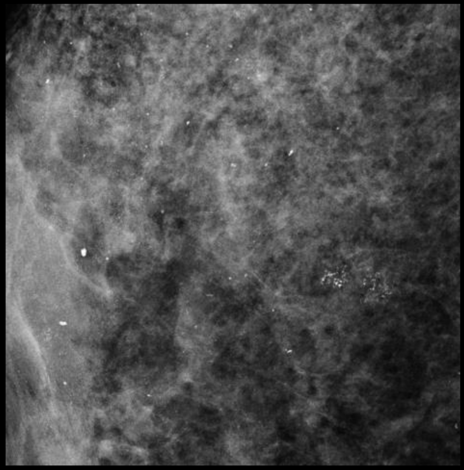


Sagittal

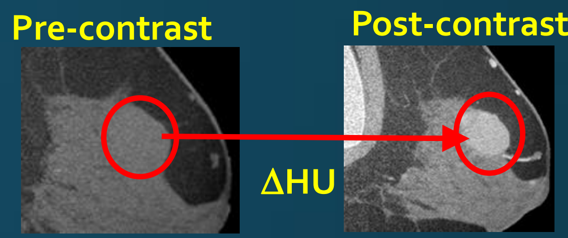


Axial

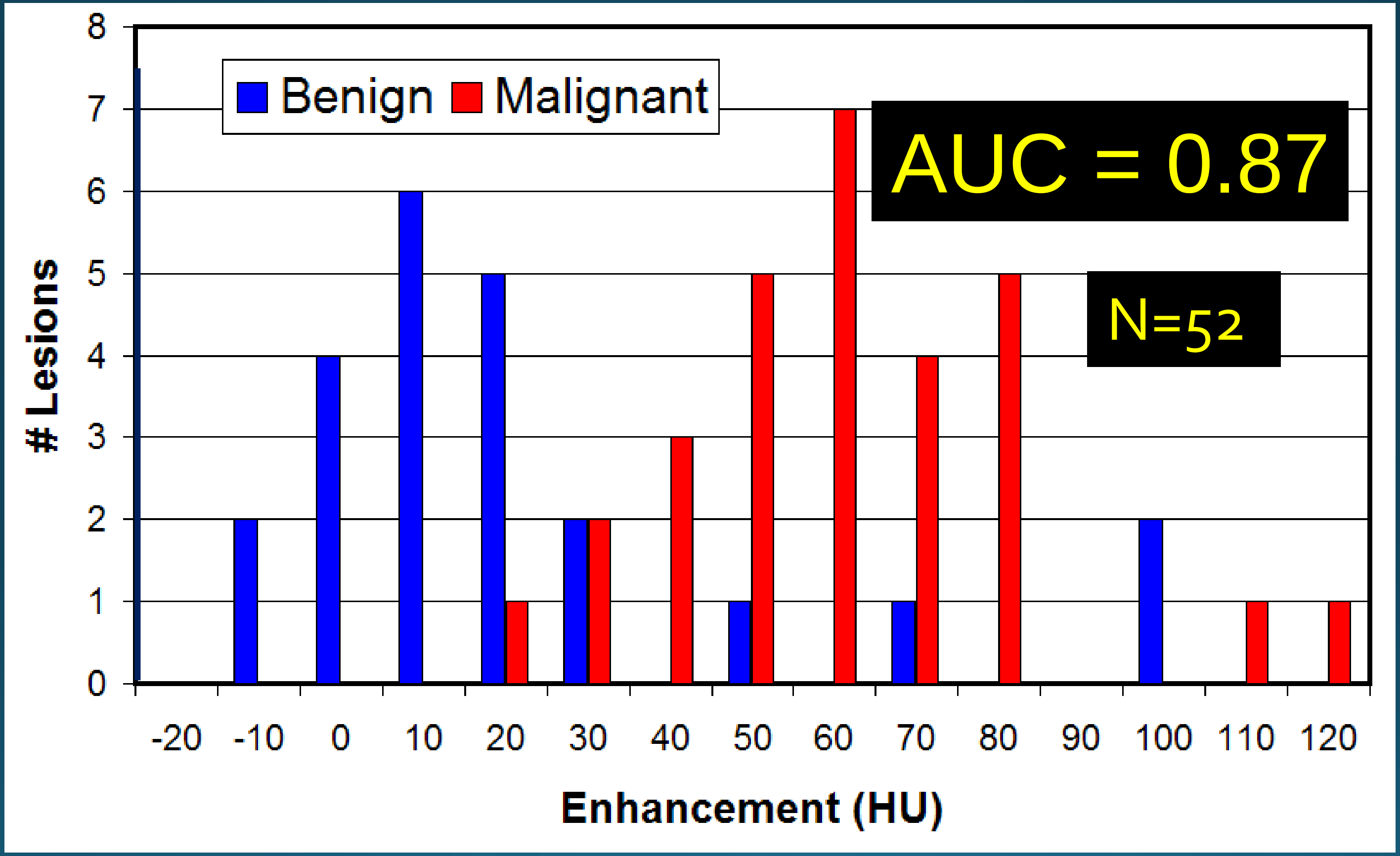
Rt ML Mag view



Breast CT clinical studies



Contrast Agent Kinetics

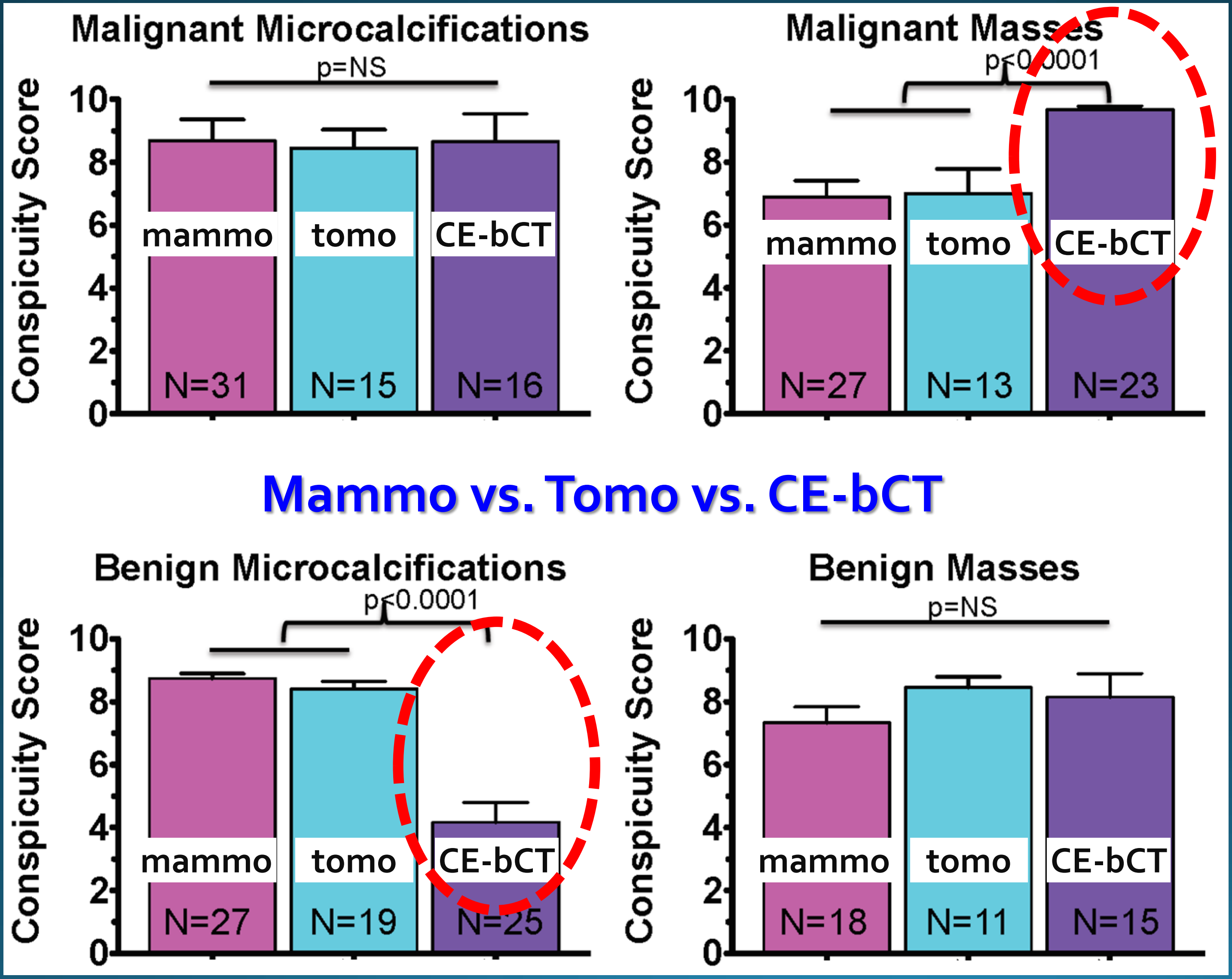


Malignant tumors tend to enhance more than benign lesions

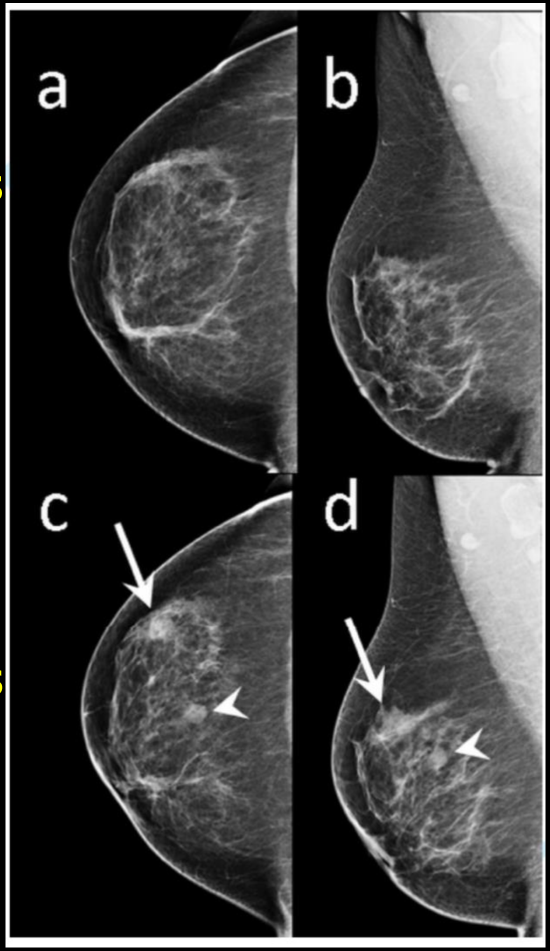
N. D. Prionas, et al Radiology 256, 714-723 (2010).

Breast CT clinical studies

Comparison between modalities

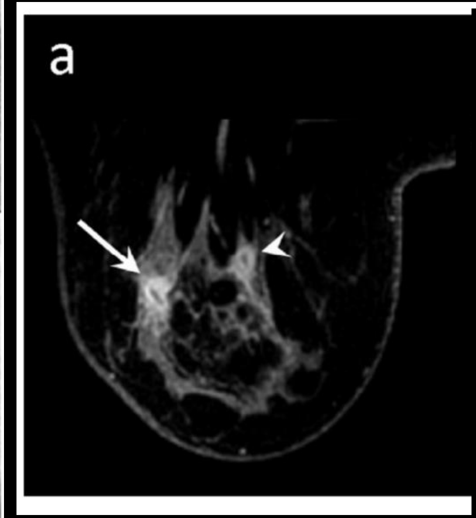


Mammograms
Apr 2010:
Normal



Mammograms
July 2011:
DCIS

2011: DCE MRI
showing
enhancement



2010: CE bCT
showing
enhancement

N. D. Prionas, et al J. Invest Med 61, 132-132 (2013)

Breast CT (bCT)

Introduction

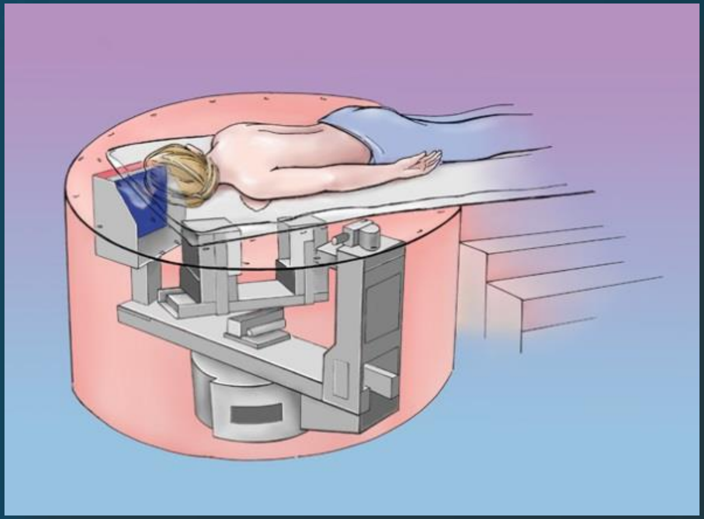
Development of bCT

Patient imaging / clinical studies

Challenges for bCT

Quality assurance for bCT

Summary



Demands on breast CT imaging

1. Full 3D capability
2. Good soft-tissue differentiation
3. Dynamic imaging capabilities
4. High isotropic spatial resolution of about 100 μm
5. Low patient dose with an AGD below 5 mGy
6. Patient comfort without breast compression
7. Low cost

Computed Tomography: Fundamentals, System Technology, Image Quality, Applications, 3rd Edition. **Willi A. Kalender**

Limitations for breast CT imaging

Radiation dose to the breast	Equal or less than two-view mammo
Patient's comfort	No breast compression Breath hold < 20 seconds Natural prone position
Available technology and the cost	Indirect flat panel detector (a-Si TFT or CMOS) Pulsed x-ray tube

Challenges for bCT

Mass-lesion detection
- Soft tissue differentiation
- Quantitative information
- Contrast kinetics

