(Un)certainties in Radiation Dosimetry in Breast Imaging

Ioannis Sechopoulos, Ph.D., DABR
Associate Professor
Advanced X-ray Tomographic Imaging Lab
Department of Radiology and Nuclear Medicine
Radboud University Medical Center and
LRCB – Dutch Reference Centre for Screening
Nijmegen, the Netherlands

advanced x-ray tomographic imaging

LRCB dutch reference centre for screening

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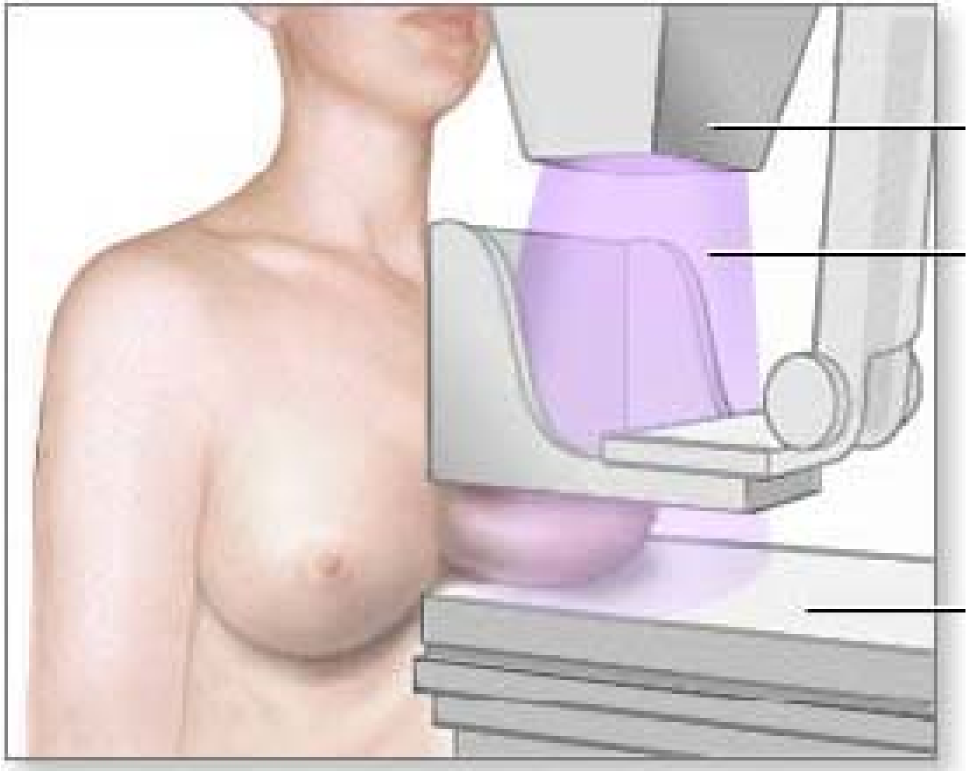
How much radiation dose does a patient get during a mammogram?

...and...

What does that mean?

