Low-Dose Cone-Beam Breast CT:
Physics and Technology Development

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OTHER CONFLICTS
Patents Pending on various breast CT concepts

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Low-Dose Cone-Beam Breast CT: Physics and Technology Development

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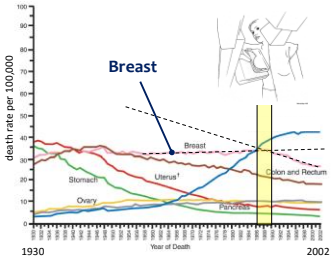
Cancer Mortality and Screening



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

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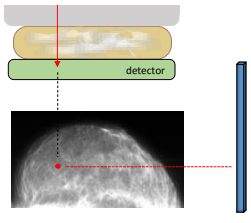
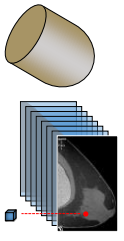
Mammography



0.50 mm^3

54 X

Dedicated Breast CT



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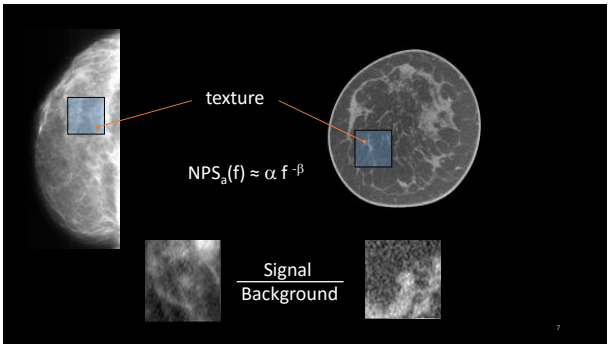
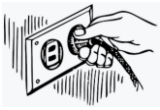


Low-Dose Cone-Beam Breast CT: Physics and Technology Development

Design, Fabrication and Integration





Images from PIXABAY.com (*royalty free images*)

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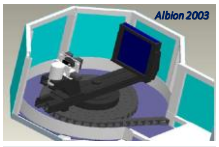
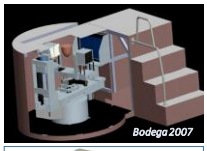
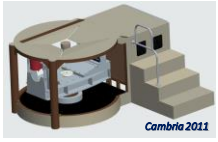
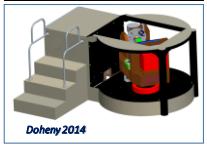
Computer aided design / computer aided manufacture (CAD/CAM)









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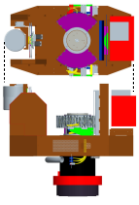
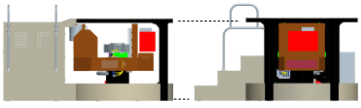
Doheny: Design

Gantry Views

George Burkett

System views

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Components

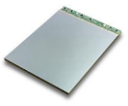
Motor / bearing / encoder

Kollmorgen

Yaskawa

Detectors

Varian TFT



Dexela CMOS

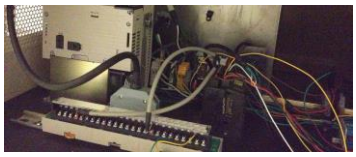
X-ray tubes

Comet X-ray

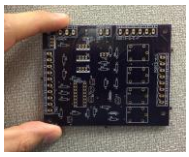
Varian 1501 X-ray

Doheny: Fabrication

Wiring



before



after

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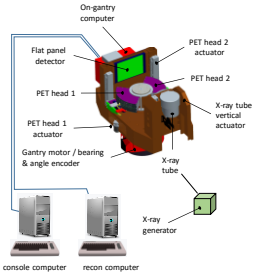
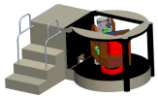
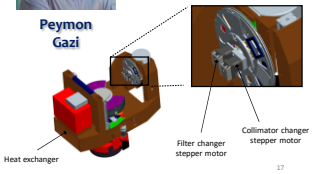
Software: Hardware Integration



Peymon Gazi





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Breast Immobilization & Beam Equalization

Andrew Hernandez

Six phantoms (V1-V6)

1st 2nd 3rd 4th 5th Largest 5 breasts

N = 219 : ~ 5 sets of 43

Mean volume and shape in each quintile

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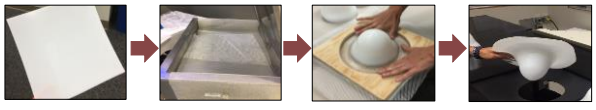
- Physical Dosimetry
- Image Quality Assessment
- Mold for breast immobilization