Micro-calcification detection

→

Spectrum optimization

Improve the spatial resolution

Improve the image SNR

Improve the accuracy of HU

Chest wall coverage
- Patient comfort

→

Table top/gantry design

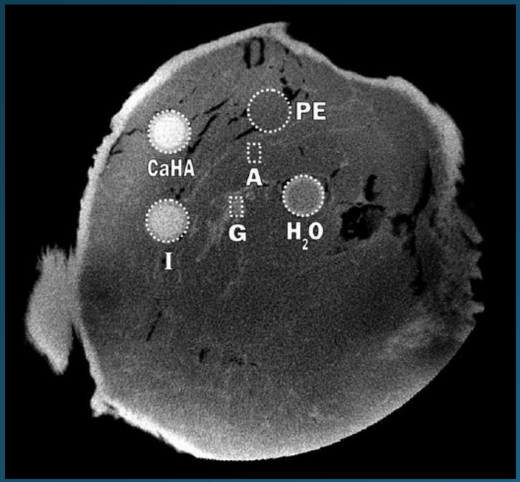
Challenges for bCT – Spectrum

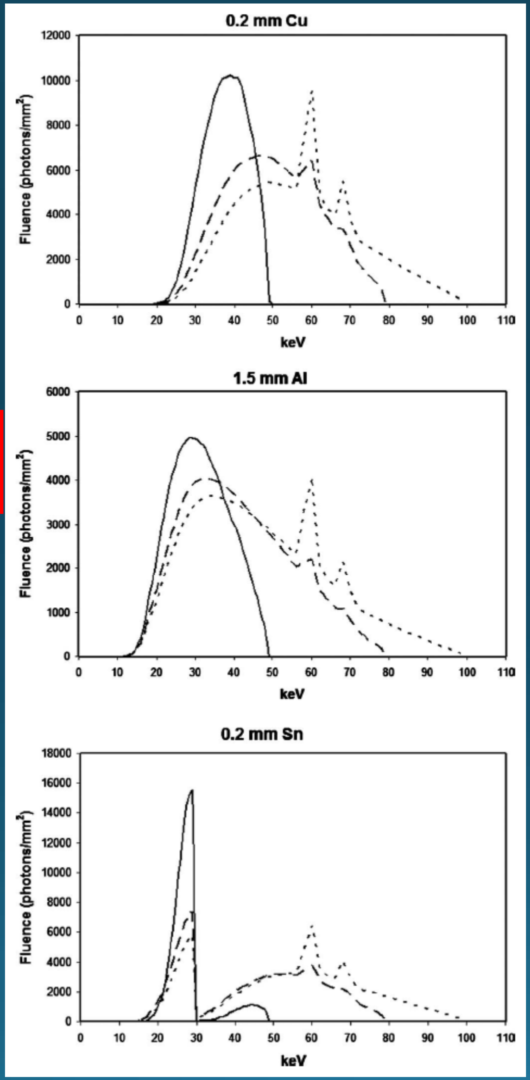
Dose-normalized CNR (CNRD)

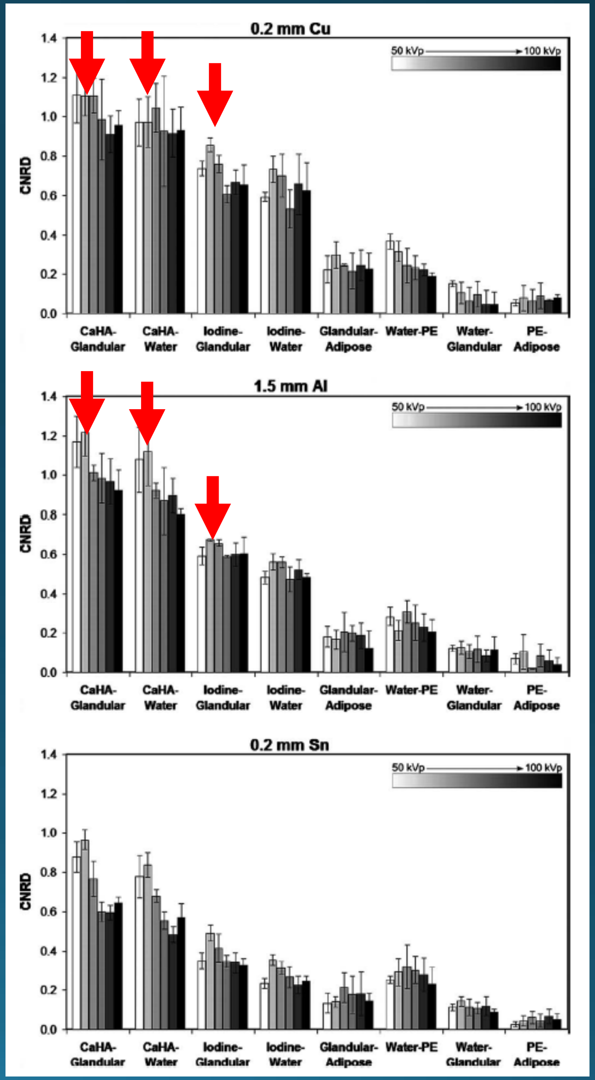
Iodine contrast:

Calcification contrast:

60 kVp + 0.2 mm Cu







N.D. Prionas, S.Y. Huang, and J.M. Boone, Med. Phys. 38, 646 (2011)

Challenges for bCT – μCalcs detection

Spatial resolution

Flat panel detector – frame rate, MTF, DQE

X-ray tube – focal spot, pulsed vs. continuous

Contrast resolution

Relatively high kV (49~80 kV vs. 20~30 kV in mammo).

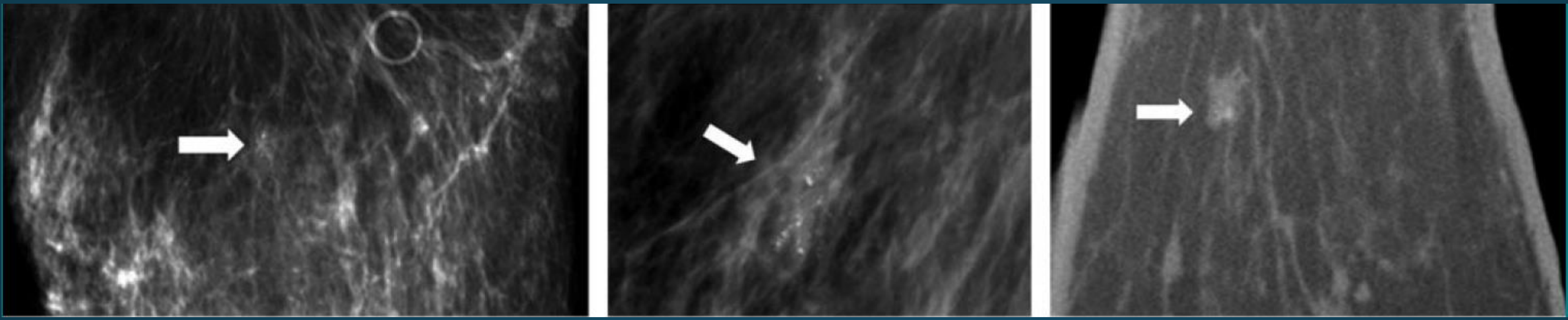
Potentially low contrast for calcifications.

Noise due to dose limit

To match the mean glandular dose of two-view mammo.

Potentially low SNR in each projection image.

Challenges for bCT – μCalcs detection

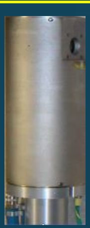
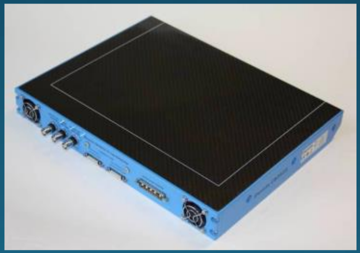


Spatial Resolution

	Breast CT	Mammography
Detector pixel size (mm)	388 (150*)	75~100
X-ray focal spot size (mm)	0.1~0.4	0.1~0.4
Magnification factor	1.5~2.0	1.0~2.0

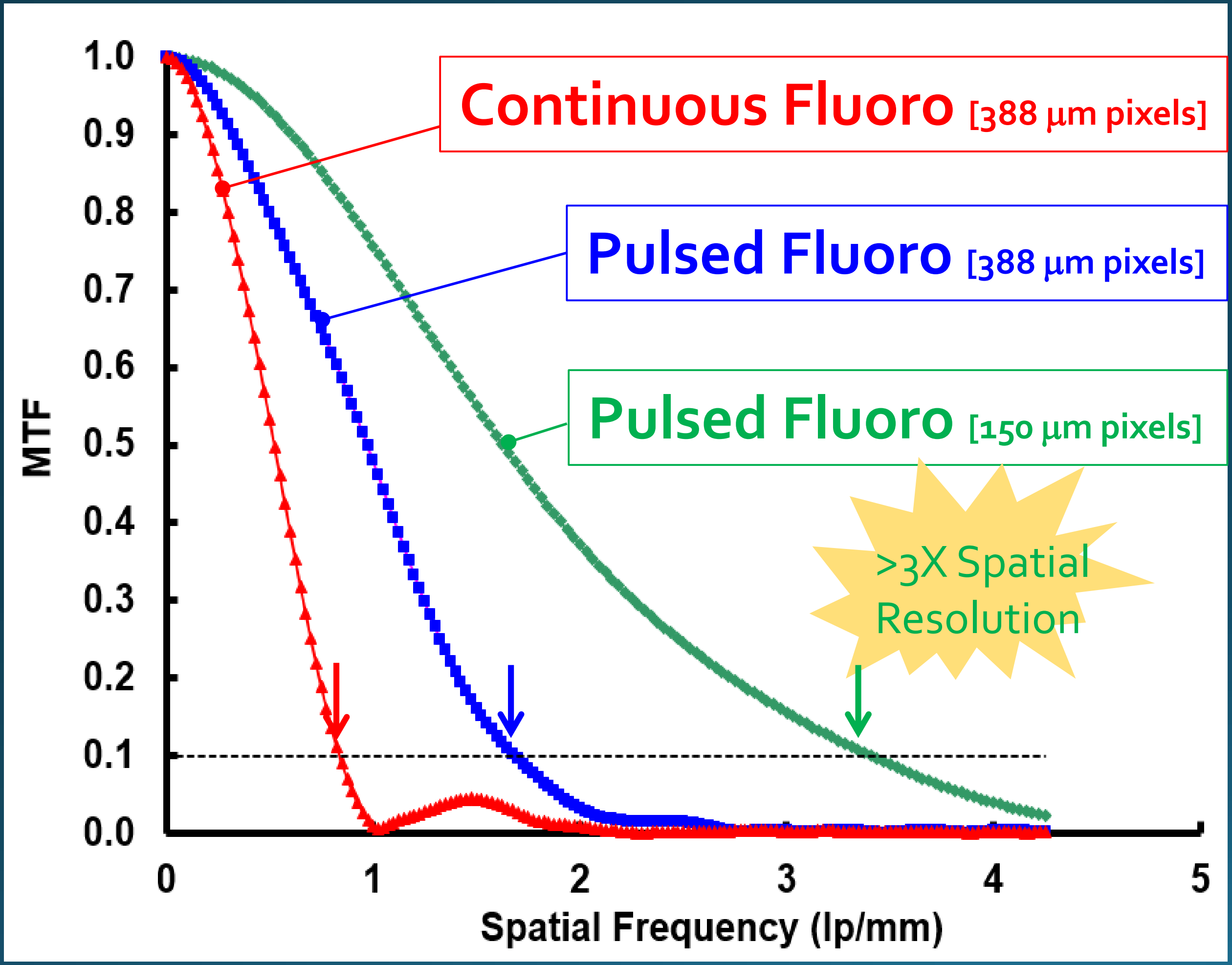
* The "Doheny" scanner at UC Davis with a DEXELA CMOS detector.

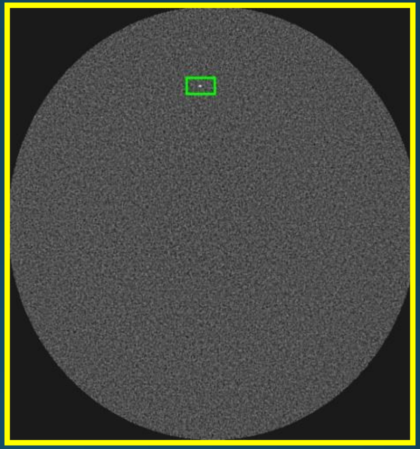
UD Davis bCT MTF - system improvement

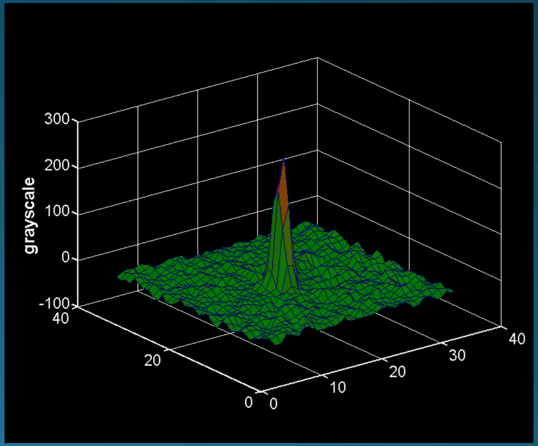
Albion Bodega		1.0 mm focal spot Continuous acquisition		388x388 μm² 30 fps
Cambria		0.3 mm focal spot Pulsed acquisition		388x388 μm² 30 fps
Doheny		0.3 mm focal spot Pulsed acquisition		150x150 μm² 60 fps

P Gazi*, TU-F-18C-7 Tuesday 4:30PM - 6:00PM Room: 18C

UD Davis bCT MTF - system improvement







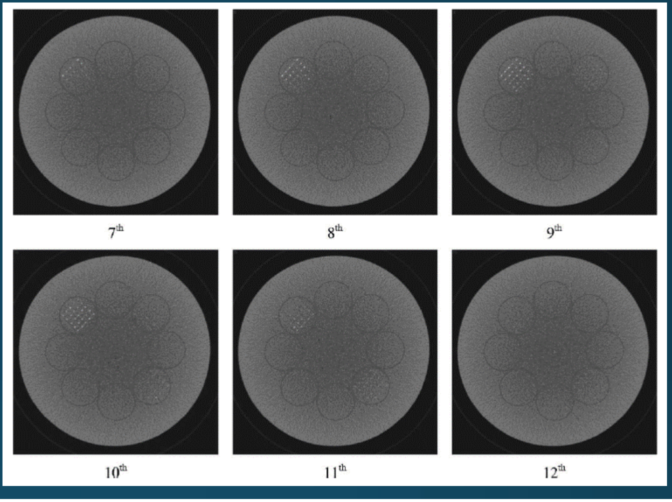
P Gazi*, TU-F-18C-7 Tuesday 4:30PM - 6:00PM Room: 18C

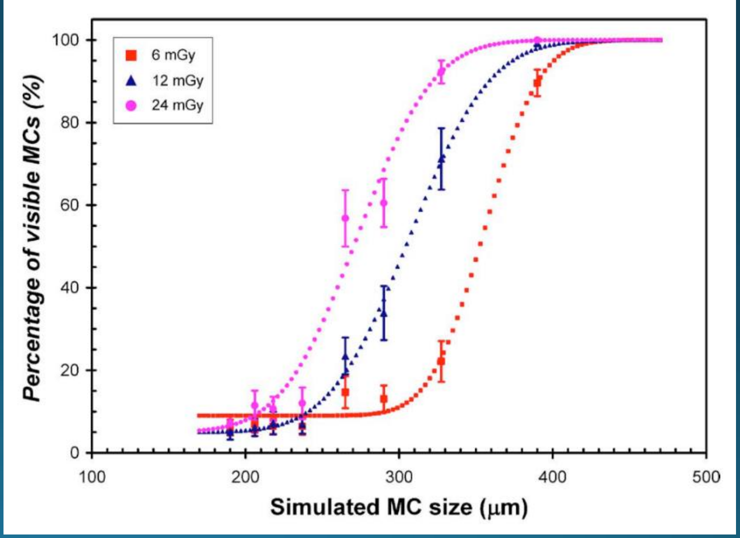
Challenges for bCT - μCalcs detection

Radiation Dose vs. Noise

TABLE V. The minimum detectable MC sizes for various conditions for the small and the large breast phantoms.