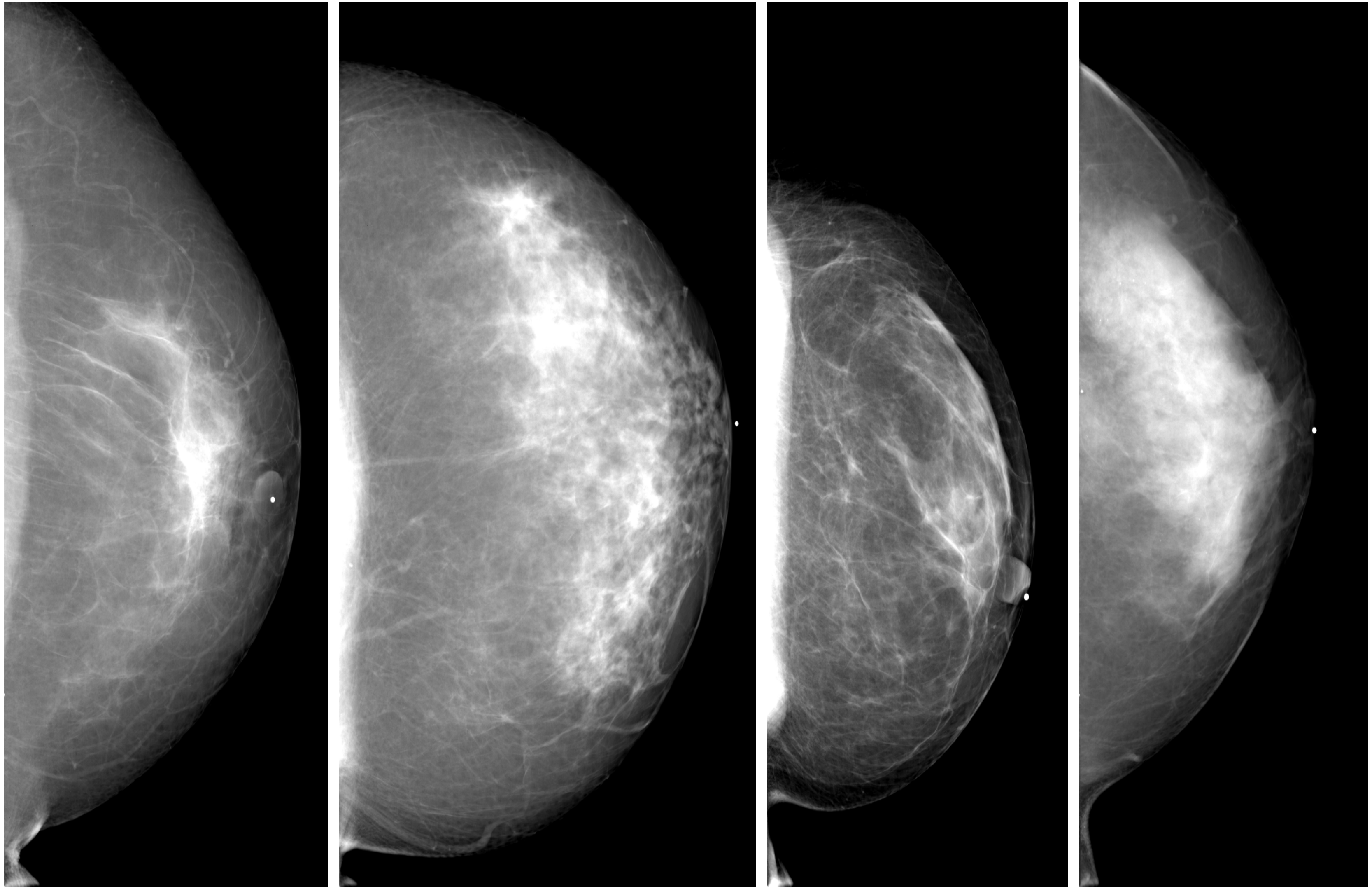
Mammogram Acquisition

Cranio-caudal (CC) View

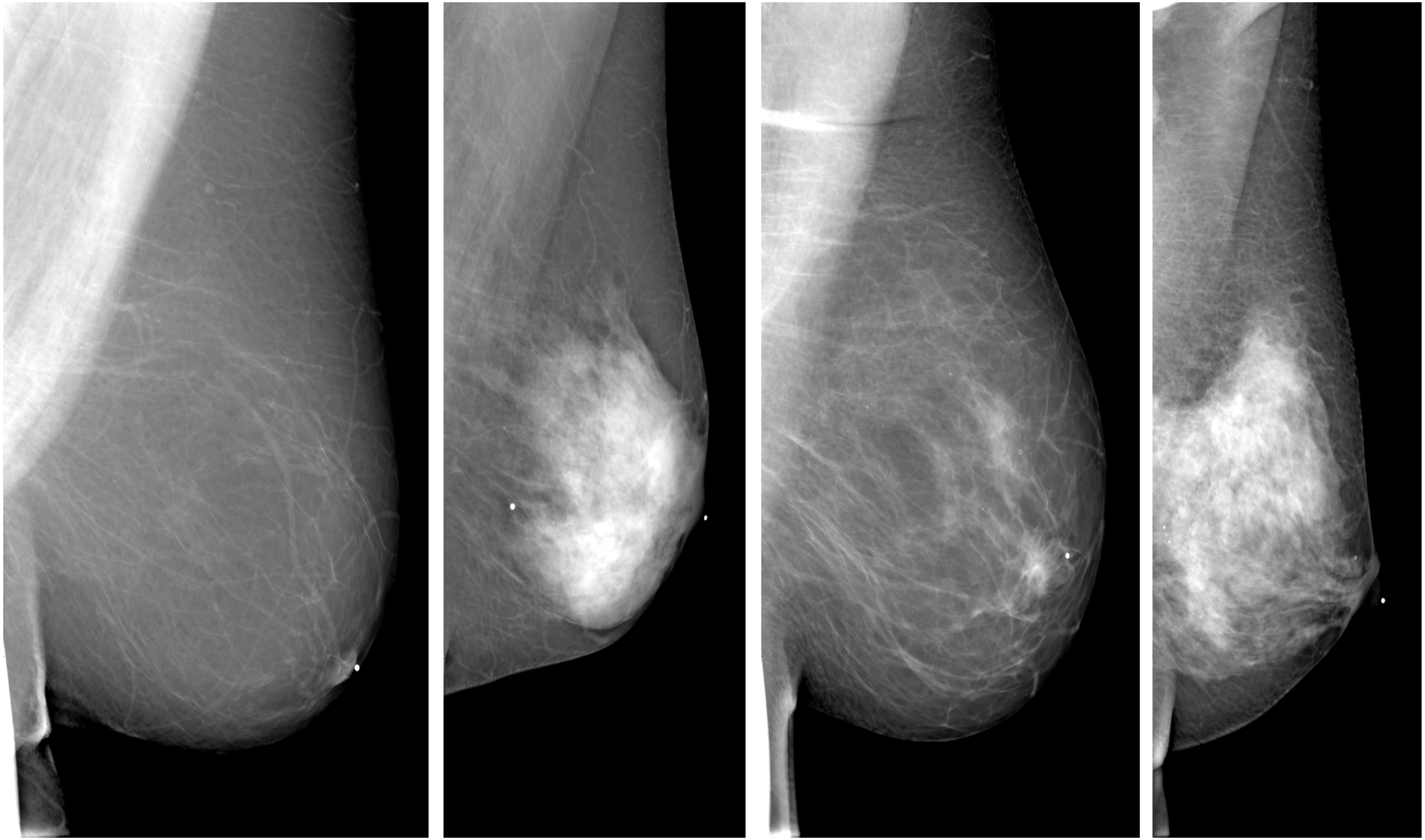


Medio-lateral oblique (MLO) View

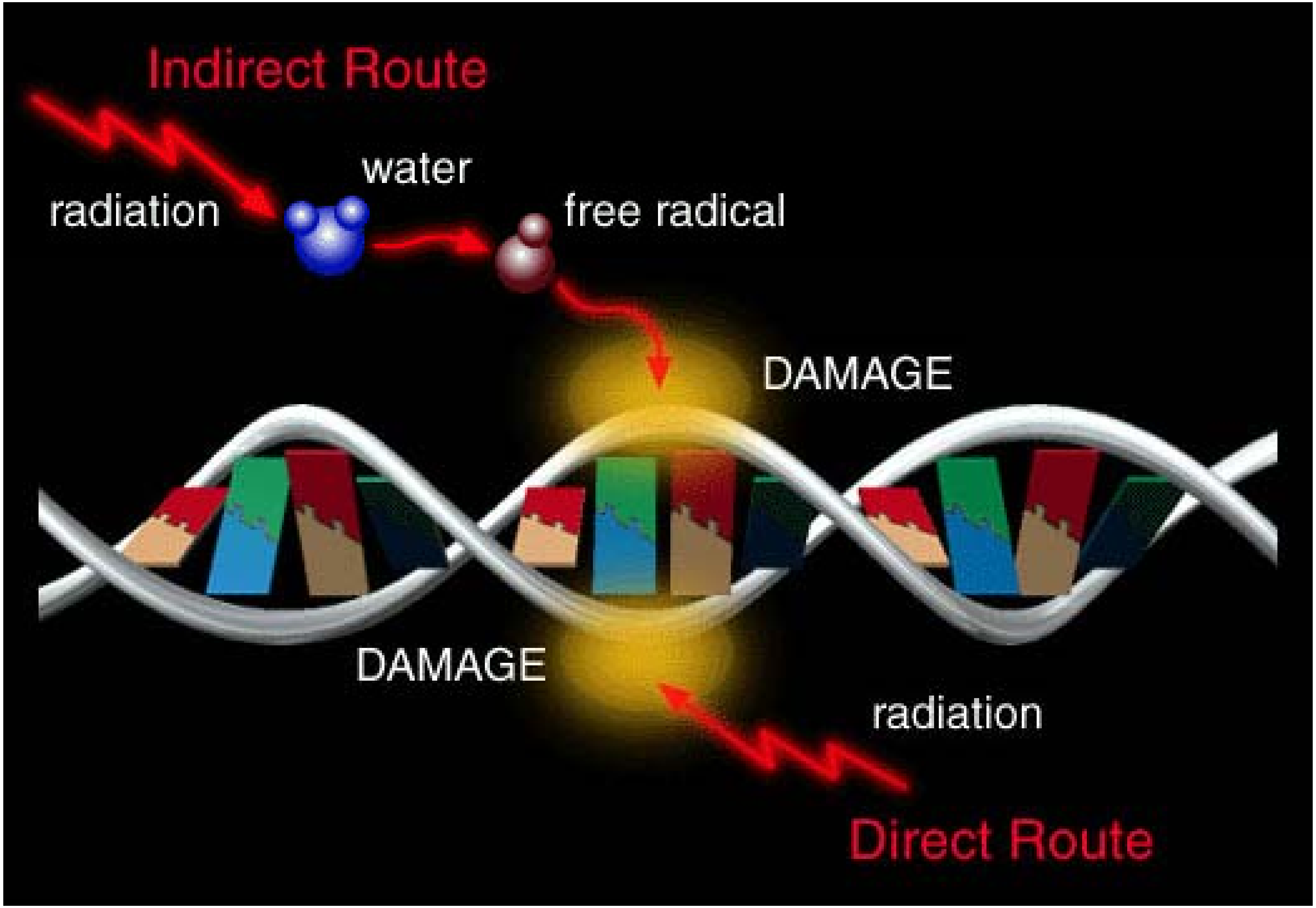
CC View Mammograms

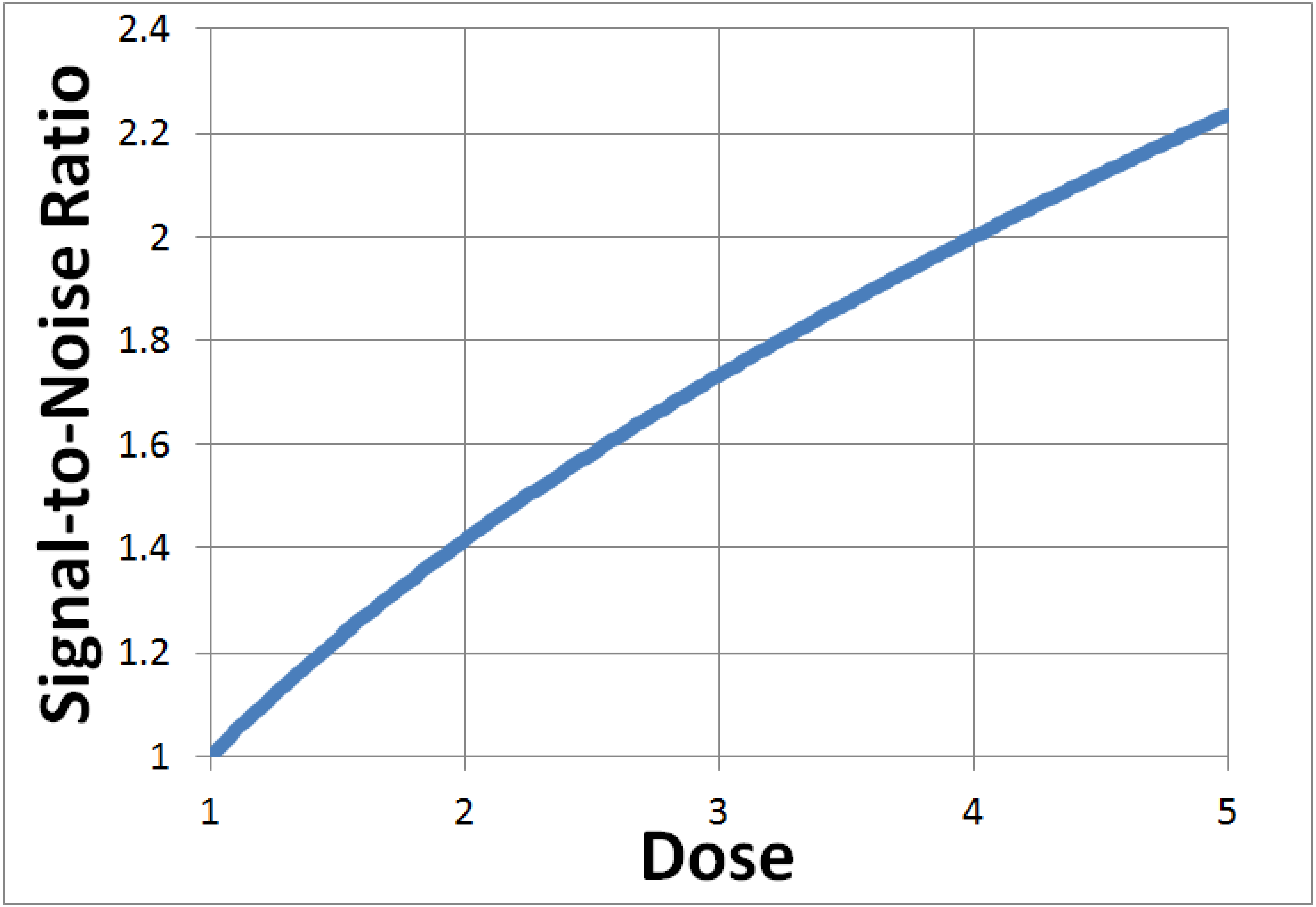


MLO View Mammograms



INTRODUCTION TO (BREAST) DOSIMETRY

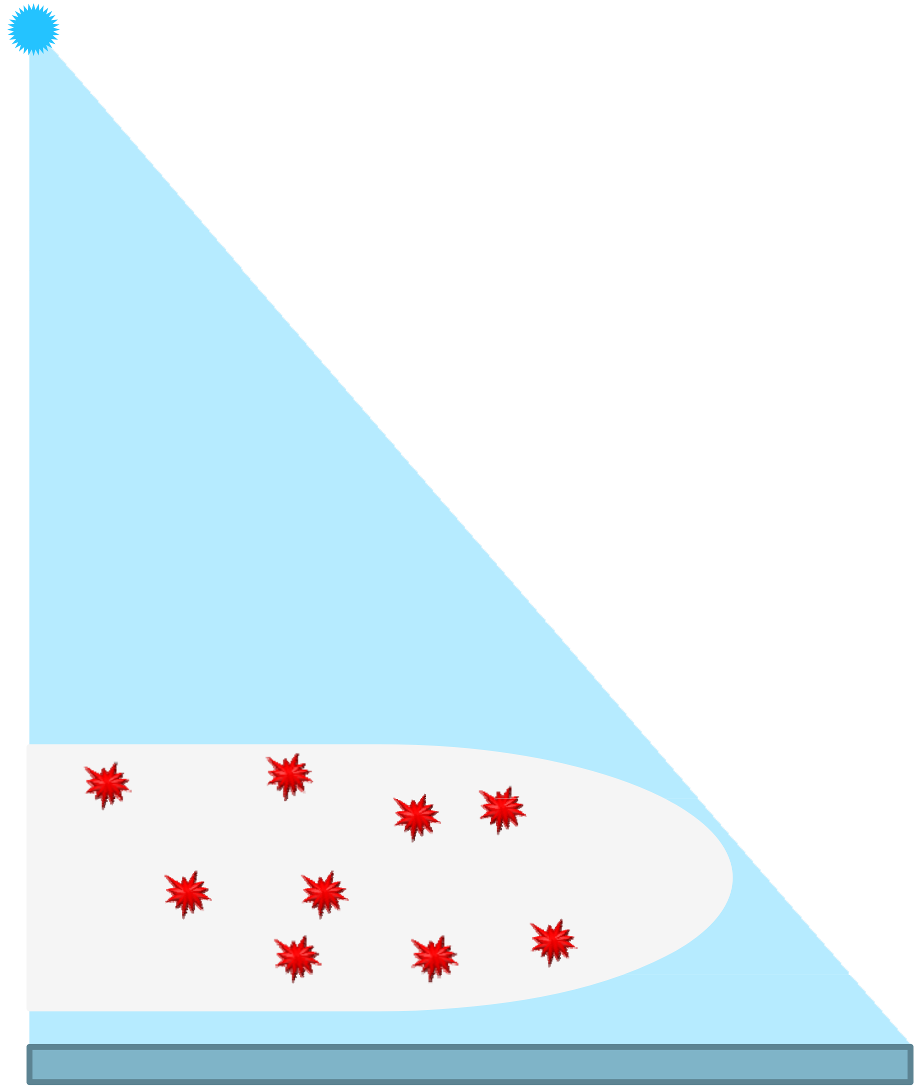

Indirect Route
water
radiation
free radical
DAMAGE
DAMAGE
radiation
Direct Route


Signal-to-Noise Ratio
2.4
2.2
2