Aquaplast® thermoplastic | hot water bath | molding | breast immobilizer

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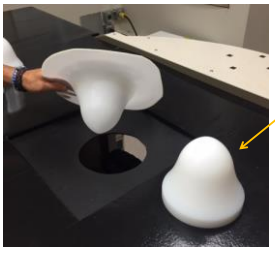
Breast Containment and Alignment



Breast Alignment System

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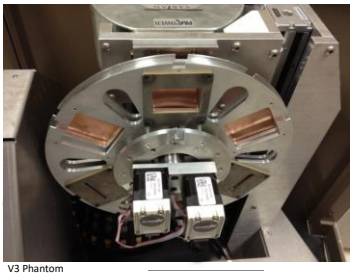
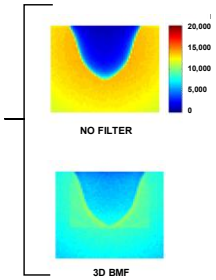
Beam Shaping Filter



V3 Phantom



Acquisition Details

- 500 views are acquired
- 16.6 seconds @ 30 FPS, or 10 seconds @ 50 FPS
- 2 x 2 binning of detector elements
  - Varian TFT Panel: 1024 x 768 (388 μm) at 30 FPS
  - Dexela CMOS Panel: 1933 x 1533 (150 μm) at 50 FPS
- FBP Recon to 512^3 or 1024^2 x 512

Performance Metrics

Spatial Resolution

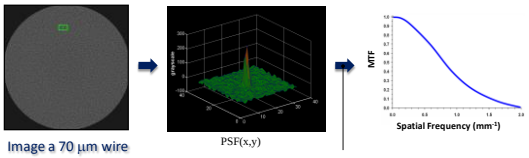


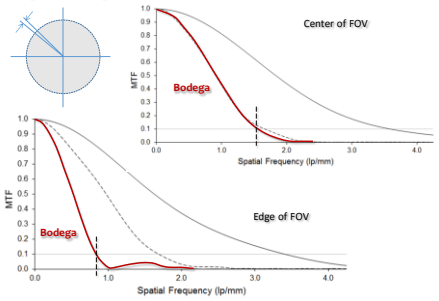
Image a 70 μm wire

PSF(x,y)

$$LSF(x) = \int PSF(x,y)dy$$

$$MTF(f) = \int dx\, LSF(x)\, e^{-2\pi ifx}$$

Engineering impacts resolution



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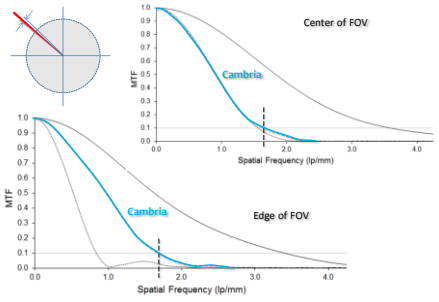
Engineering impacts resolution

pulsed acquisition (4 ms)



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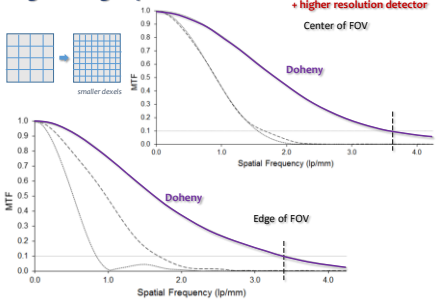
Engineering impacts resolution

pulsed acquisition (4 ms)
+ higher resolution detector



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Performance Metrics

Contrast Resolution

total noise (variance) — anatomical noise — quantum noise

$$NPS(f) = NPS_a(f) + NPS_q(f)$$

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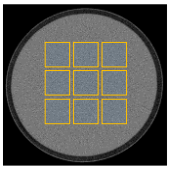
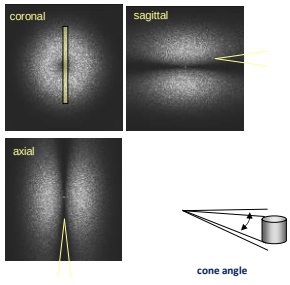
Contrast Resolution: NPS measurements

$$NPS(u,v) = \frac{|F(u,v)|^2}{N_X N_Y} \Delta_X \Delta_Y$$





cone angle

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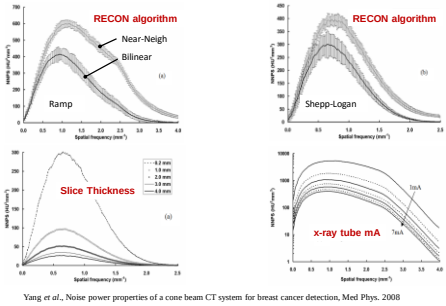
Noise Power Spectrum (NPS) measurements (Bodega)