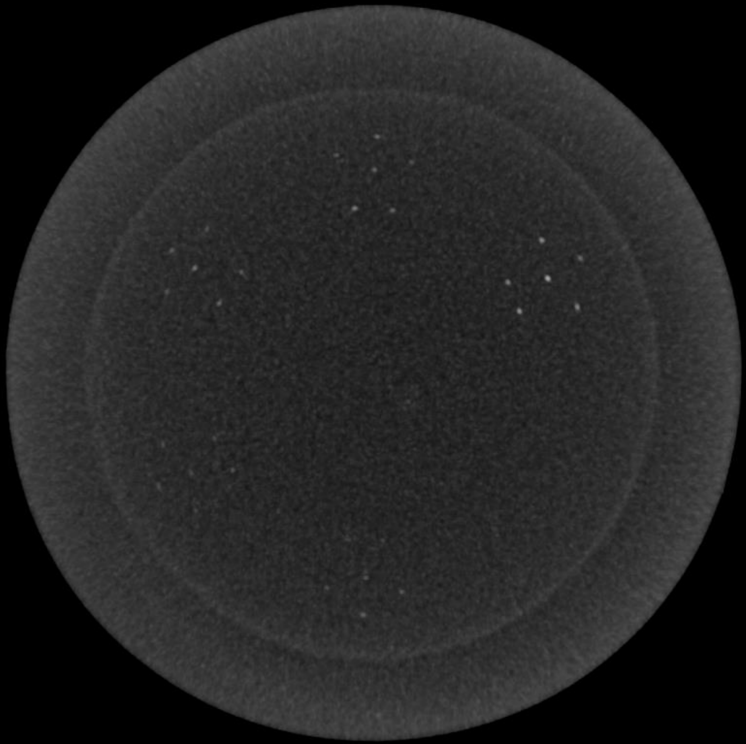
Threshold	Breast phantom	MGD	X-ray tube voltage		
			60 kVp	8 kVp	100 kVp
50%	Small	3 mGy	346	349	—
		6 mGy	282	280	301
		12 mGy	253	258	259
	Large	6 mGy	357	353	354
		12 mGy	296	304	320
		24 mGy	—	270	279
75%	Small	3 mGy	368	366	—
		6 mGy	311	308	329
		12 mGy	261	264	271
	Large	6 mGy	382	373	376
		12 mGy	325	333	343
		24 mGy	—	298	301



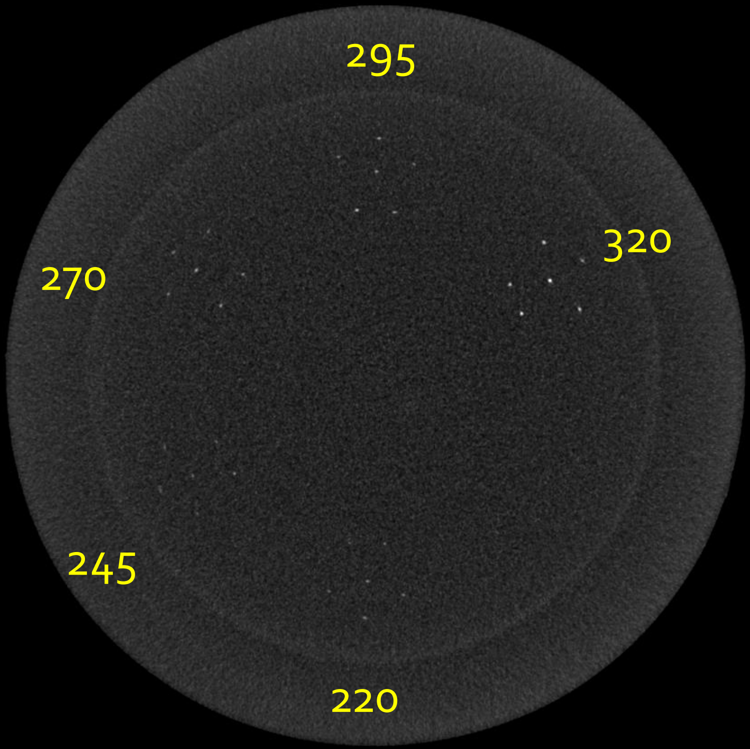


Chao-Jen Lai, Chris C. Shaw, et al, Med. Phys. 34, 2995 (2007)

14 cm diameter f_g = 0.15 breast-equivalent phantom; Calcifications located at r = 3.5 cm.



FBP: 273 microns
Modified Shepp-Logan



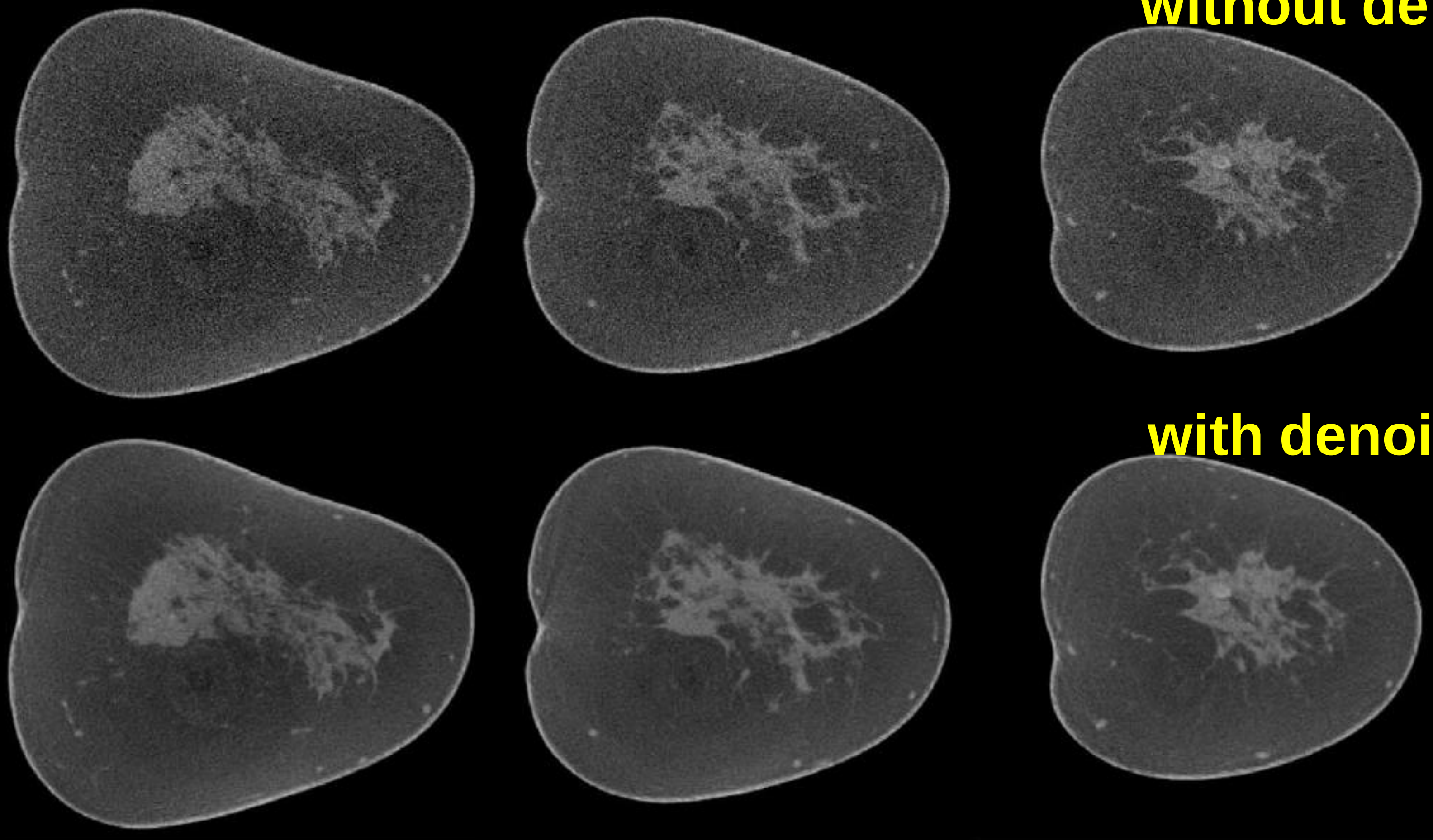
FBP: 155 microns
Ramp filter

Can visualize 220 μm calcifications @ AGD matched to **diagnostic** mammography (12 mGy)

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass

Challenges for bCT – μCalcs detection

BCT Denoise – Projection domain (PDEtomo)



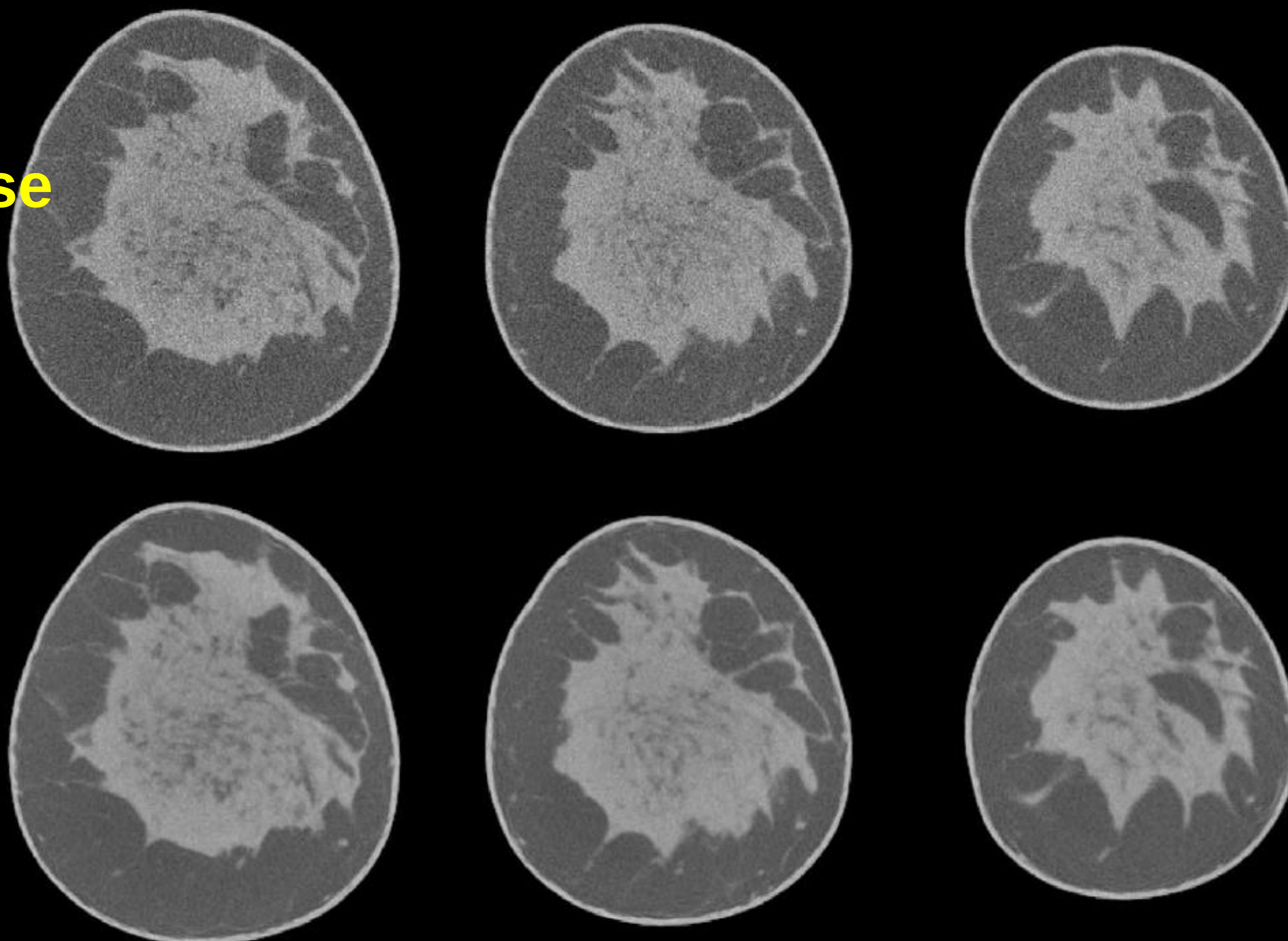
Jessie Q. Xia et al, Medical Physics, 35, 1950-1958 (2008)