1.8
1.6
1.4
1.2
1
1
2
3
4
5
Dose

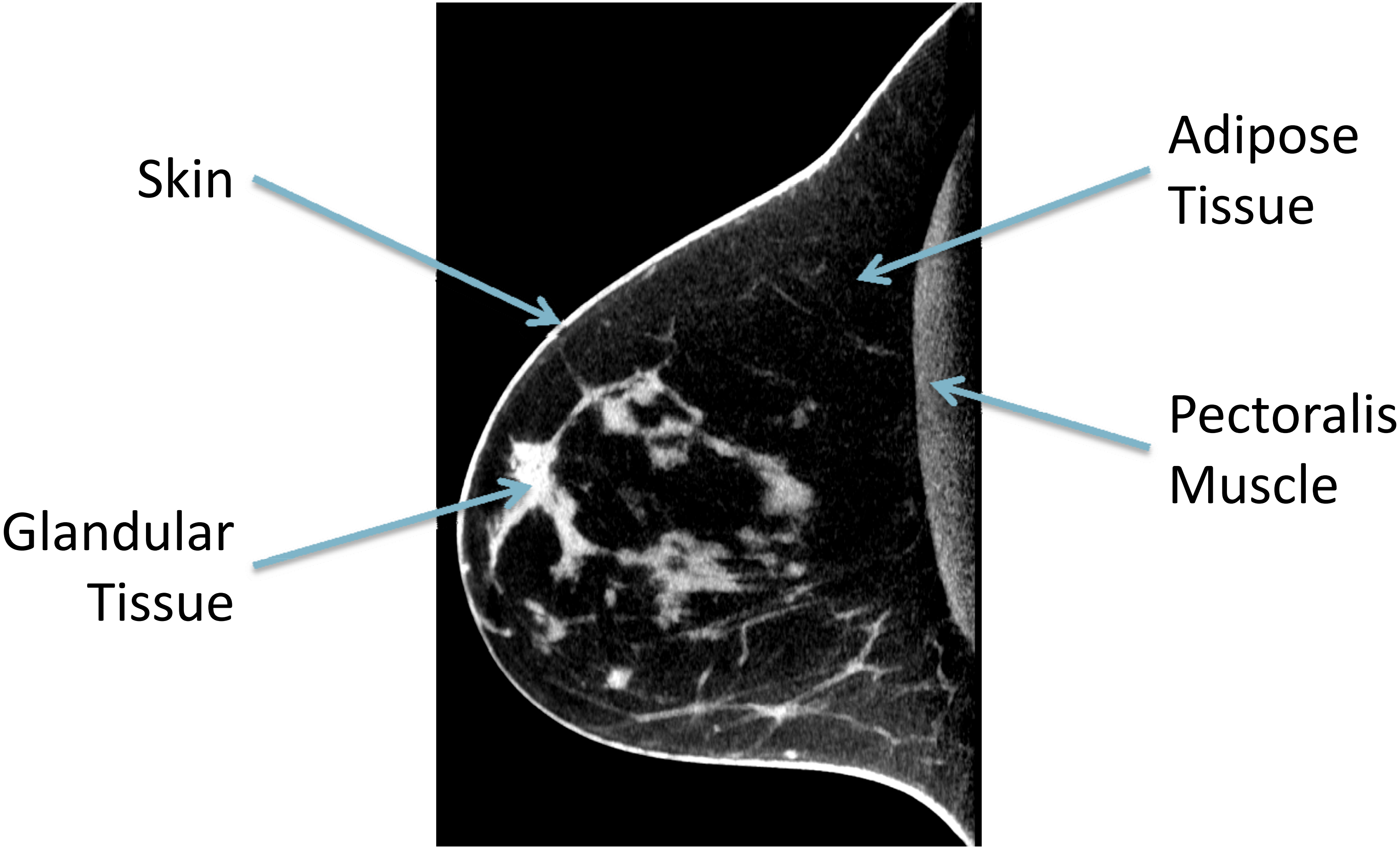

HAPPY
&
HEALTHY

Absorbed Dose

$$\frac{\text{Amount of energy deposited by x-rays in tissue}}{\text{Amount of tissue}}$$

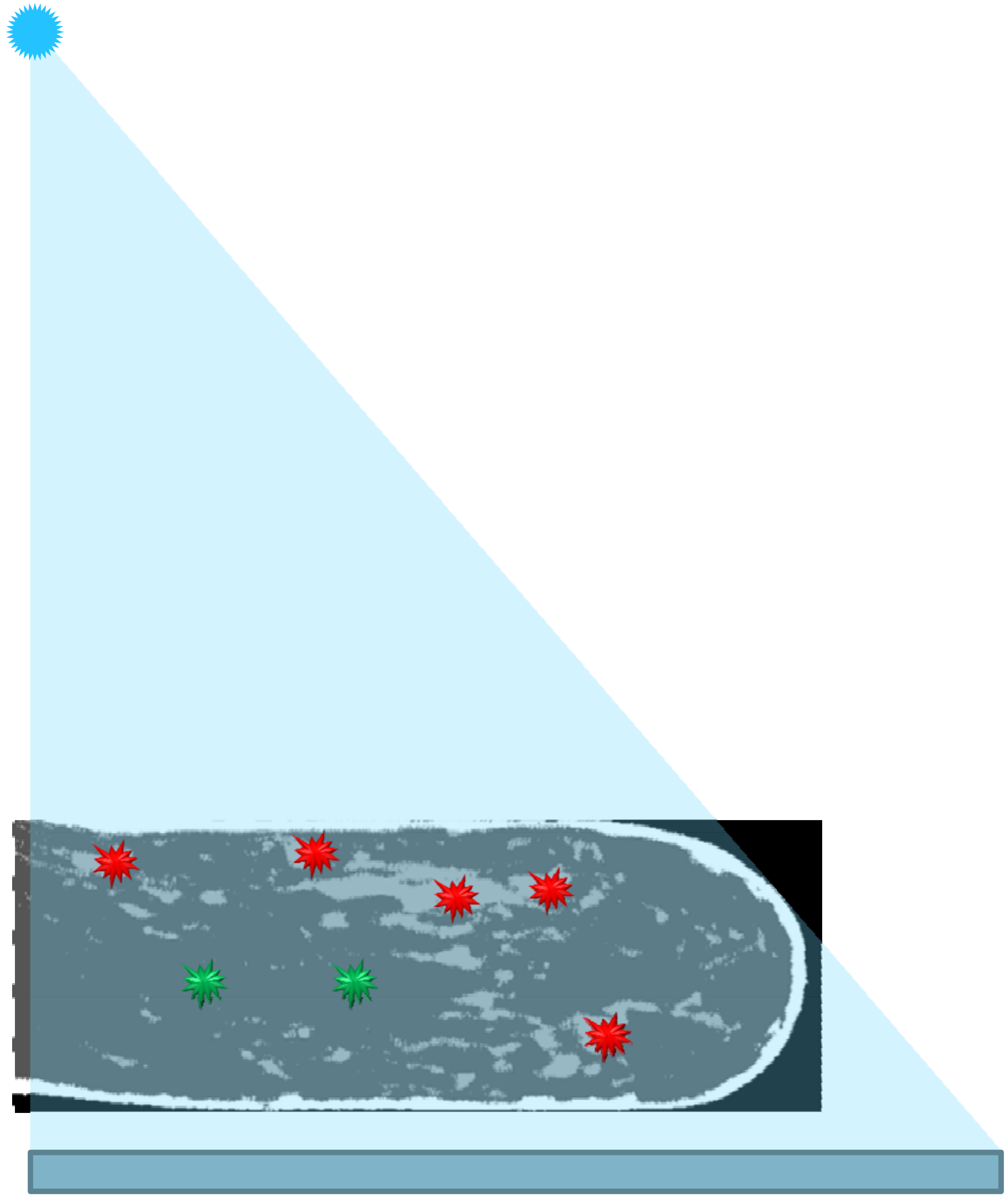


Breast Composition



Average Glandular Dose

$$\frac{\text{Amount of energy deposited by x-rays in glandular tissue}}{\text{Amount of glandular tissue}}$$



What can we measure?

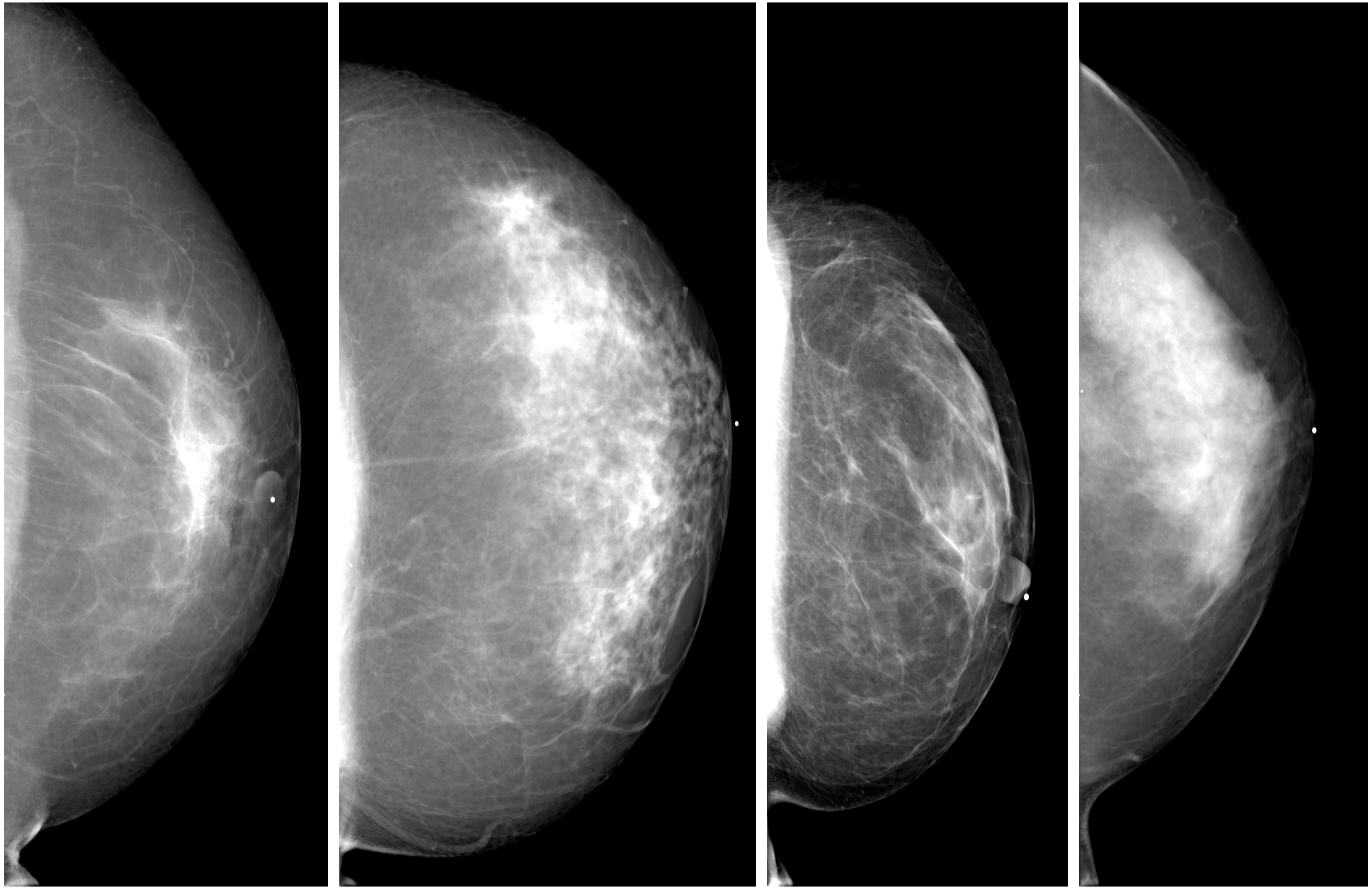
Air Kerma (K) ➔ Dose ?