Yang *et al*., Noise power properties of a cone beam CT system for breast cancer detection, Med Phys. 2008

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Low-Dose Cone-Beam Breast CT: Physics and Technology Development

Clinical Trials

- Over 600 women on UC Davis scanners
- women with suspicion of breast cancer (BIRADS 4 & 5)
- Informed consent / HIPAA compliant
- 10 - 16 second scan (breath hold)
- >200 have had contrast injection

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Low-Dose Cone-Beam Breast CT: Physics and Technology Development

Breast CT Clinical Trials

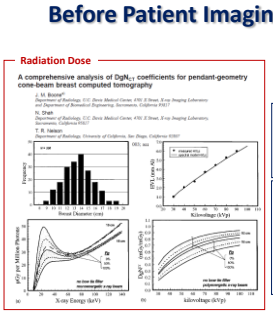
- **Images**

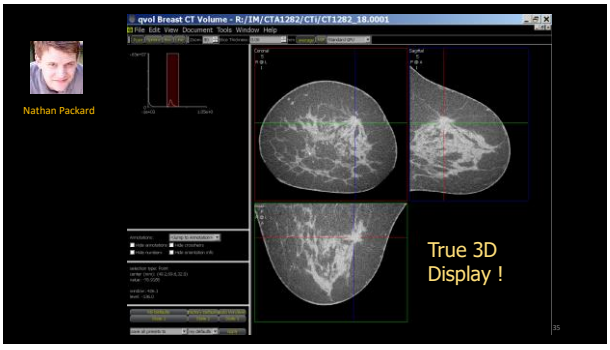
Anatomical Noise

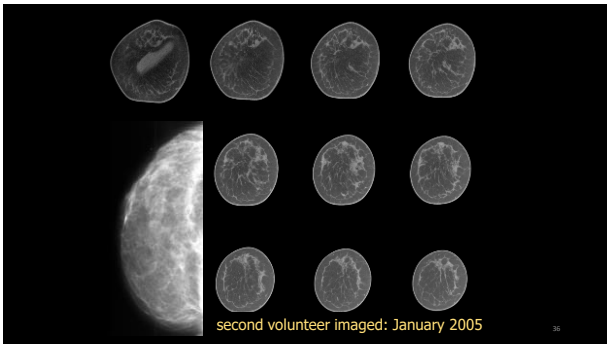
Computer Observer Performance

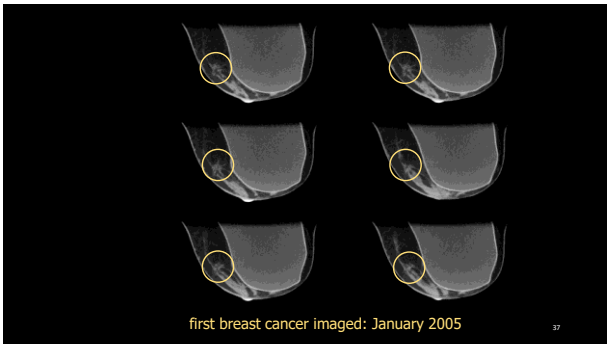
Human Observer Performance

Before Patient Imaging








first breast cancer imaged: January 2005
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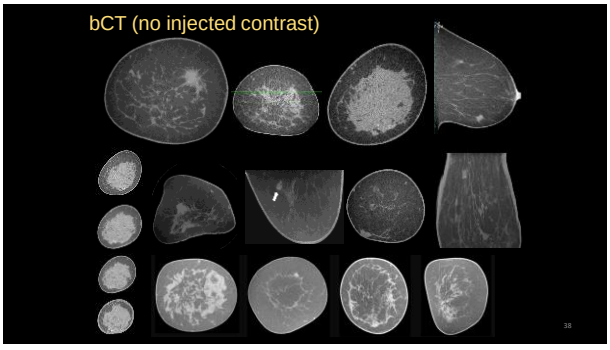
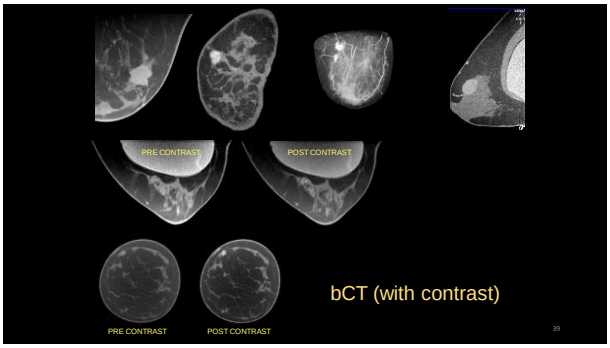