Challenges for bCT – μCalcs detection

BCT Denoise – Projection domain (PDEtomo)

without denoise

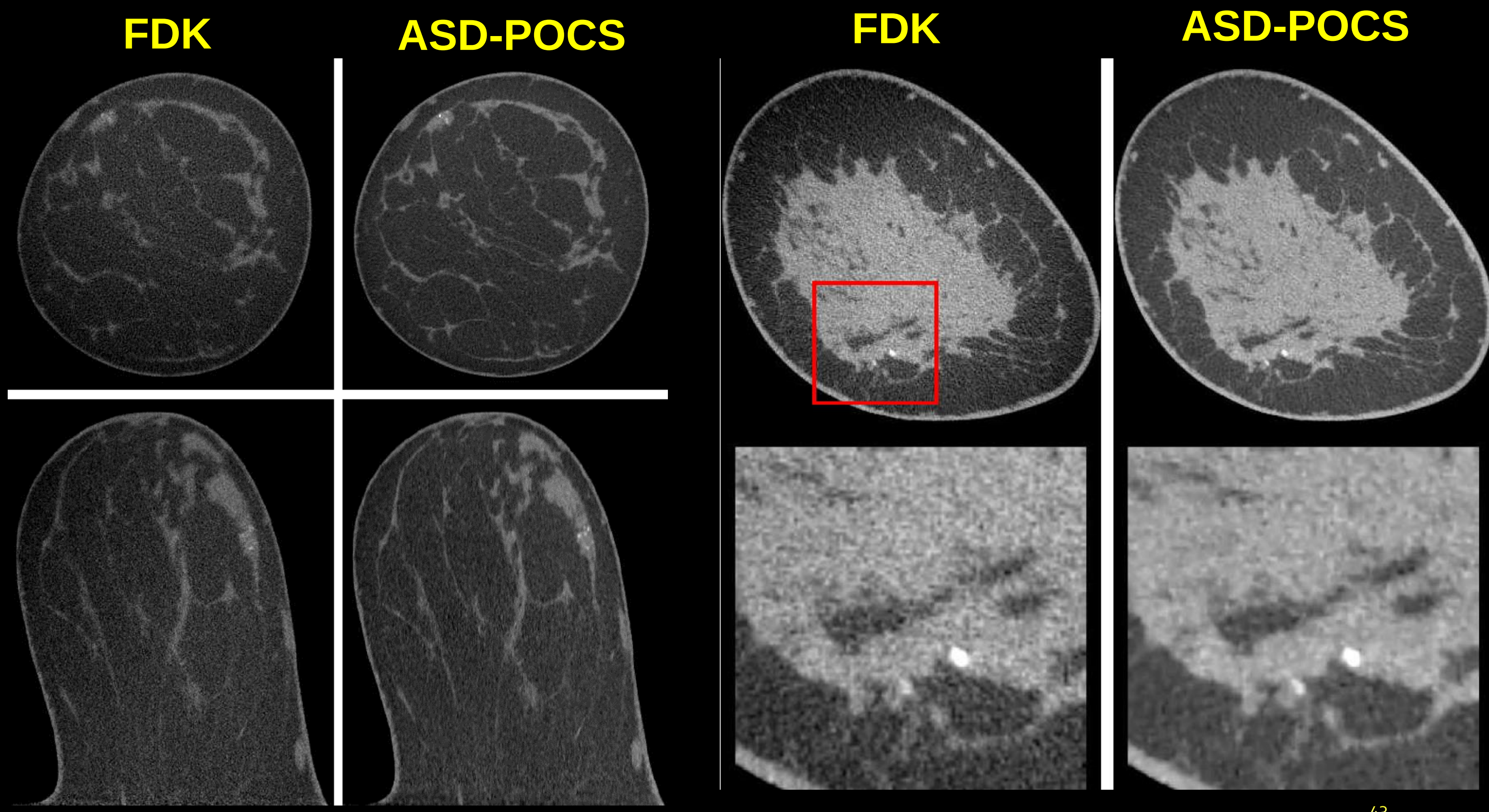
with denoise



Jessie Q. Xia et al, Medical Physics, 35, 1950-1958 (2008)

Challenges for bCT – μCalcs detection

BCT Denoise – CT image domain (iterative reconstruction).

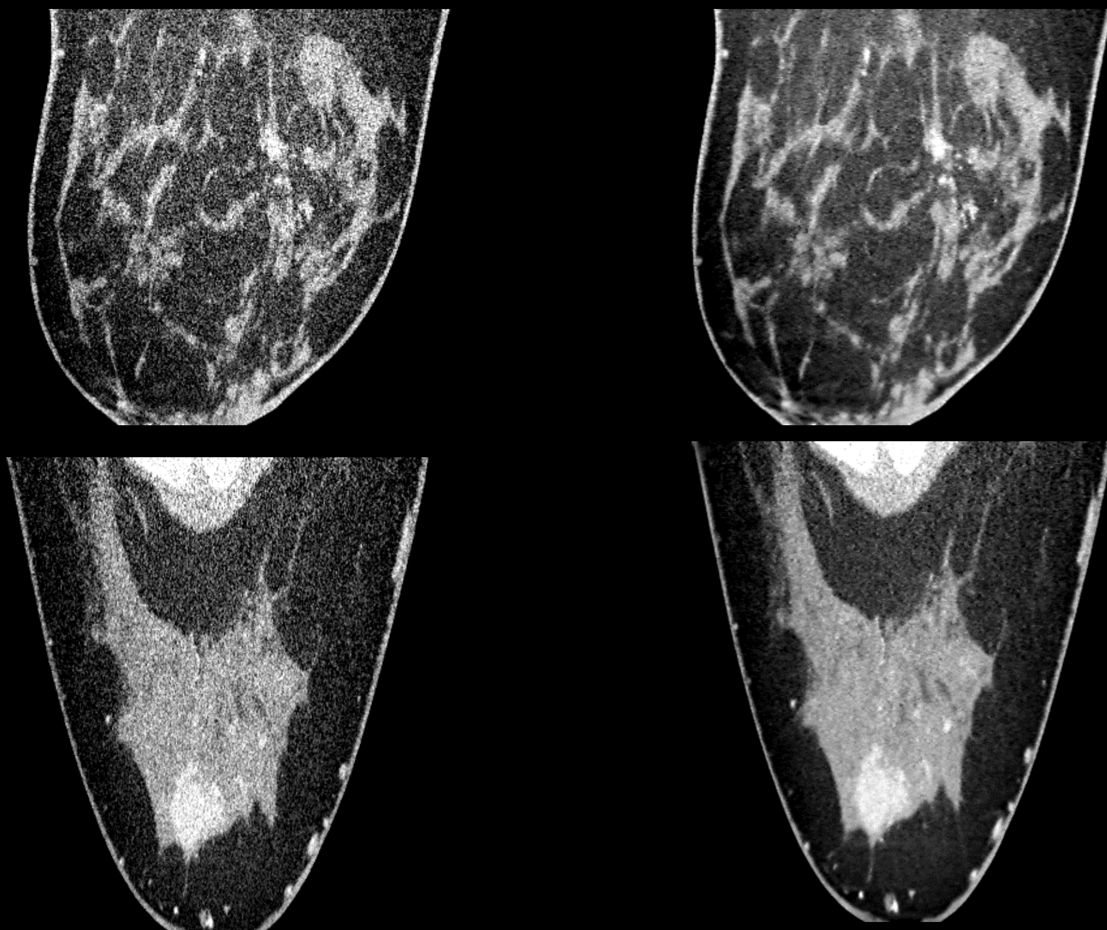


Junguo Bian *et al* 2014 *Phys. Med. Biol.* 59 2659

Challenges for bCT – μCalcs detection

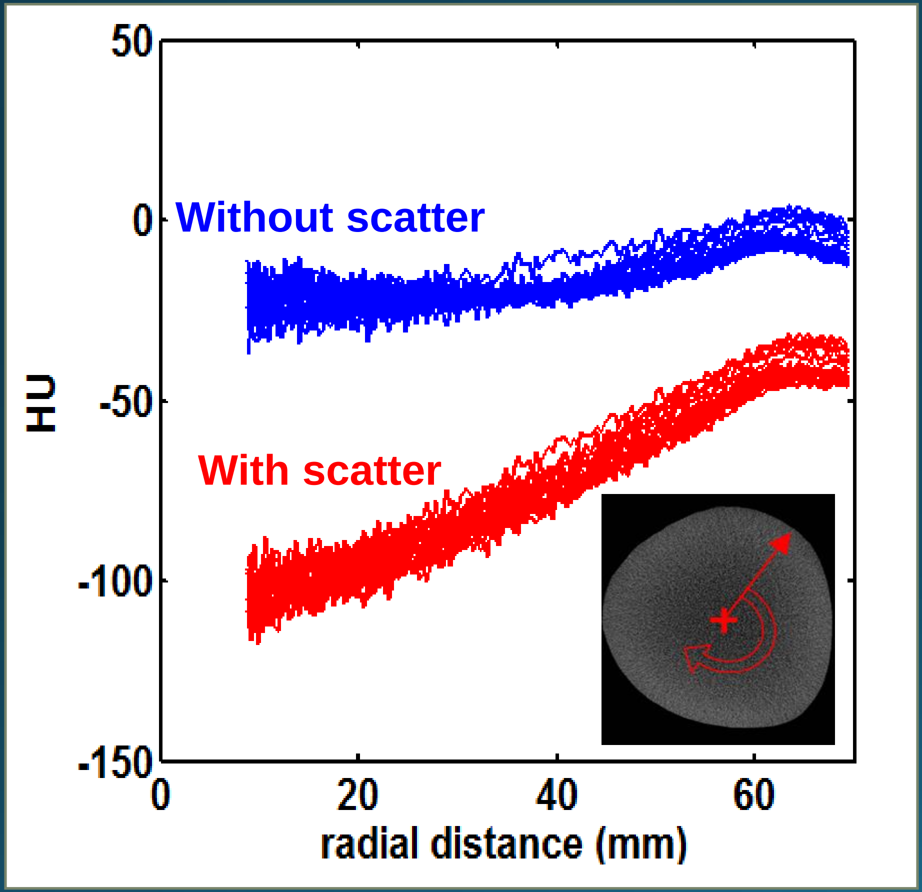
BCT Denoise – CT image domain (iterative reconstruction).

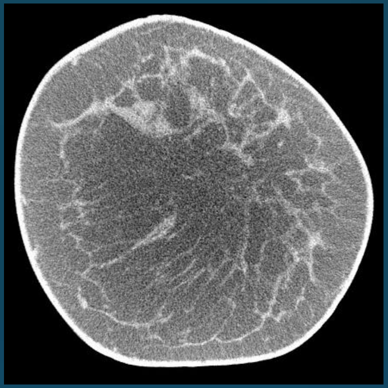
FDK PICCS

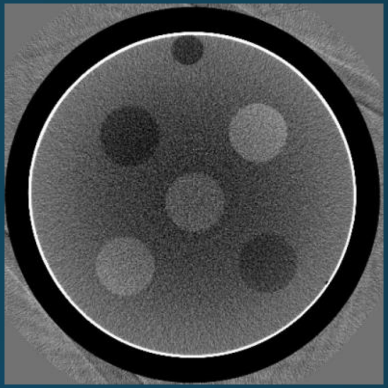


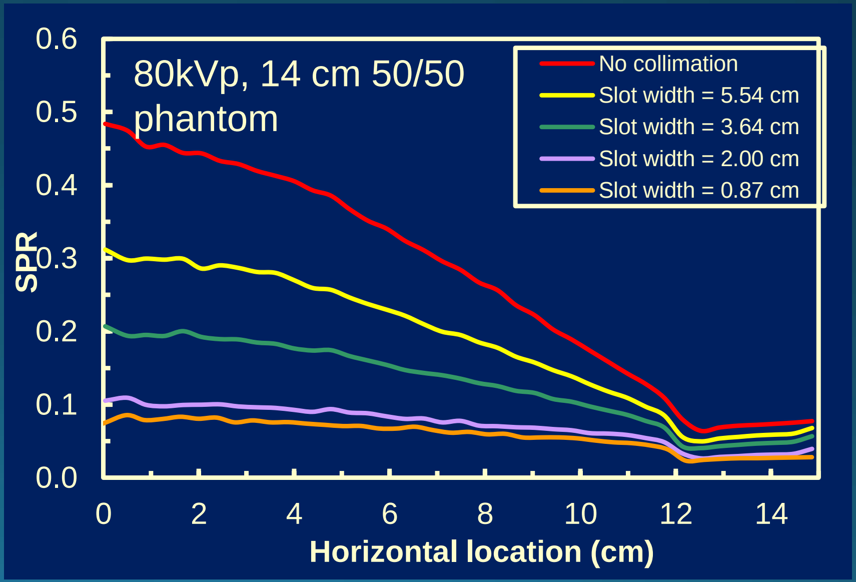
Zhihua Qi, et al AAPM Annual Meeting 2010

Challenges for bCT – Scatter









A. Kwan, et al, Medical Physics 32, 2967-2975 (2005)

Scatter correction approaches (Partial list)

- **CT image processing based**
  - Kachelriess et al. Medical Physics 33, 1269-1274 (2006).
  - Altunbas et al. Medical Physics 34, 3109-18 (2007).

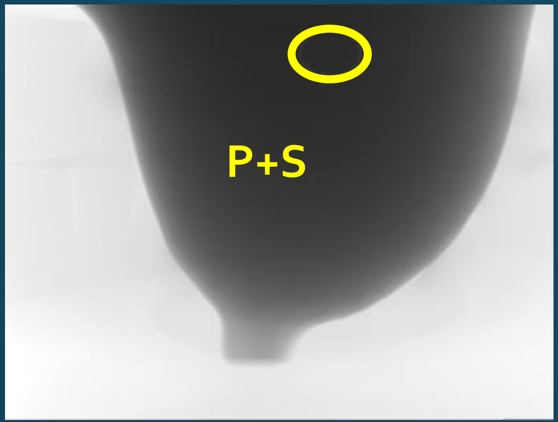
- **Monte Carlo simulation based**

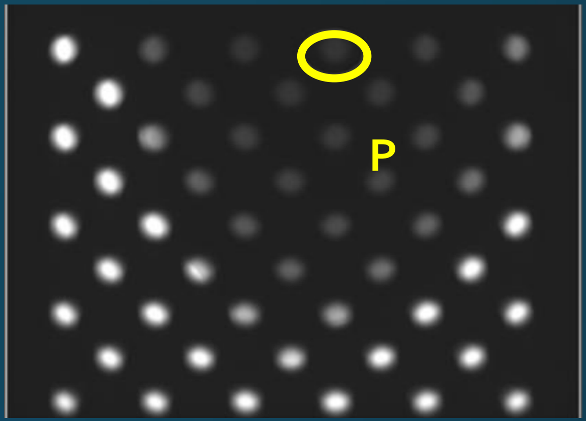
The absolute accuracy of HU is equally important as the image uniformity!