Average Glandular Dose

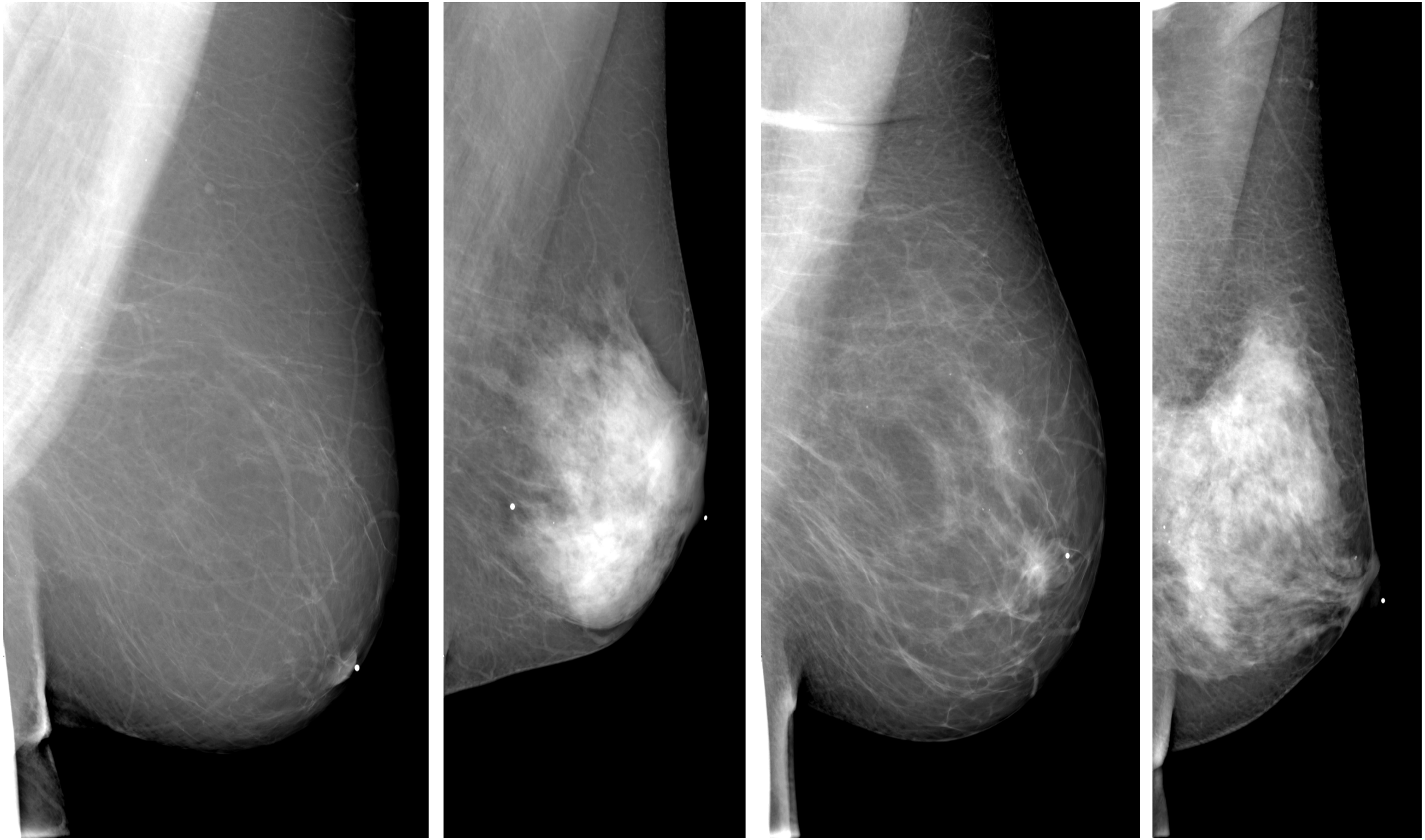
D = Air Kerma (K) * g c s

Obtained with Monte Carlo simulations

CC View Mammograms



MLO View Mammograms



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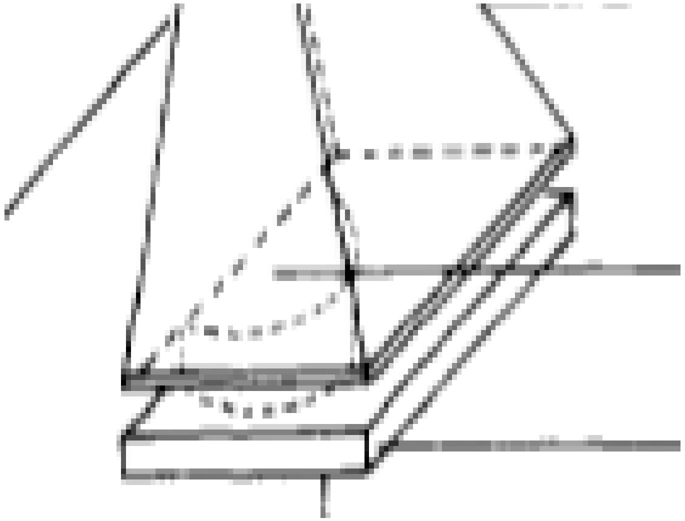
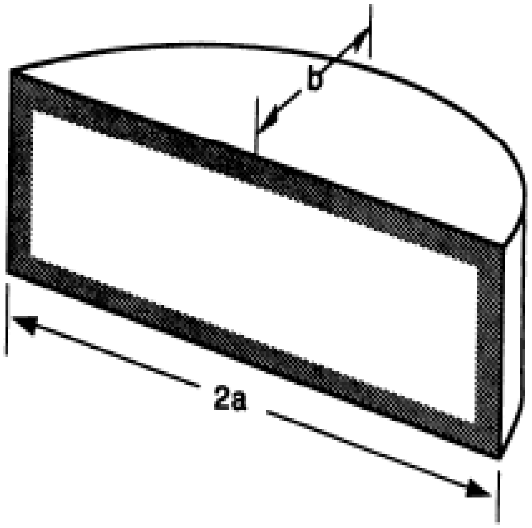
Standard Breast Shape - CC View

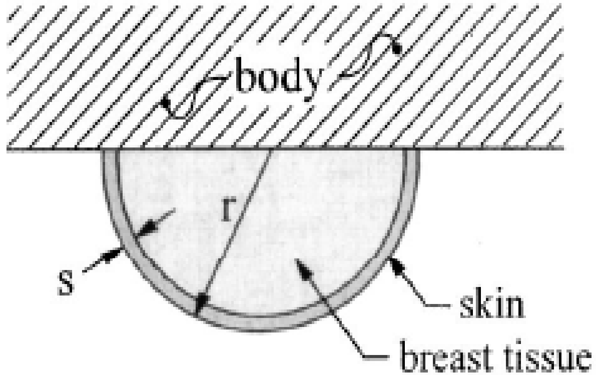


Dance, PMB, 1980; 25(1): 25-37



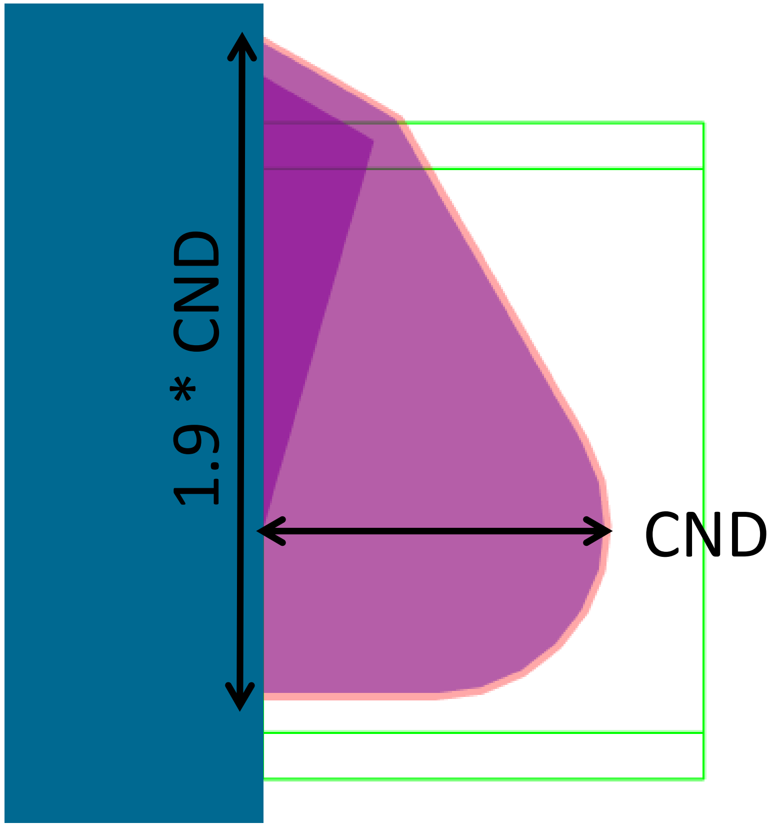
1.