bCT (no injected contrast)
38


PRE CONTRAST
POST CONTRAST
bCT (with contrast)
PRE CONTRAST
POST CONTRAST
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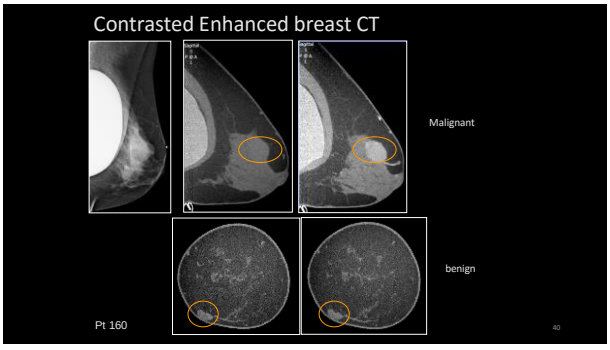

Low-Dose Cone-Beam Breast CT: Physics and Technology Development

- **Breast CT Clinical Trials**
  - **Images**
  - **Anatomical Noise**
  - **Computer Observer Performance**
  - **Human Observer Performance**

Anatomical Noise

Burgess, et al (2001)

$NPS_a(f) = \alpha f^{-\beta}$

total noise — anatomical noise — quantum noise

$NPS(f) = NPS_o(f) + NPS_q(f)$

[1] A. E. Burgess, F. L. Jacobson, and P. F. Judy, "Human observer detection experiments with mammograms and power-law noise," Med. Phys. **28**, 419–437 (2001).

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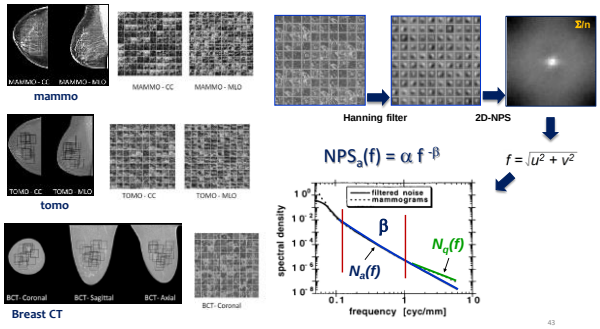

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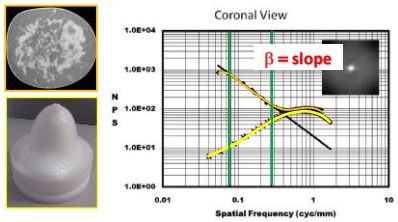
$NPS(f) = NPS_a(f) + NPS_q(f)$



$NPS_a(f) = \alpha f^{-\beta}$

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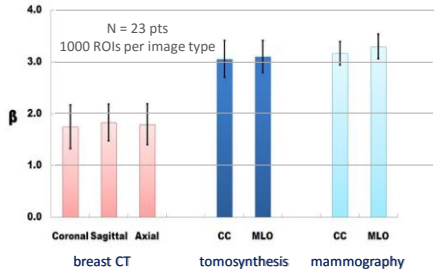
Breast CT, Tomosynthesis, and Mammography Texture Comparisons



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Low-Dose Cone-Beam Breast CT: Physics and Technology Development

- Breast CT Clinical Trials
  - Images
  - Anatomical Noise
  - **Computer Observer Performance**
  - Human Observer Performance

Computer (PWMF) Observer Performance

Effect of slice thickness on detectability in breast CT using a prewhitened matched filter and simulated mass lesions

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Craig K. Abbey
Department of Psychology, University of California, Santa Barbara, California 93106
Kai Yang
Department of Radiology, University of California Davis Medical Center, Sacramento, California 95817
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Department of Radiology, University of California Davis Medical Center, Sacramento, California 95817 and Department of Biomedical Engineering, University of California, Davis, California 95616