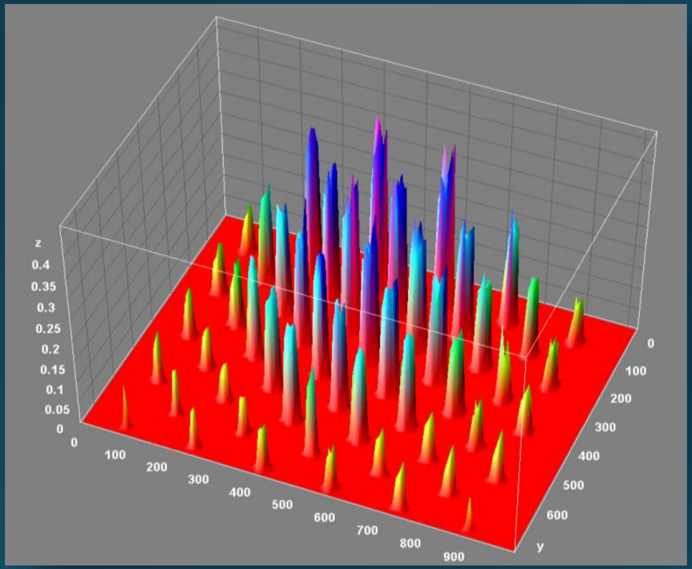
  - Ning et al. Medical Physics 31, 1195-202 (2004).
  - X. Tang, United States Patent No. US 6876718B2 (2005).
  - Siewerdsen et al. Medical Physics 33, 187-97 (2006).
  - Maltz et al. Medical Physics 35, 2452-62 (2008).
  - Jin et al. Medical Physics 37, 5634-44 (2010).
  - Niu et al. Medical Physics 38, 6027-38 (2011).
  - I. Sechopoulos, Medical Physics 39, 2896 (2012).

Scatter Correction – The BPA Approach

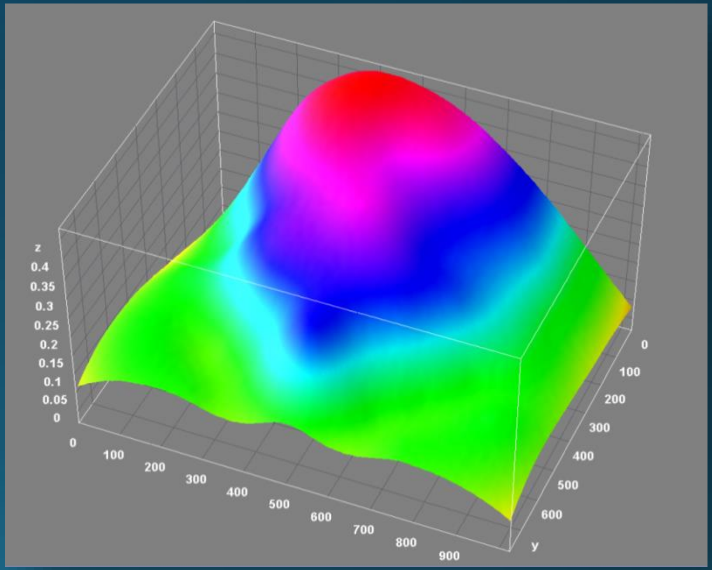
$$\frac{(P+S) - P}{P} = SPR$$







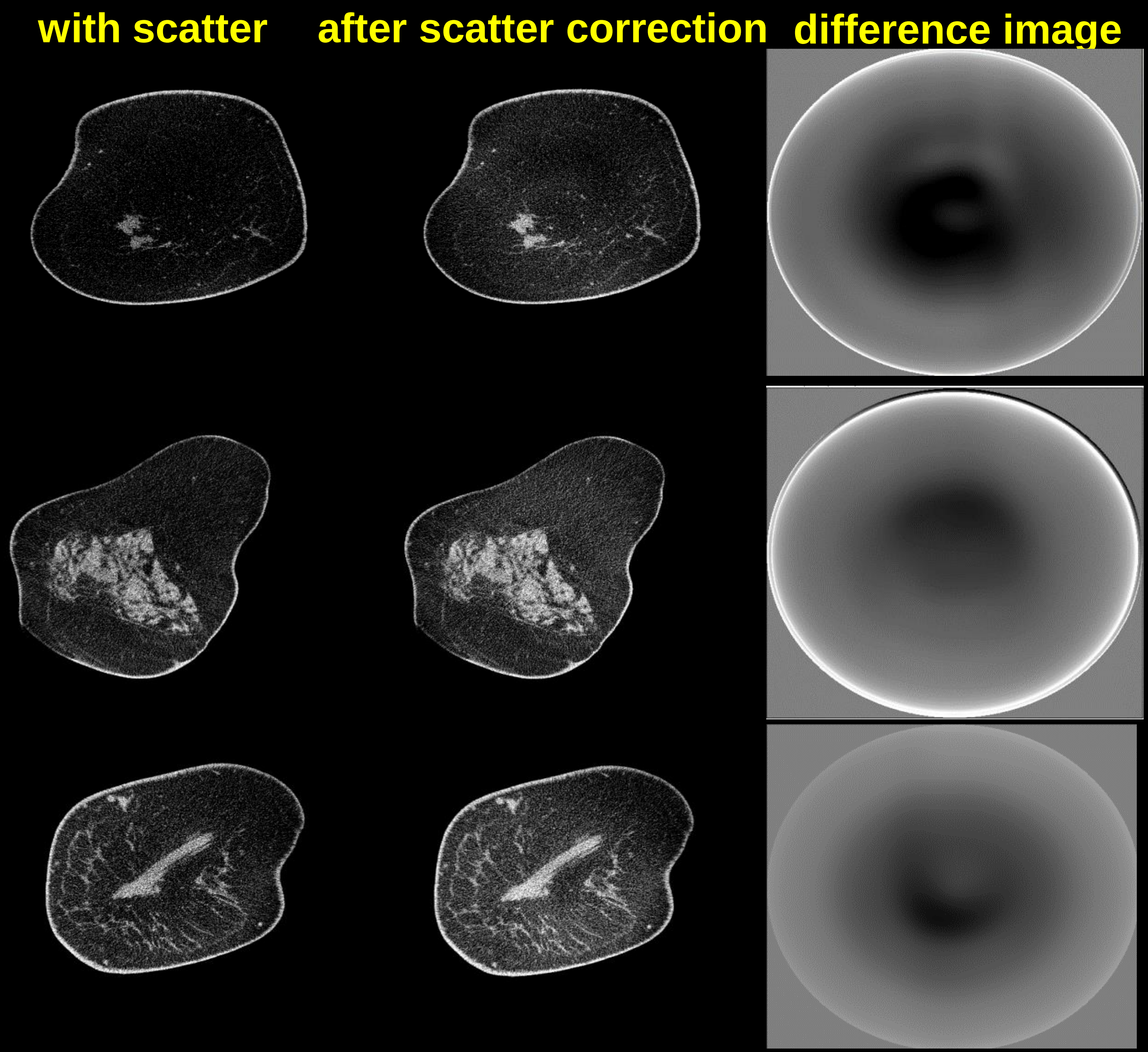
SPR defined at various points



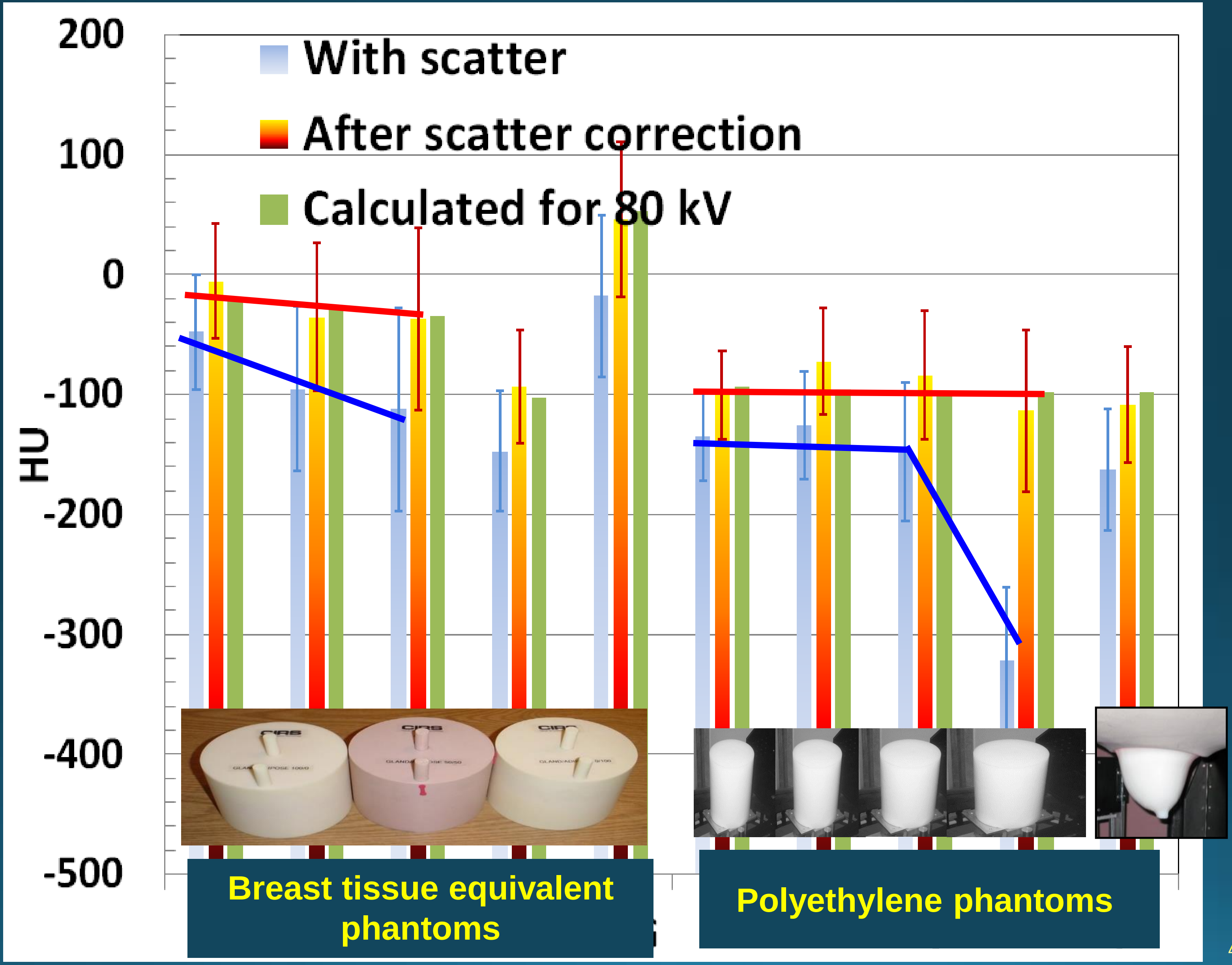
SPR Interpolated to entire image

K. Yang, et al, *Proc. SPIE, Vol. 8313*, (2012), pp. 831303.

Scatter Correction – Cupping Correction

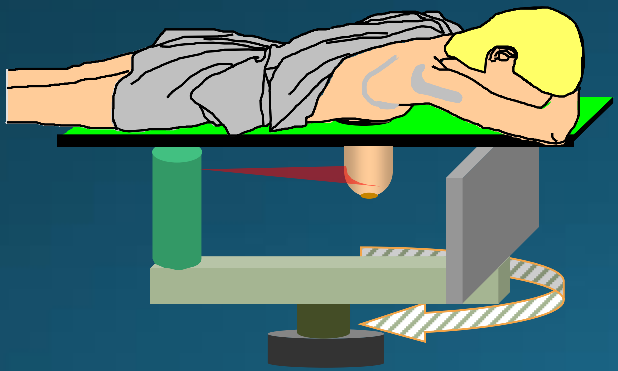


Scatter Correction – HU Accuracy

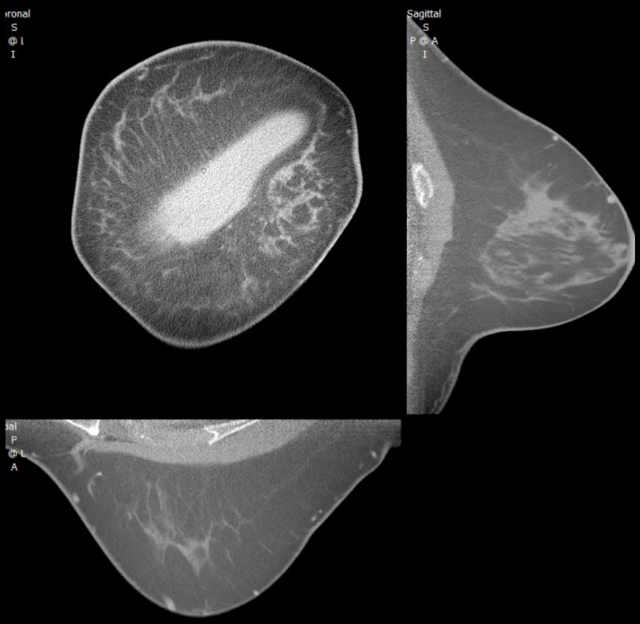


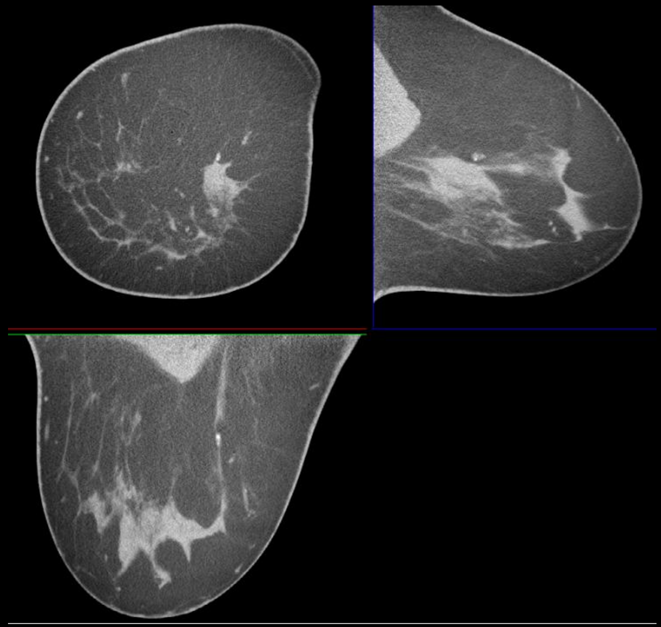
Challenges for bCT – Chest wall

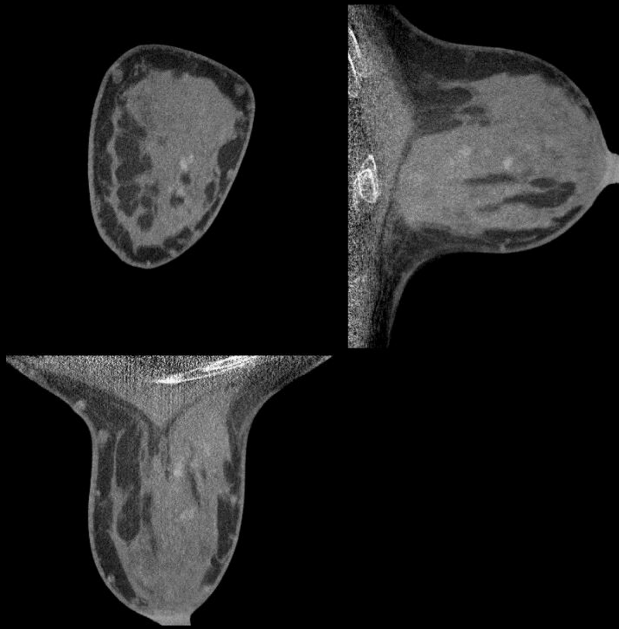
- Tabletop design
- Patient comfort level
- Physical limitations
  - Focal spot location
  - Detector dead space