Wu et al, Radiology, 1991; 179: 143-148



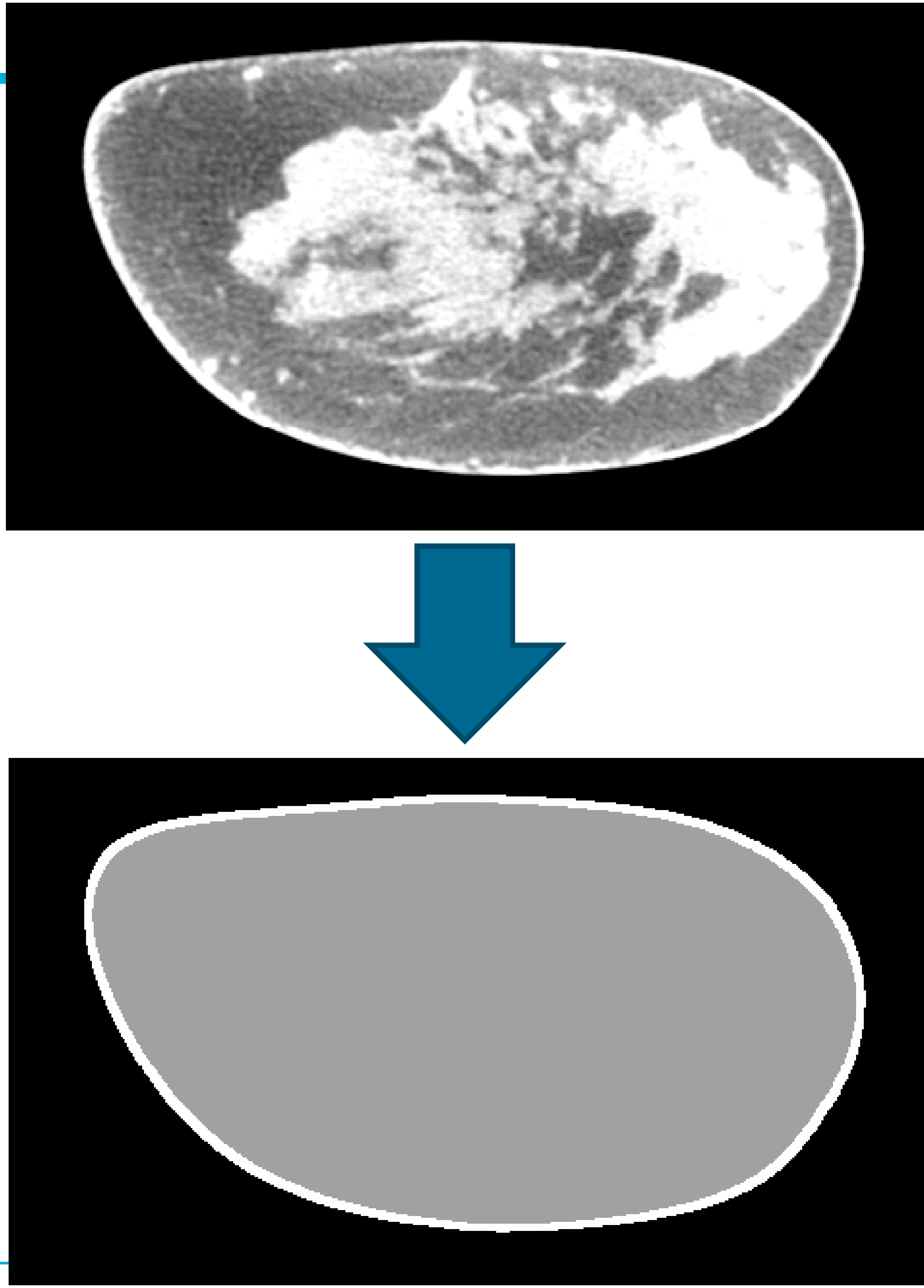
Boone, Med Phys, 2002; 29(5): 869-875

Standardized Breast Shape
MLO View



Sechopoulos et al, Med Phys, 2007; 3(1): 221-232
Sechopoulos et al, JACMP, 2008; 9(4): 161-171

And the inside?



Hammerstein et al, Radiology, 1979; 130, 485–491.

Conversion factors

Table 2. The conversion factor g which relates incident air kerma (without backsca
dose for the 'standard' breast phantom.

HVL mm Al	g (mGy mGy^{-1}) for breast thicknesses of 2 cm	3 cm	4 cm	4.5 cm	5 cm	6 cm
0.25	0.339	0.234	0.174	0.155	0.137	0.112
0.30	0.390	0.274	0.207	0.183	0.164	0.135
0.35	0.433	0.309	0.235	0.208	0.187	0.154
0.40	0.473	0.342	0.261	0.232	0.209	0.172
0.45	0.509	0.374	0.289	0.258	0.232	0.192
0.50	0.543	0.406	0.318	0.285	0.258	0.214
0.55	0.573	0.437	0.346	0.311	0.287	0.236

Table 3. s-factors for clinically used spe
are used.

Spectrum	s-factor	Maximum error (%)
Mo/Mo	1.000	3.1
Mo/Rh	1.017	2.2
Rh/Rh	1.061	3.6
Rh/Al	1.044	2.4
W/Rh	1.042	2.1

Dance (1990 and 2000)

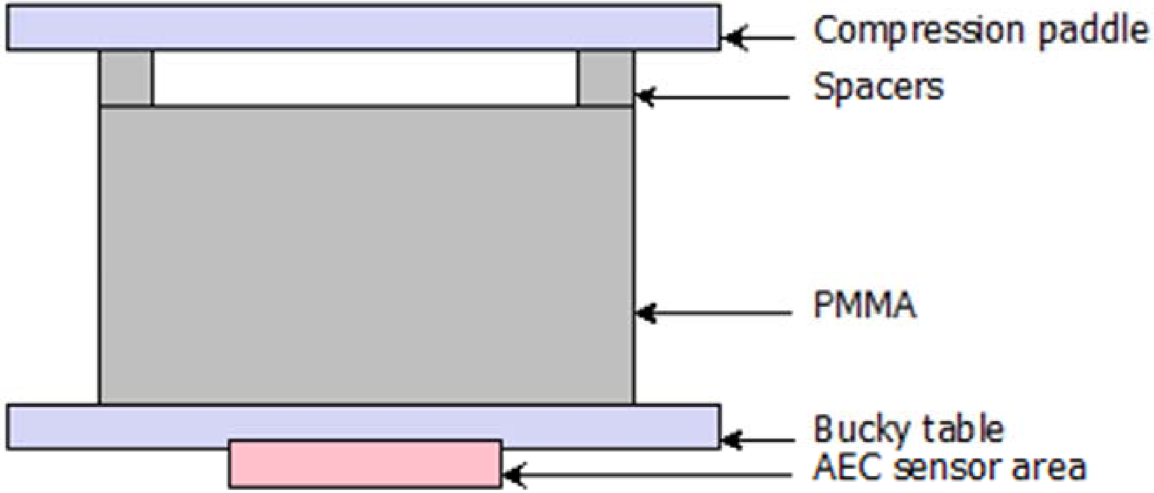
Average Glandular Dose

$$D = \text{Air Kerma (K)} * g\ c\ s$$

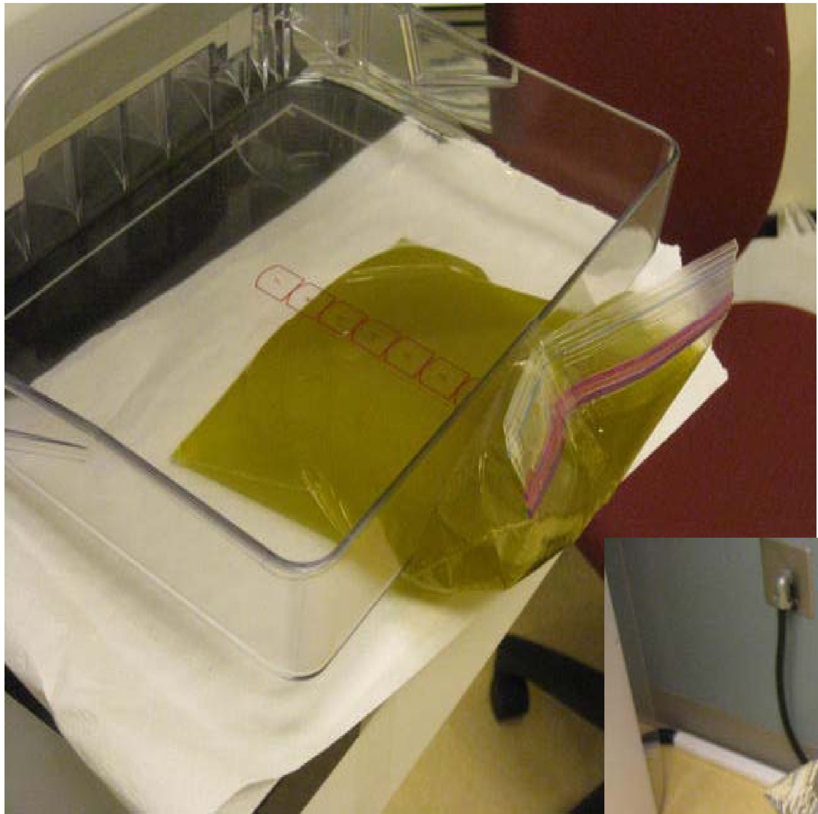
Obtained with Monte Carlo simulations

Phantom (Prospective) Dosimetry

Prospective (phantom) dosimetry



Bouwman et al, PMB, 60 (2015) 7893



Mammography Mean Glandular Dose (mGy)

Breast Thickness (cm)	14.3% Density	50% Density
2	0.313	0.376
5	0.775	1.20
8	1.66	2.28

Tomosynthesis Mean Glandular Dose (mGy)

Breast Thickness (cm)	14.3% Density	50% Density
2	0.735	0.670
5	1.48	1.30
8	3.07	2.64

Mammography and Tomosynthesis Dose

Table 8

Ratio of MGD for DBT (from Table 7) to MGD for FFDM (from Table 6)

Breast Thickness (cm)	1% Glandular Fraction	14.3% Glandular Fraction	25% Glandular Fraction	50% Glandular Fraction	75% Glandular Fraction	100% Glandular Fraction
2	2.45	2.35	1.87	1.76	1.65	1.65
3	2.08	1.67	1.28	1.19	1.14	1.11
4	2.63	2.11	1.86	1.27	1.19	1.16
5	2.36	1.88	1.53	1.08	0.930	0.880
6	1.90	1.83	1.95	1.25	1.12	1.00
7	2.26	1.76	1.39	1.12	0.810	0.700
8	2.13	1.85	1.47	1.16	0.820	0.670

(could we do better?)