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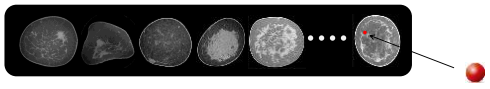
Signal Known Exactly (SKE)

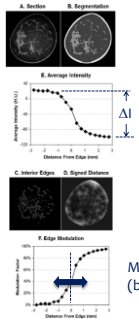
Evaluated versus slice thickness (from 0.4 mm to 44 mm)

bCT "mammo"



Real breast CT data sets (N=151)

Simulated Spherical Lesions
from 1 mm to 15 in diameter

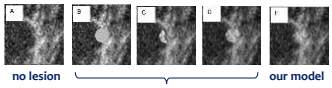


Simulated lesion insertion into real breast CT data sets with different slice thickness

$$f_{sim}[i,j,k] = f[i,j,k] + \Delta I\, M_{TB}(d[i,j,k])\, M([D/2] - d_{EC}[i,j,k])$$

Lesion Intensity

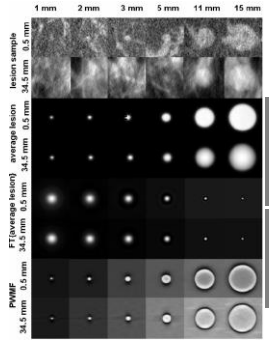
adaptive lesion insertion model



no lesion **our model**

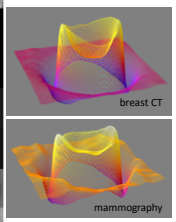
other lesion insertion models

Modulation (blurring)



Pre-whitened Matched Filter

$$PWMF = FT^{-1}\left\{\frac{FT\{\overline{S}(x,y)\}}{\overline{PS}(f_x,f_y)}\right\}$$



S(x,y): 1000 samples

PS(x,y): 1000 samples

For 9 slice thicknesses

From 0.3 to 44 mm

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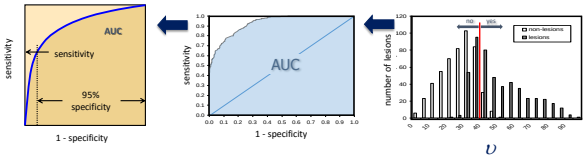
For each bCT data set:

1000 true lesions &

1000 non-lesions

$$\sum_{\text{over all pixels}} \{ \text{SKE lesion} \times \text{PWMF template applied} \} = \upsilon$$



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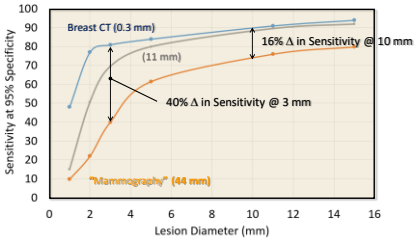
Computer (PWMF) Observer Performance



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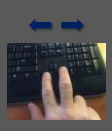
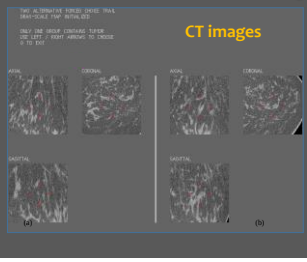
Low-Dose Cone-Beam Breast CT: Physics and Technology Development

- Breast CT Clinical Trials
  - Images
  - Anatomical Noise
  - Computer Observer Performance
  - Human Observer Performance

Human Observer Performance

2-Alternative Forced Choice Design





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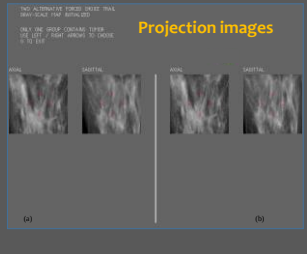
Human Observer Performance

2-Alternative Forced Choice Design



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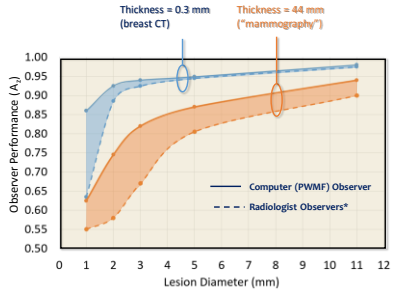