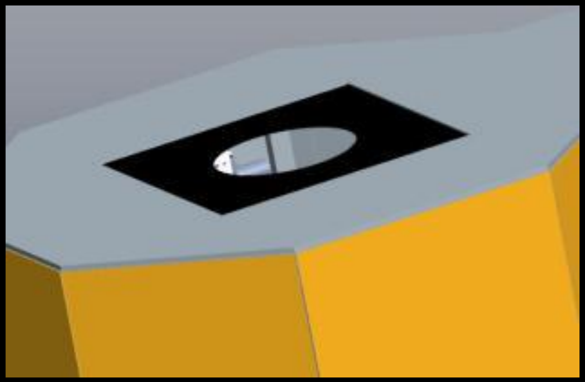


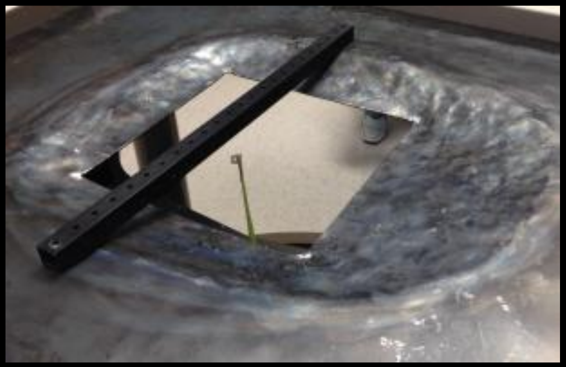
Challenges for bCT – Chest wall



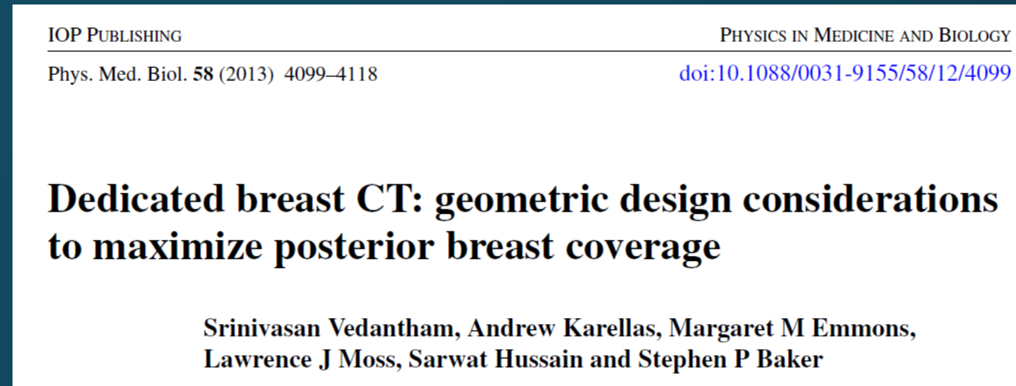








Improving chest wall coverage

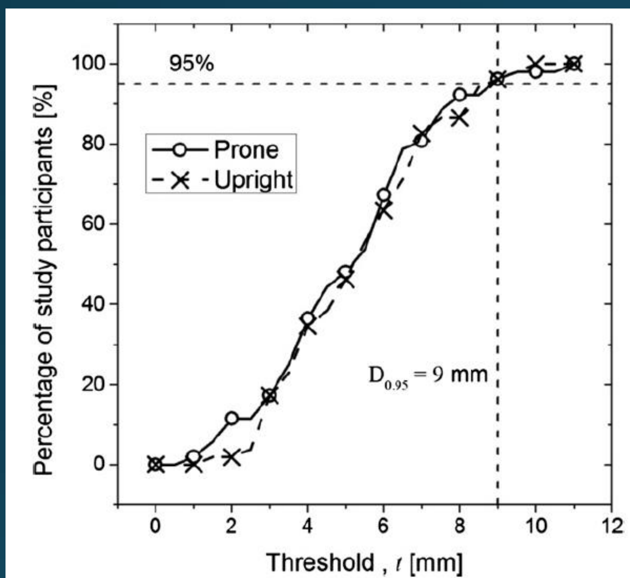


IOP PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

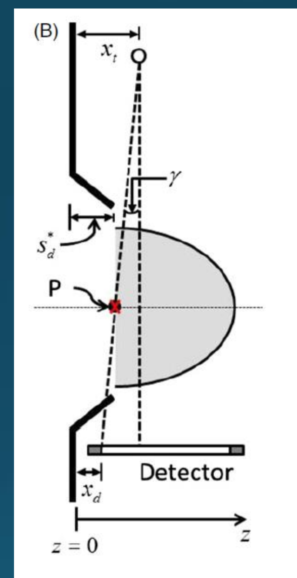
Phys. Med. Biol. 58 (2013) 4099–4118 doi:10.1088/0031-9155/58/12/4099

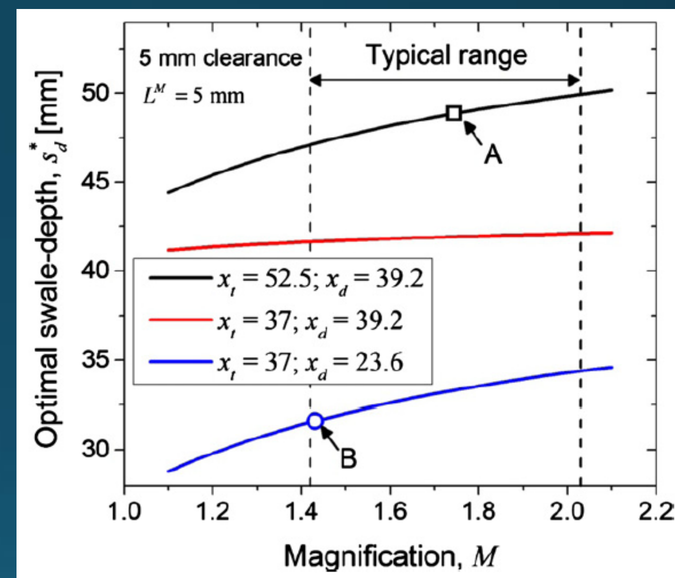
Dedicated breast CT: geometric design considerations to maximize posterior breast coverage

Srinivasan Vedantham, Andrew Karellas, Margaret M Emmons, Lawrence J Moss, Sarwat Hussain and Stephen P Baker



If using ideal tube/detector – breast CT would miss at the most 9 mm compared to mammography in 95% of women studied





Optimal swale depth, s_d^* depends on x-ray tube/detector dead-space and magnification [B - corresponds to the geometry with UMass prototype (3.2 cm)]

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass

Breast CT (bCT)

Introduction

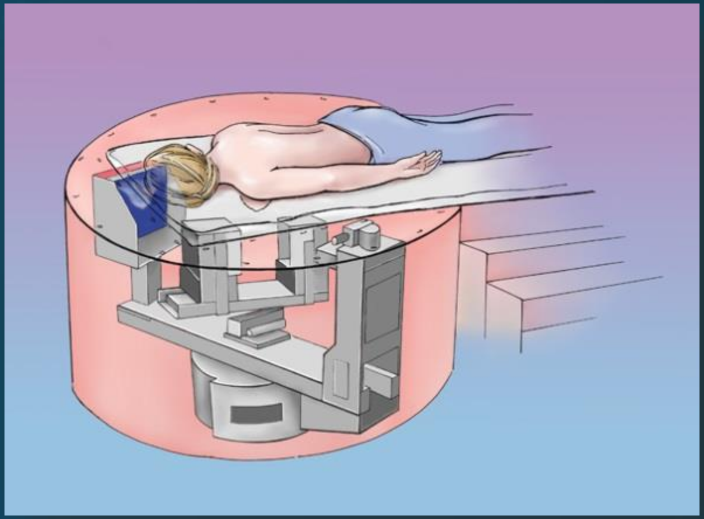
Development of bCT

Patient imaging / clinical studies

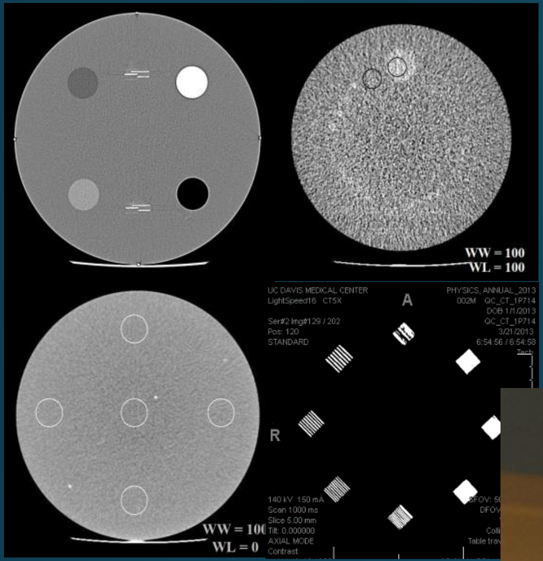
Challenges for bCT

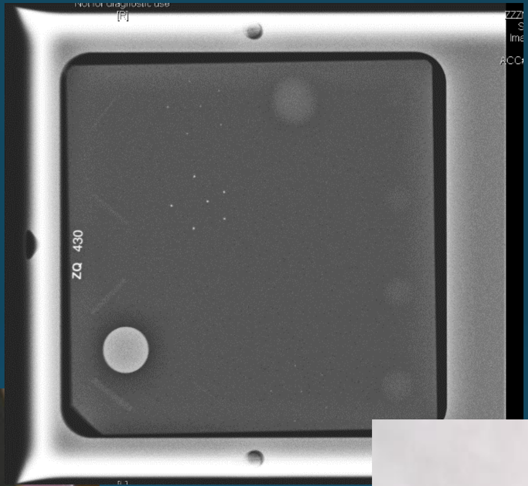
Quality assurance for bCT

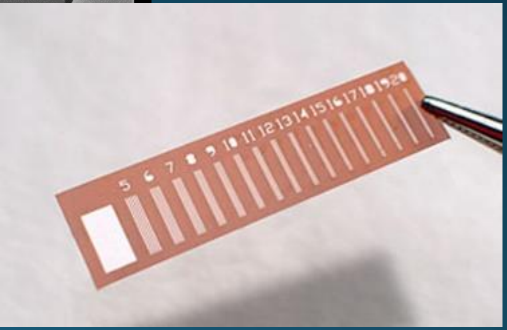
Summary



Quality assurance for bCT







A combination of CT and Mammo?

Quality assurance for bCT

Mammo Style

- Mechanical stability and safety
- kV accuracy, filtration and tube output linearity
- Focal spot size
- Collimation and field coverage
- Detector uniformity and lag

CT Style

- Geometrical calibration (spatial accuracy)
- Image quality – MTF and NPS
- HU accuracy
- Cone beam artifact
- Chest wall coverage

One consolidated phantom?

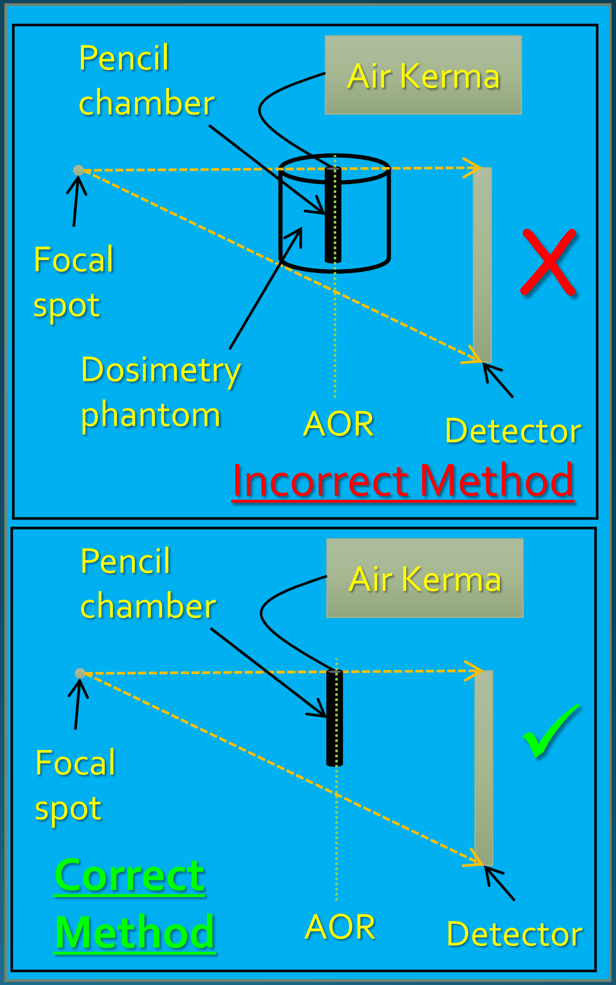
CT + Mammo

- Radiation dose
- Image quality – μCalcs, mass

ACR phantom?