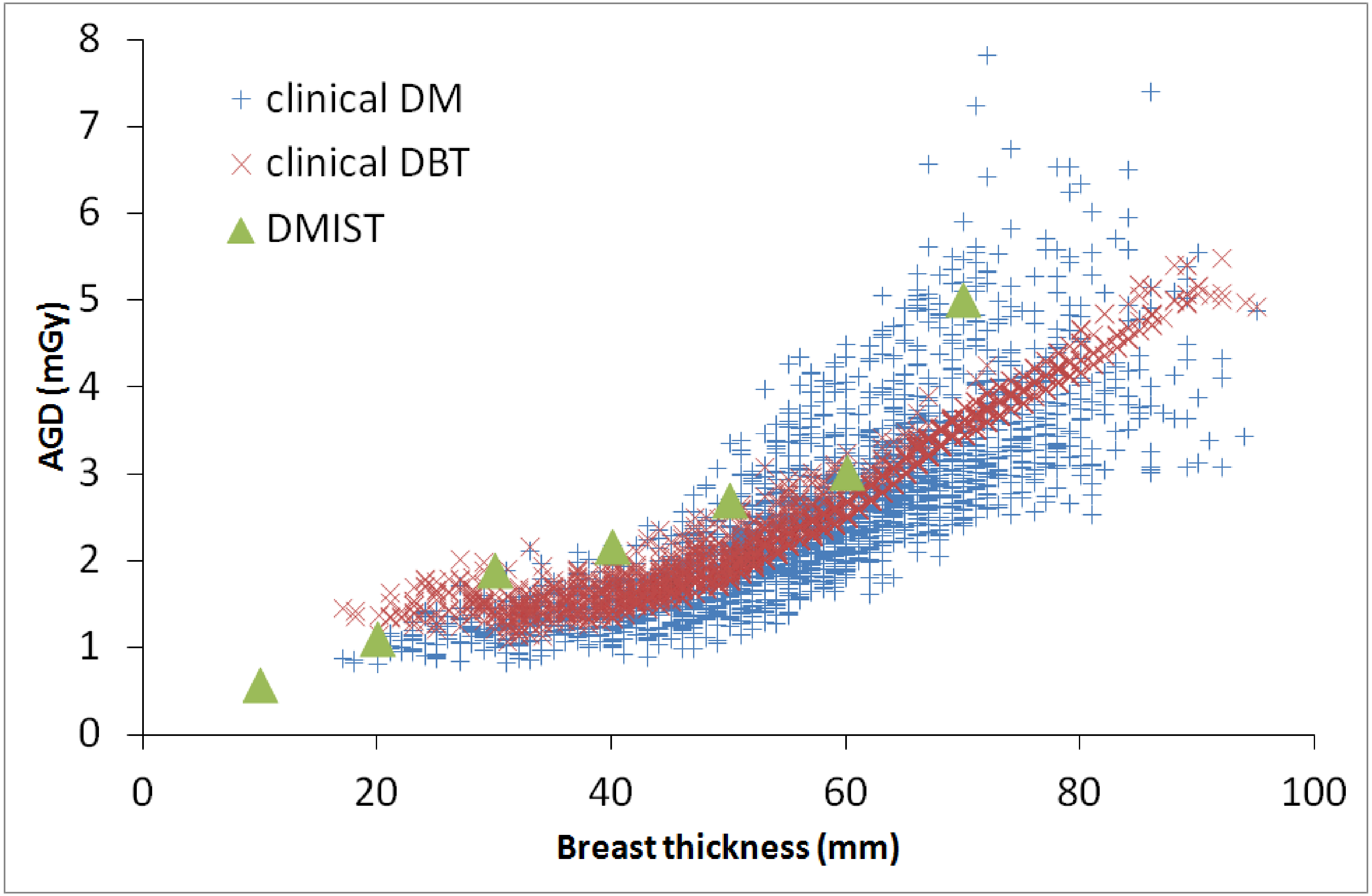
Patient (Retrospective) Dosimetry

DICOM header

0018,0060 KVp: 31
0018,1000 Device Serial Number: 6250
0018,1020 Software Versions(s): VB41A(VX16B) (SL6!
0018,1030 Protocol Name: TOMO_PROJ
0018,1110 Distance Source to Detector: 650
0018,1111 Distance Source to Patient: 633
0018,1114 ---: 1.0268562401264
0018,1138 ---: 0
0018,113A ---: NONE
0018,1147 Field of View Shape: RECTANGLE
0018,1149 Field of View Dimensions(s): 305\239
0018,1150 Exposure Time: 88
0018,1151 X-ray Tube Current: 121
0018,1152 Exposure: 11
0018,1153 Exposure in uAs: 10640
0018,1156 Rectification Type: CONST POTENTIAL
0018,1164 Imager Pixel Spacing: 0.085\0.085
0018,1166 Grid: FOCUSED\PARALLEL
0018,1190 Focal Spot(s): 0.3
0018,1191 Anode Target Material: TUNGSTEN
0018,11A0 Body Part Thickness: 72

System I

Ratio DBT/DM:
Mean = 1.08 (0.54 – 1.81)



Bouwman et al, Phys. Med. Biol. 60 (2015) 7893
Hendrick et al, AJR. 194 (2010) 362

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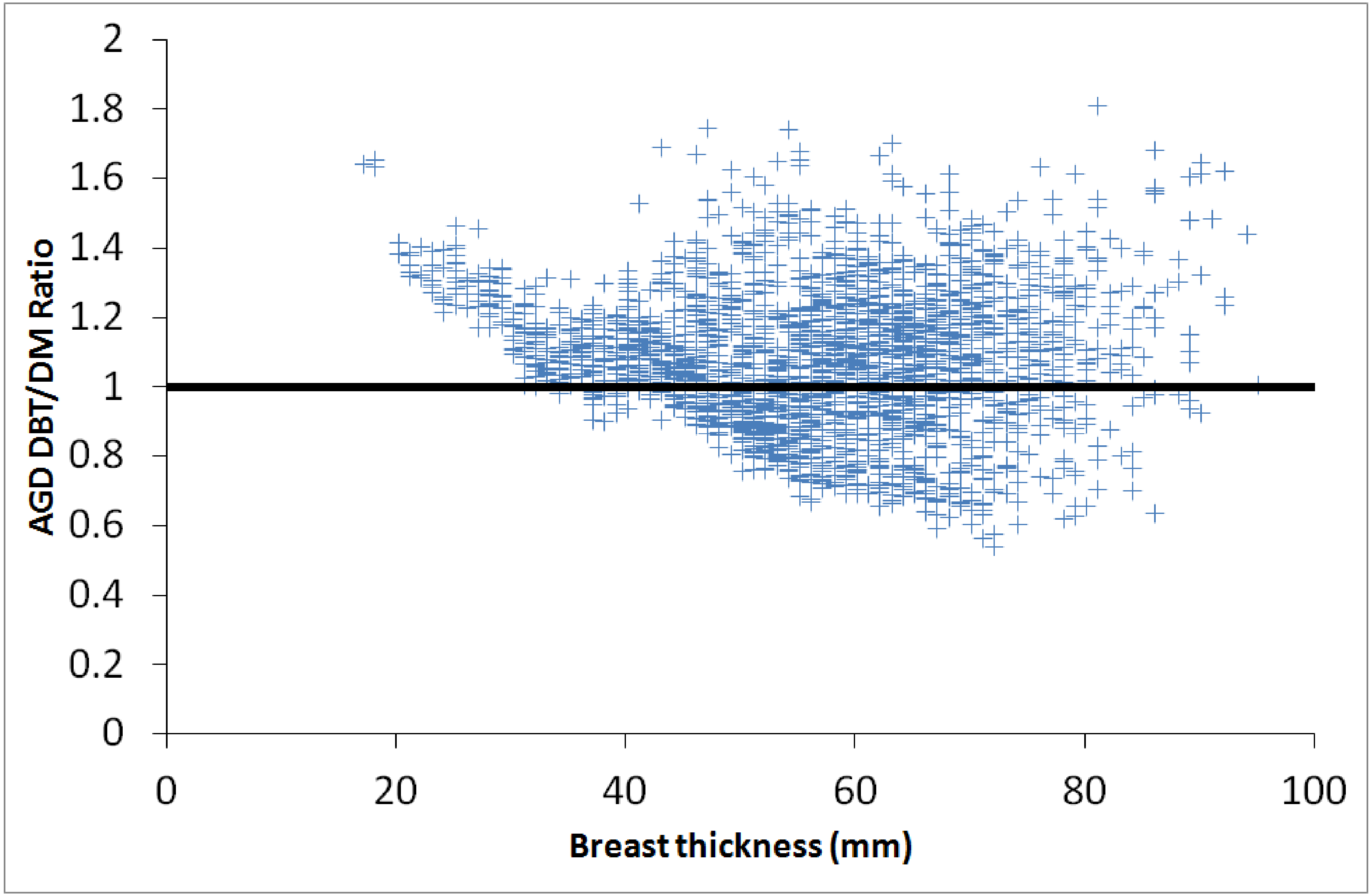
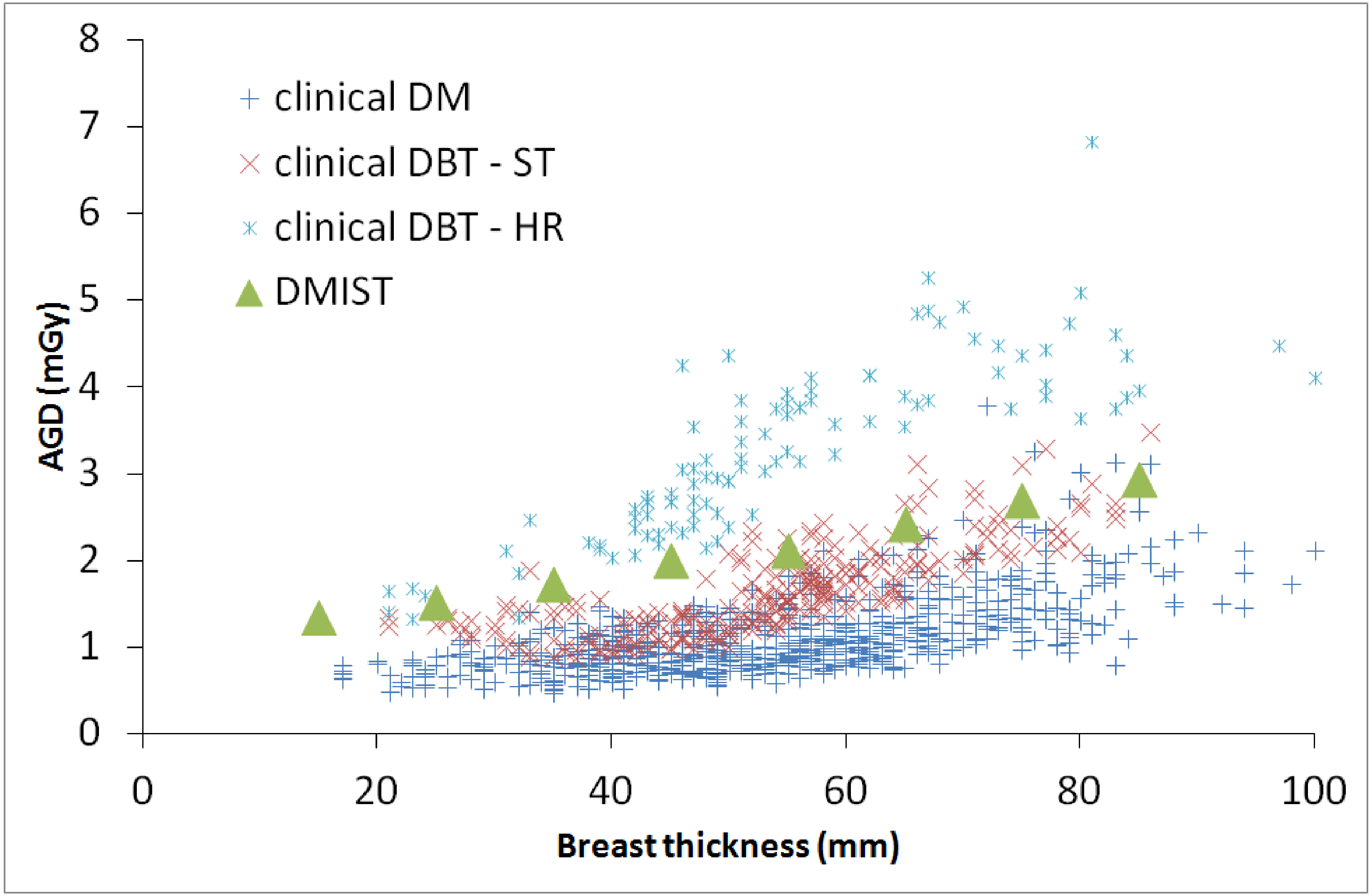
System I