*average of 3 fellowship-trained (in breast imaging) radiologists

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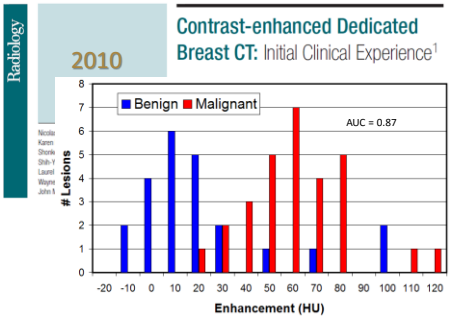
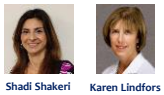
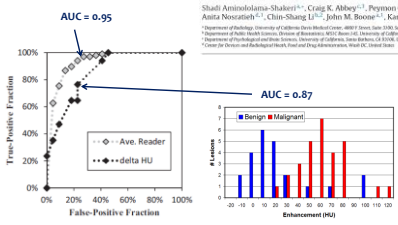



Shadi Shakeri

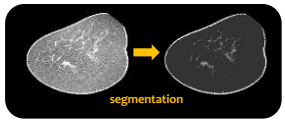
Karen Lindfors

Differentiation of ductal carcinoma in-situ from benign micro-calcifications by dedicated breast computed tomography



Low-Dose Cone-Beam Breast CT: Physics and Technology Development

Breast Density (amplitude)



The myth of the 50-50 breast

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O. Alonzo-Proulx
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C. L. Peressotti
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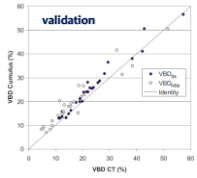
(Received 30 April 2009; revised 23 September 2009; accepted for publication 29 September 2009; published 5 November 2009)



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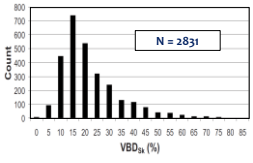
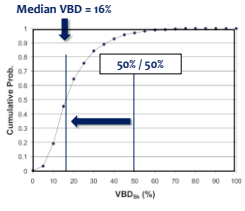
Breast Density (amplitude)





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Breast Density (distribution)

The characterization of breast anatomical metrics using dedicated breast CT

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(Received 17 September 2010; revised 23 February 2011; accepted for publication 24 February 2011; published 28 March 2011)

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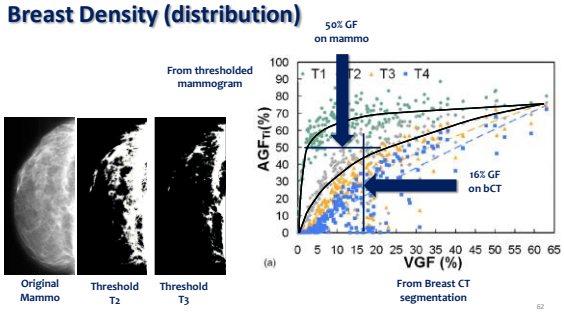
Breast Density (distribution)



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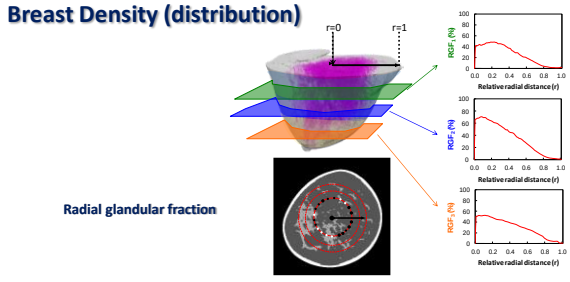
Breast Density (distribution)



Huang S.-Y., Boone J.M. *et al.* "The characterization of breast anatomical metrics using dedicated breast CT" *Med Phys.* 38 (4), 2011

Breast Volume and Shape

Protocol Optimization
- **Molds for Breast Immobilization**
- **Physical Dosimetry (polyethylene ~ adipose)**
- **Image Quality Assessment**

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Low-Dose Cone-Beam Breast CT: Physics and Technology Development

Summary:

- Breast CT has superior mass detection than mammography, based upon texture analysis, computer and human observer studies
- CE breast CT highlights malignant calcifications and is likely equivalent to CE-breast MRI
- Breast CT is FDA approved for diagnostic breast imaging, need to push the technology to achieve superior screening performance
- Breast CT is an emerging technology which will have an important role in reducing breast cancer mortality in the near future.

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Breast Tomography Project
University of California Davis