BCT QA – Radiation Dose

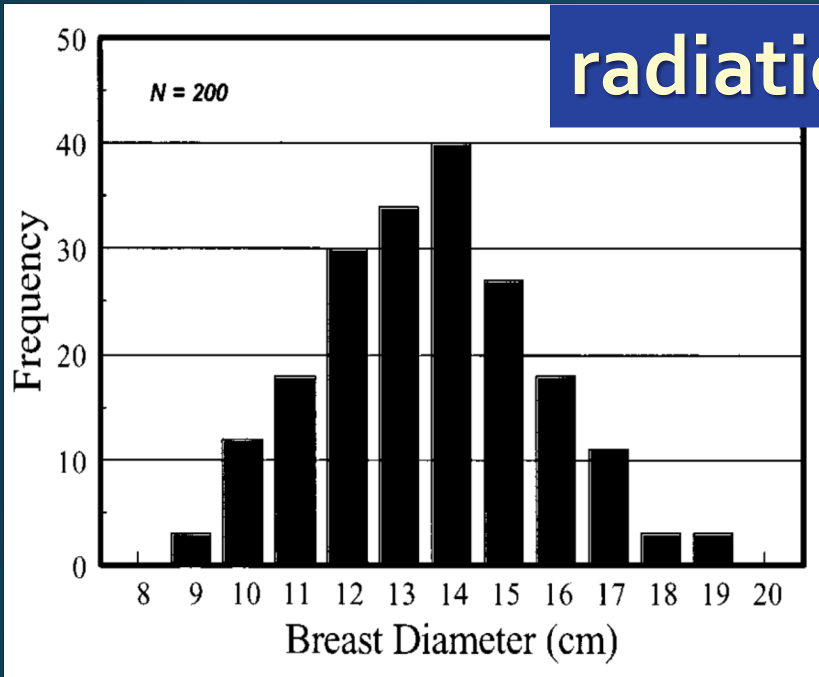
- Metric: Average Glandular Dose (AGD)
- Measure of radiation dose to "at-risk" glandular tissue
- Facilitates direct comparison with mammography
- Method:
  - Measure air kerma (mGy) at axis of rotation (AOR) without object (e.g., dosimetry phantom) over entire scan
  - Multiply by Monte Carlo-derived conversion factor (D_gN^{CT}) in units of (mGy/mGy)



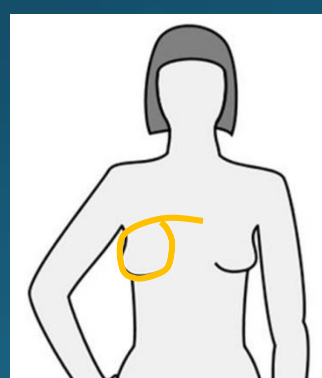
Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass

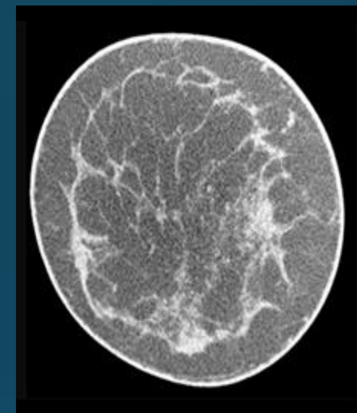
BCT QA – Radiation Dose

radiation dose is size dependent!



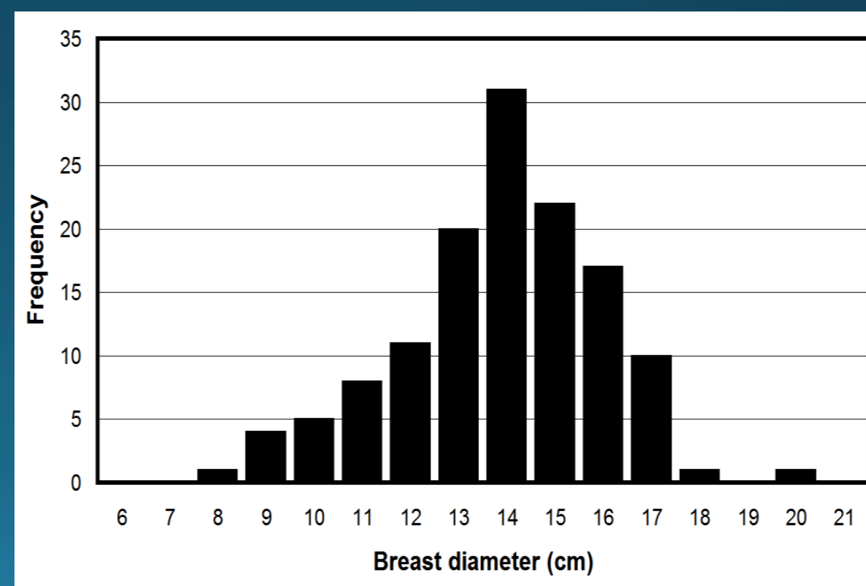
2001 tape measure results (N = 200)





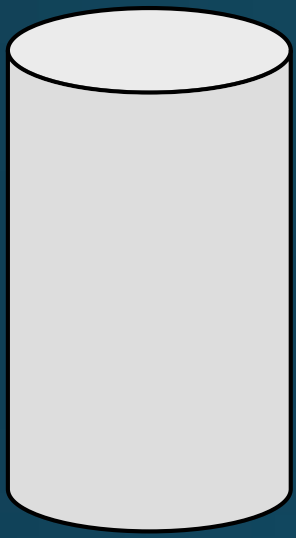
X = 13.4 cm
σ= 2.0 cm
Median = 13.6 cm

2008 assessment on bCT images (N = 137)

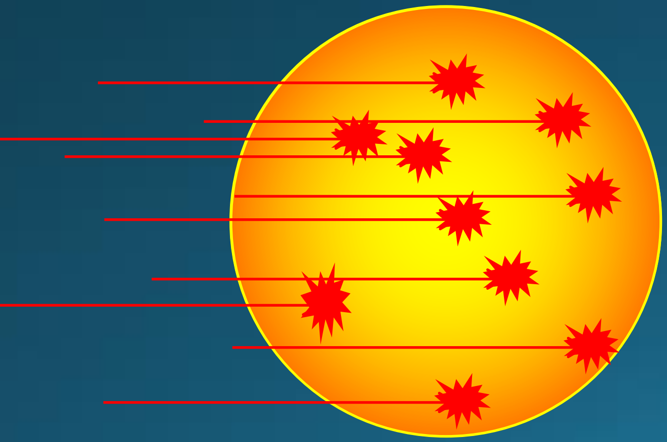


BCT QA – Radiation Dose

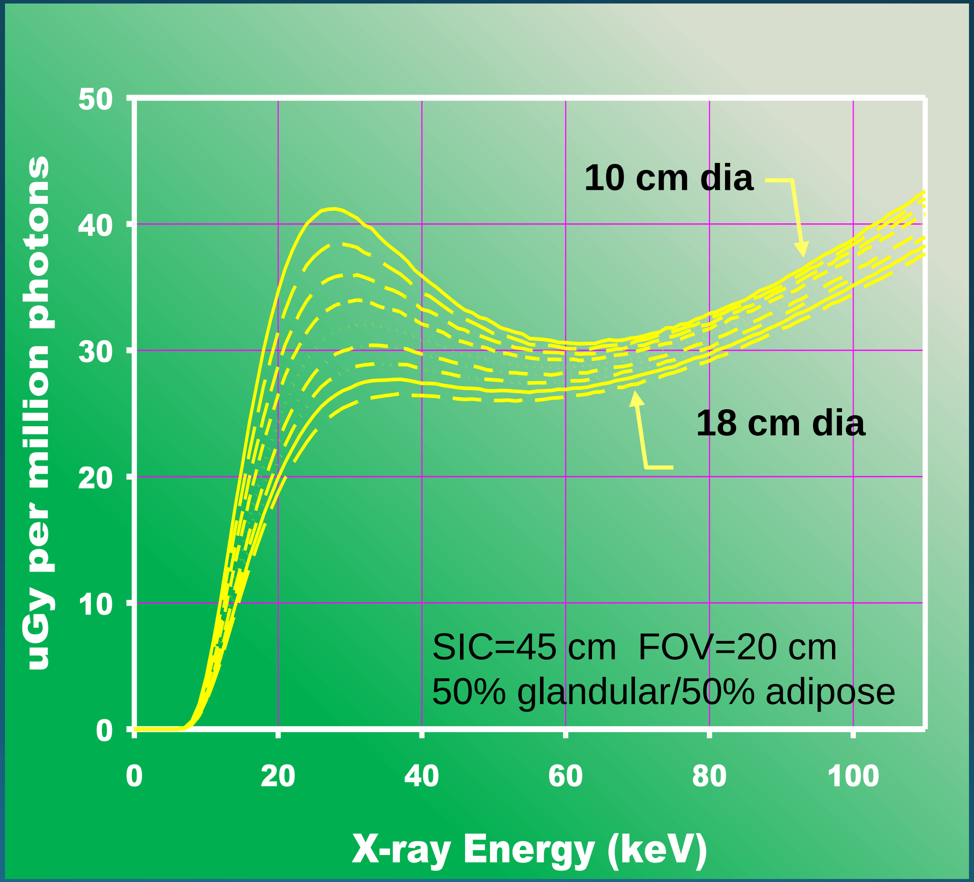
Monte Carlo Assessment of Dose Deposition



breast modeled as a cylinder

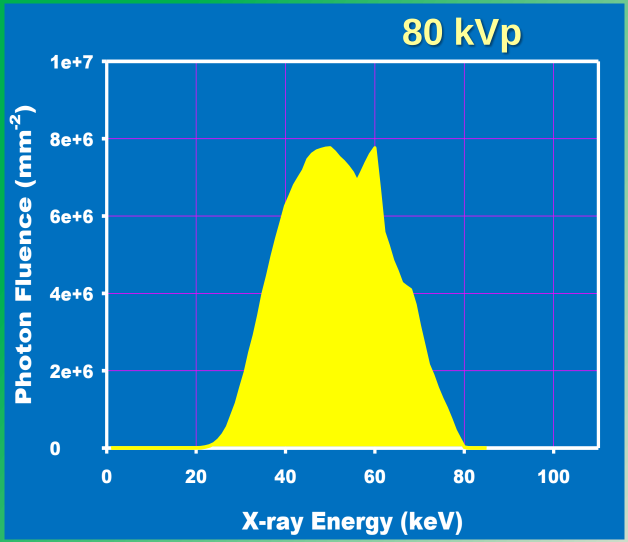


monoenergetic functions



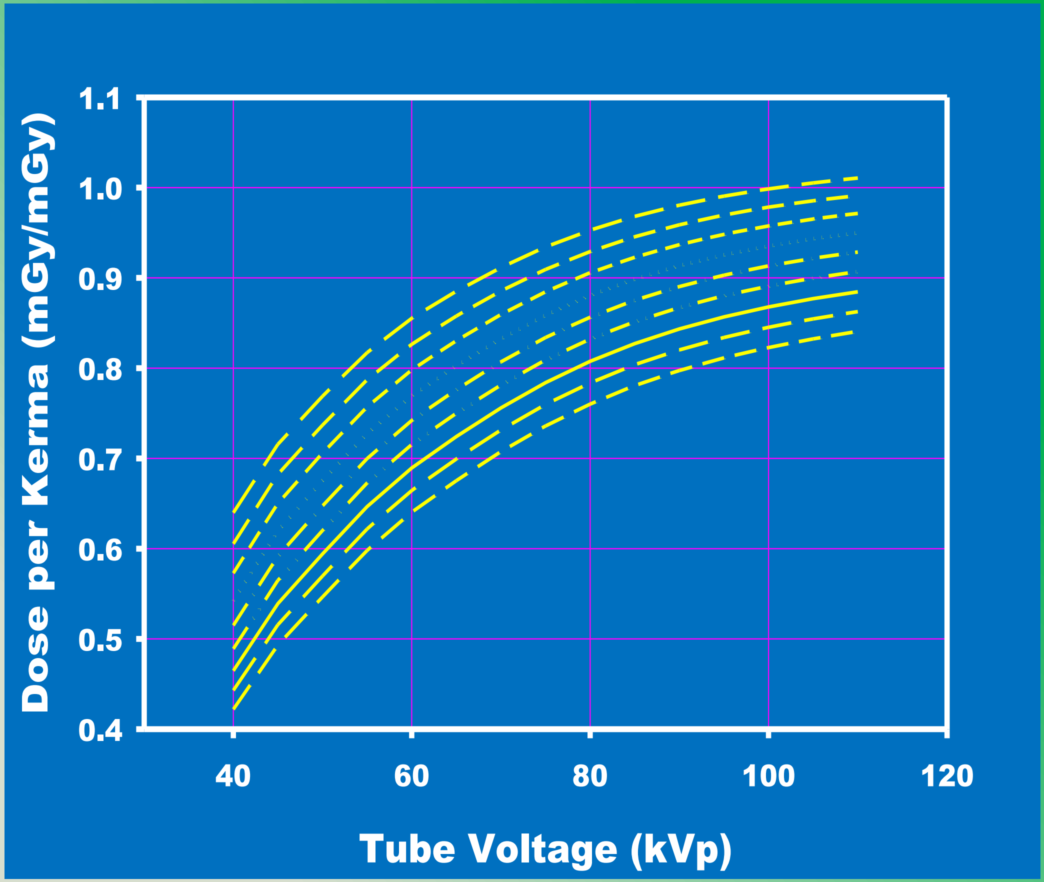
Mean Glandular Dose in Breast CT

spectral model*



*The TASMIP model, JM Boone and JA Seibert, Medical Physics 24;1661-670, 1997.