Ratio DBT/DM:
Mean = 1.08 (0.54 – 1.81)



System IV

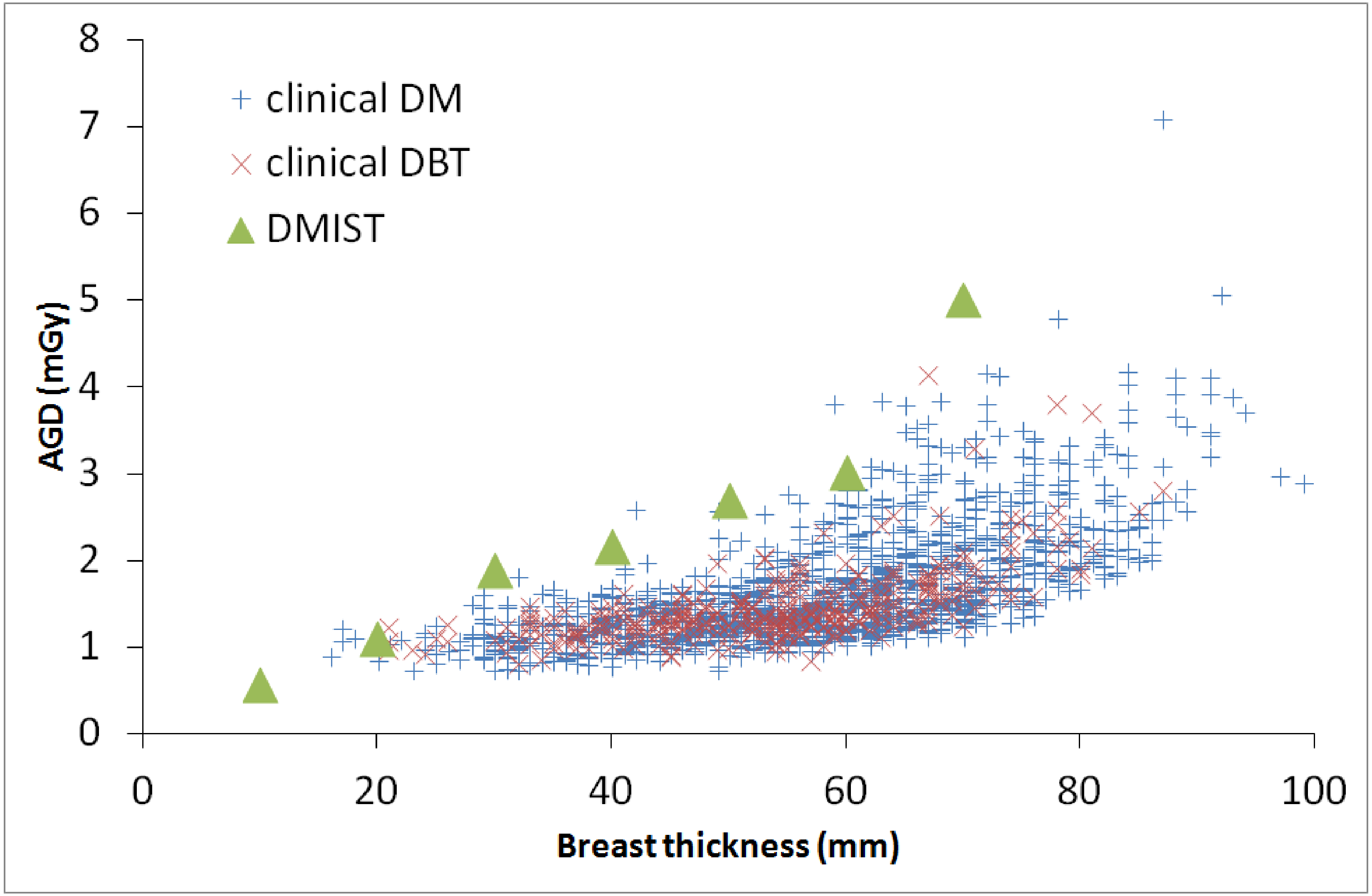
Ratio DBT-ST / DM:
Mean = 1.48 (unpaired)



Bouwman et al, Phys. Med. Biol. 60 (2015) 7893
Hendrick et al, AJR. 194 (2010) 362

System V

Ratio DBT / DM:
Mean = 0.90 (!) (unpaired)



Bouwman et al, Phys. Med. Biol. 60 (2015) 7893
Hendrick et al, AJR. 194 (2010) 362

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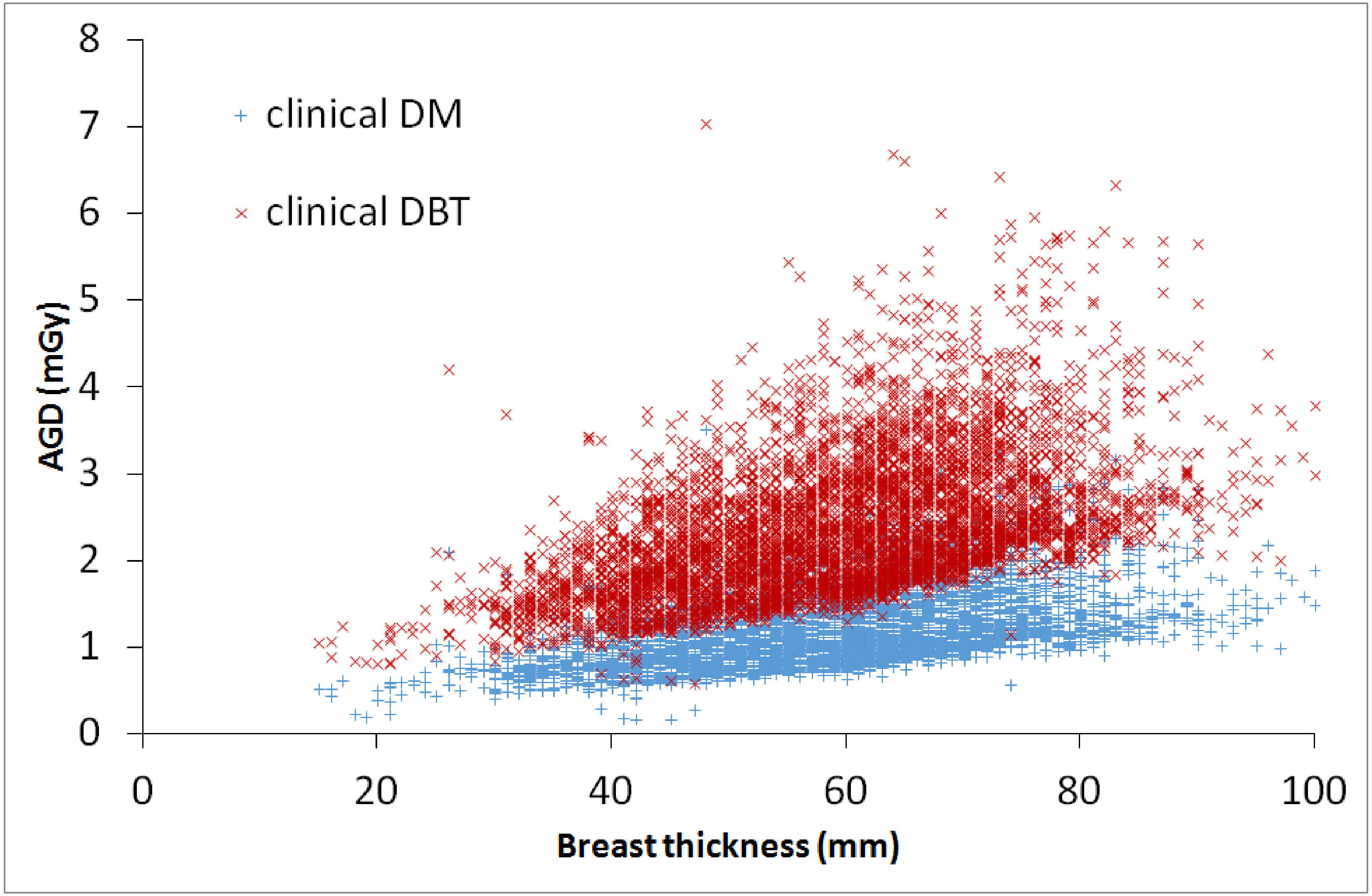
Are these final?