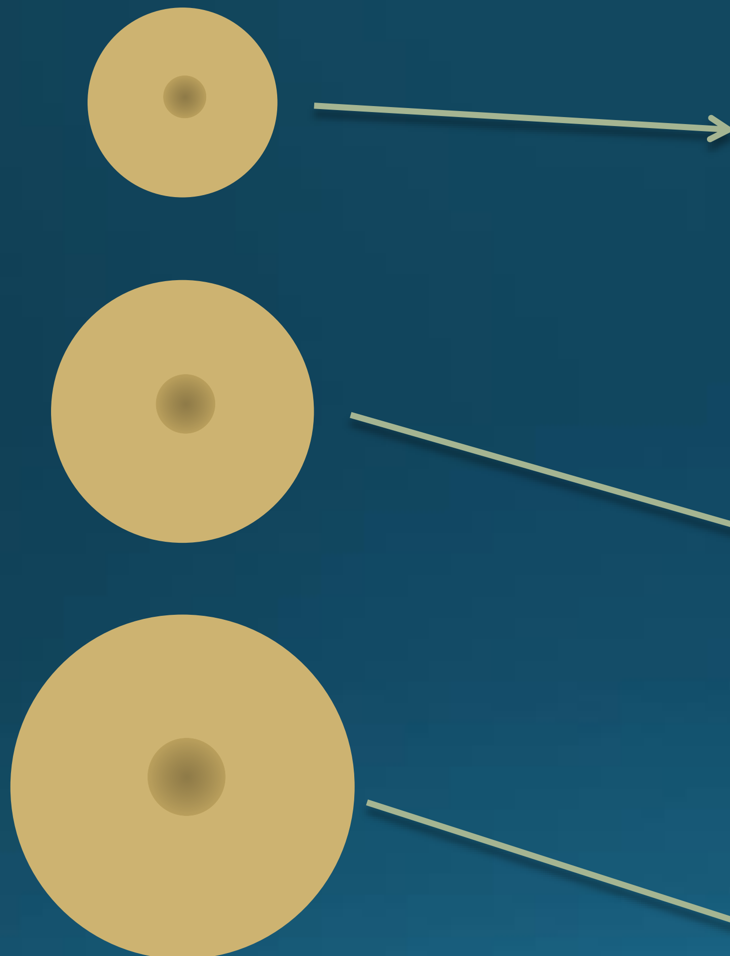
polyenergetic functions



Boone, JM., AIP Conf. Proc. 682, 3(2003)

Thacker, SC & Glick, SJ (2004). PMB, 49(24), 5433.

Breast CT technique chart

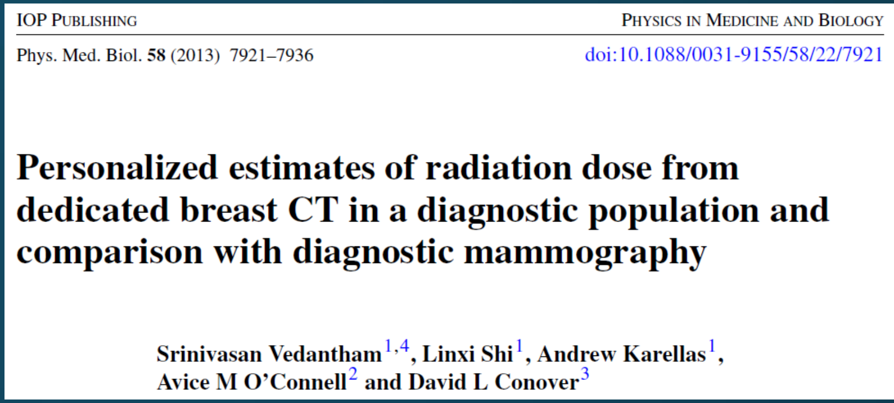


mA setting on Cambria

Breast Diameter (cm)	0% Gland	50% Gland	1.00 Gland
10.0	37	51	72
10.5	48	67	95
11.0	59	82	117
11.5	72	100	143
12.0	87	123	175
12.5	106	150	214
13.0	130	184	263
13.5	157	224	322
14.0	189	271	389
14.5	224	323	465
15.0	262	379	548
15.5	301	437	633
16.0	340	495	719
16.5	377	550	800
17.0	409	598	872
17.5	433	636	929
18.0	447	658	964

*Dose in breast CT is set to be **EQUAL** to the dose of two-view mammography for that women.*

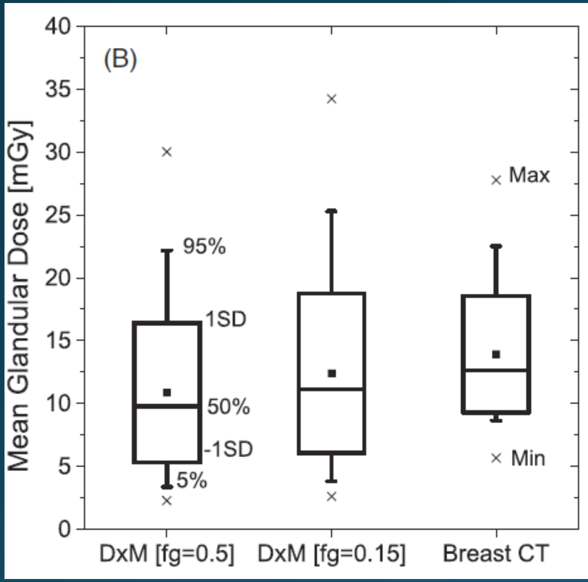
BCT Radiation dose: diagnostic studies


IOP PUBLISHING — PHYSICS IN MEDICINE AND BIOLOGY

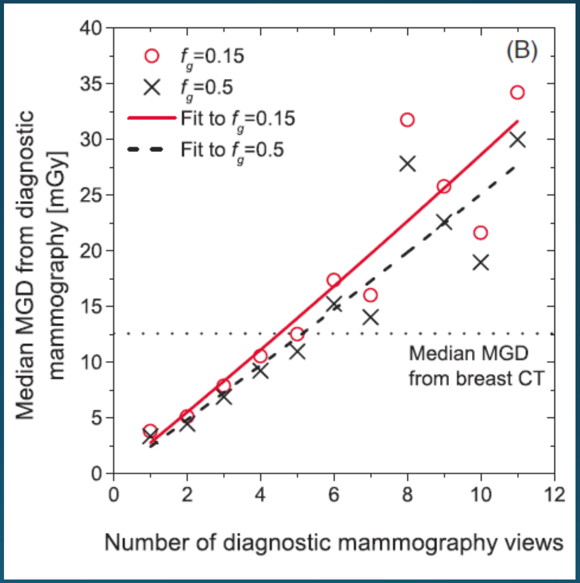
Phys. Med. Biol. 58 (2013) 7921–7936 doi:10.1088/0031-9155/58/22/7921

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

Srinivasan Vedantham[1,4], Linxi Shi[1], Andrew Karellas[1], Avice M O'Connell[2] and David L Conover[3]



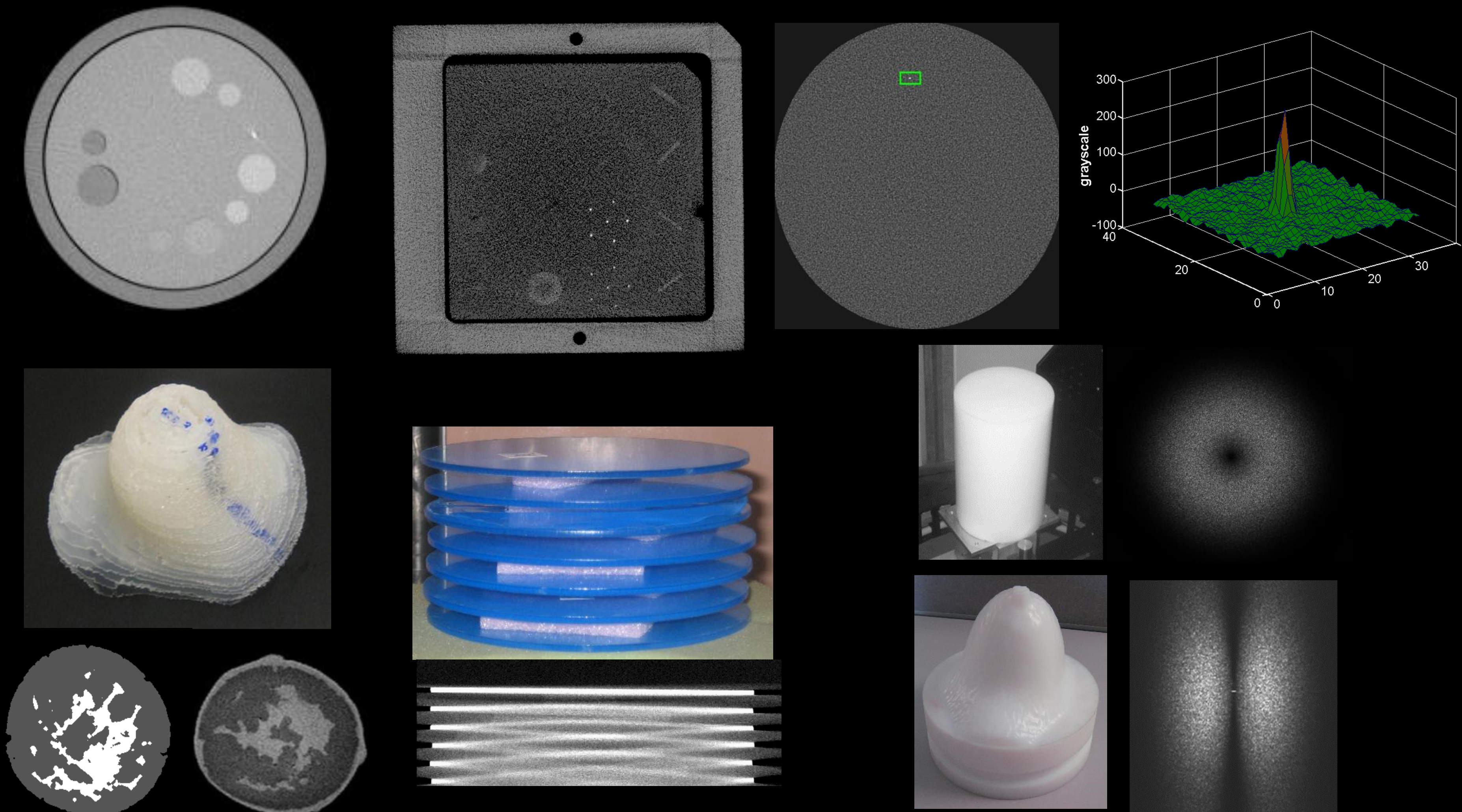
Median of MGD from diagnostic breast CT is similar to diagnostic mammography with smaller range.



Median MGD from diagnostic breast CT is equivalent to 4-5 mammography views. Mean number of diagnostic mammography views in study: 4.53

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass

BCT QA – Image Quality



Prionas, *et al.*, PMB 57 2012: 4293

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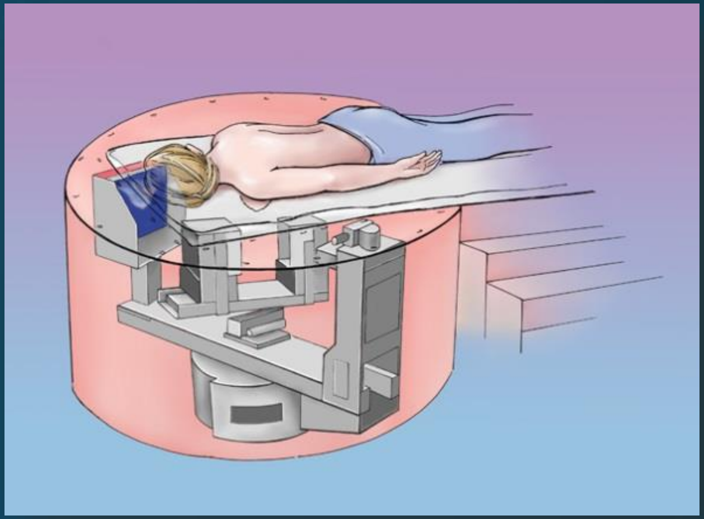

Summary

- BCT can be performed in a dose efficient manner
- BCT almost certainly outperforms mammo for masses
- BCT might be possible for screening / need CALCS
- Needs to solve the challenges:

  Resolution, SNR, Micro-Calcification, HU accuracy, and Chest wall

- BCT QA is a combination of CT and Mammo.

Question #1:

Compared to mammography, current available clinical data showed that dedicated bCT______

20%	1.	takes shorter time for the exam.
20%	2.	requires same amount of compression.
20%	3.	has a better coverage of the chest wall.
20%	4.	can detect micro-calcifications better.
20%	5.	can detect mass-lesions better.

10

Question #1:
Compared to mammography, current available clinical data showed that dedicated bCT ______.

1. takes shorter time for the exam.
2. requires same amount of breast compression.
3. has a better coverage of the chest wall.
4. can detect micro-calcifications better.
5. can detect mass-lesions better.

Answer: 5. can detect mass-lesions better.

Reference: K.K. Lindfors, et al. Radiology 246.3 (2008) 725.

Question #2:
From one study mentioned in this talk, which of the following spectrum provides the highest dose-normalized CNR (CNRD) for bCT?

20%	1. 40 kV + 1.5 mm Al
20%	2. 60 kV + 1.5 mm Al
20%	3. 60 kV + 0. 2 mm Cu
20%	4. 60 kV + 0. 2 mm Sn
20%	5. 80 kV + 0.2 mm Cu

10

Question #2:
From one study mentioned in this talk, which of the following spectrum provides the highest dose-normalized CNR (CNRD) for bCT?

1. 40 kV + 1.5 mm Al
2. 60 kV + 1.5 mm Al
3. 60 kV + 0. 2 mm Cu
4. 60 kV + 0. 2 mm Sn
5. 80 kV + 0.2 mm Cu

Answer: 3. 60 kV + 0.2 mm Cu

Reference: N.D. Prionas, et al, Med. Phys. 38, 646 (2011)

Question #3:
As described in this talk, the radiation dose to the breast from a dedicated bCT scan is _____.

20% 1. not related to the detection of micro-calcs.
20% 2. independent to the size & density of the breast.
20% 3. determined by the CTDI with a phantom.
20% 4. proportional to the air kerma at isocenter.
20% 5. unable to match mammographic procedures.

10

Question #3:
As described in this talk, the radiation dose to the breast from a dedicated bCT scan is ______.

1. not related to the detection of micro-calcs.
2. independent to the size & density of the breast.
3. determined by the CTDI with a phantom.
4. proportional to the air kerma at isocenter.
5. unable to match mammographic procedures.

Answer: 4. proportional to the air kerma at isocenter.

Reference: Boone, J. M. et al Med. Phys. 32, 3767 (2005)

Acknowledgement

This work was supported by grants from the California Breast Cancer Research Program (Grant Nos. 7EB-0075 and 11 IB-0114), the National Cancer Institute (Grant No. CA-89260), the National Institute for Biomedical Imaging and Bioengineering (Grant No. EB002138-03), and the Susan G. Komen Foundation.

The Breast Tomography Project

University of California, Davis

UCDAVIS

University of California, Davis

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