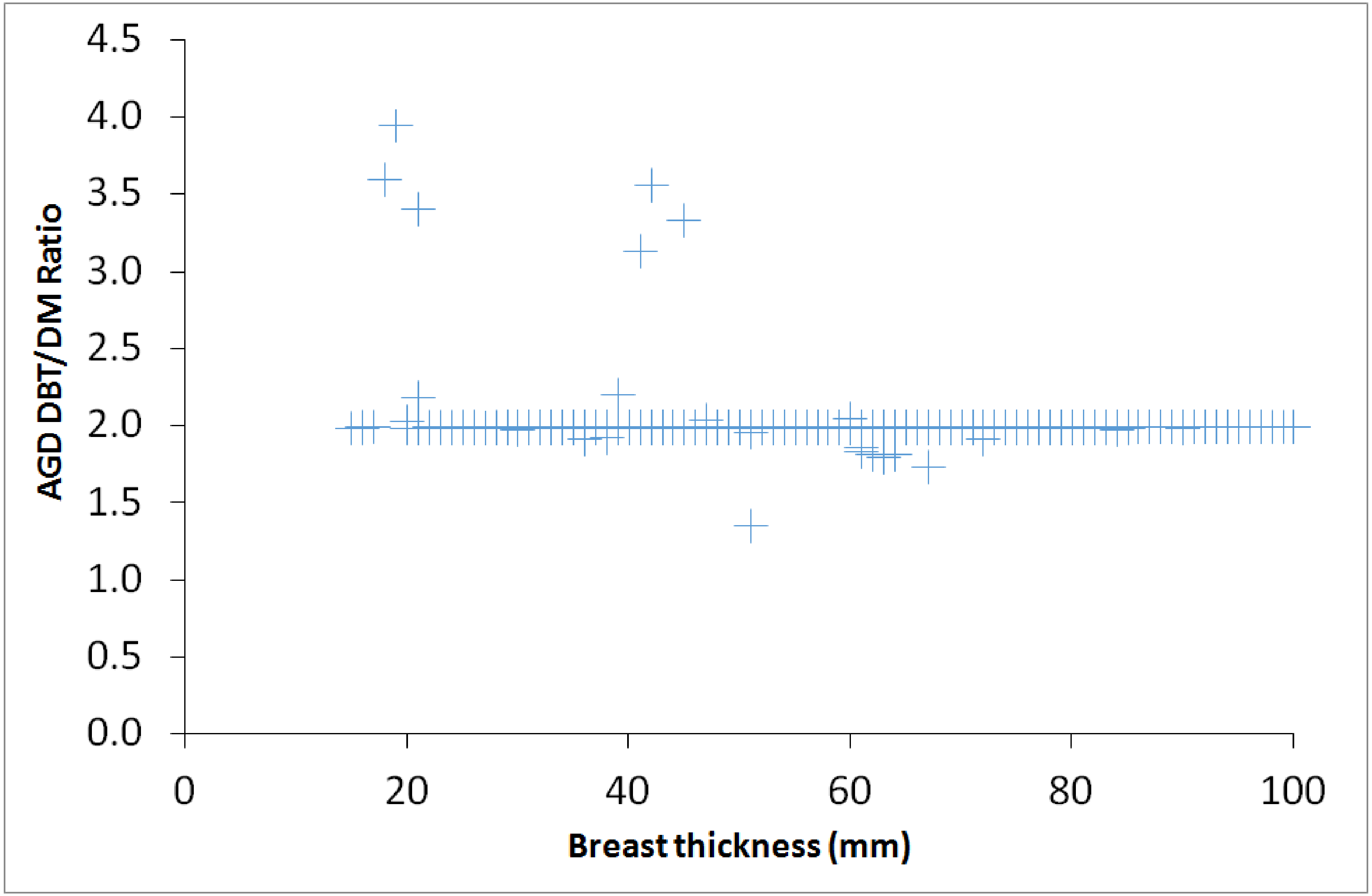
System III

Ratio DBT / DM:
Mean = **2.00 (!)**



System III

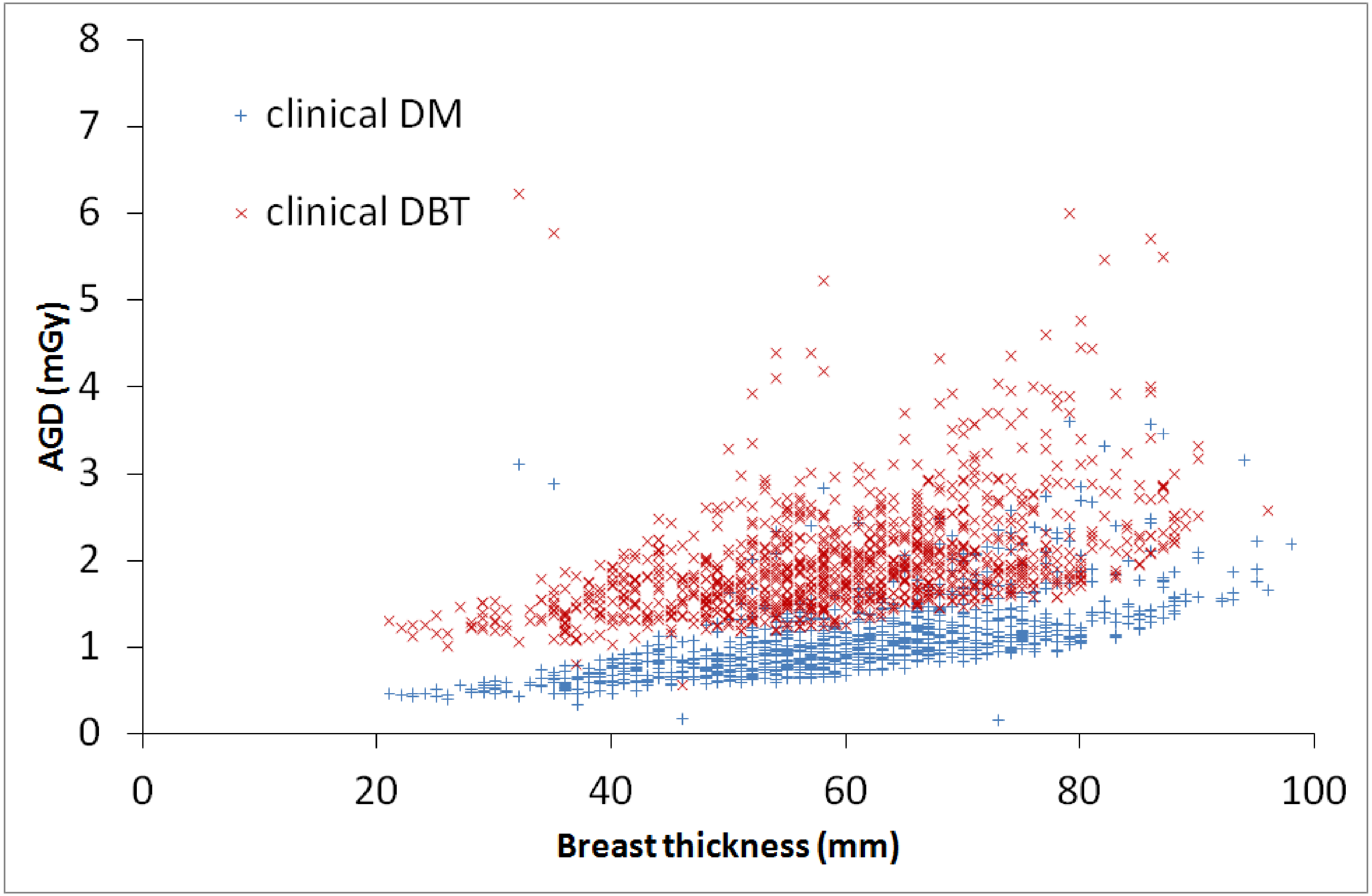
Ratio DBT / DM:
Mean = **2.00 (!)**



After software upgrade…

System III

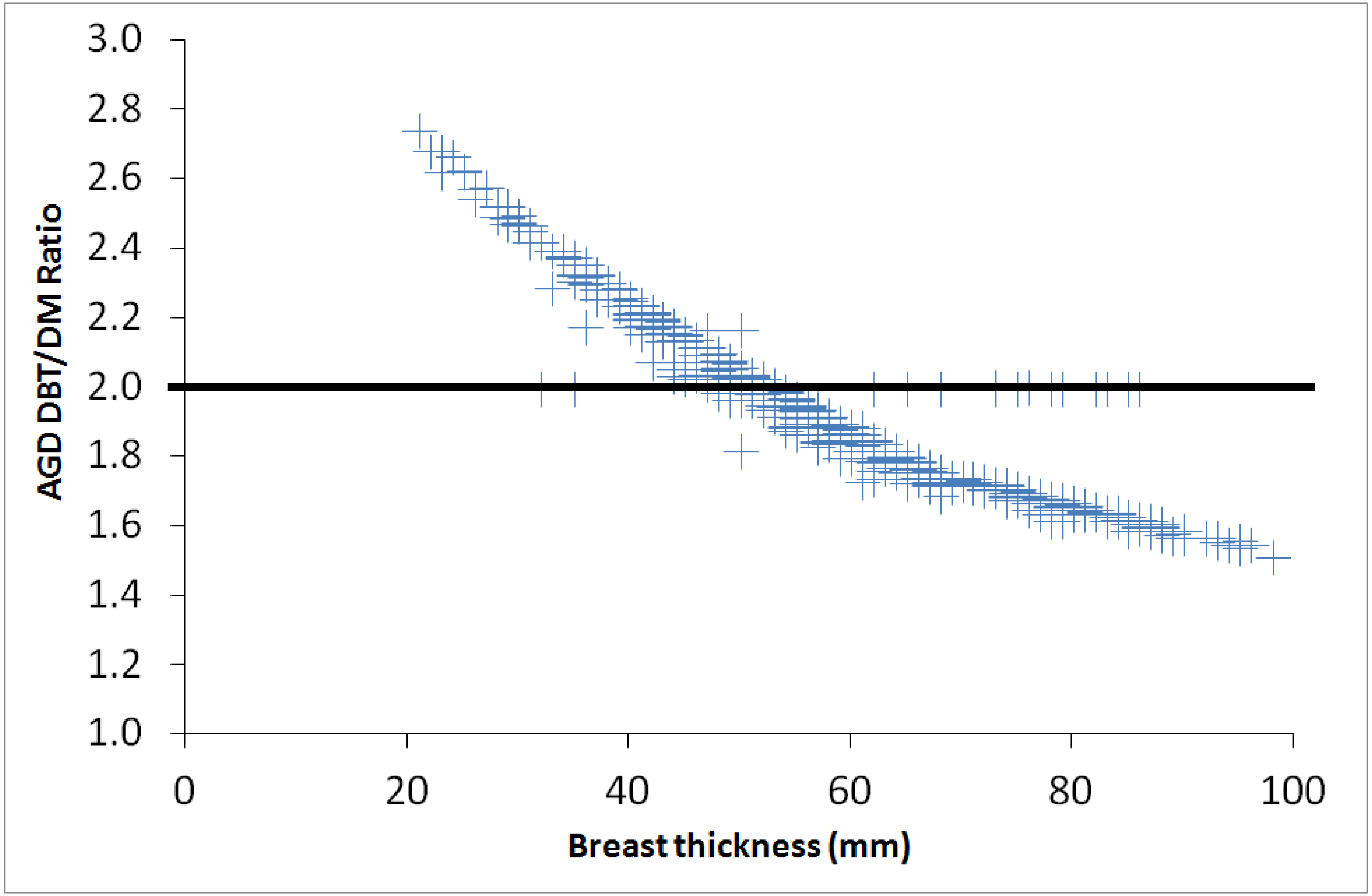
Ratio DBT / DM:
Mean = **1.90 (1.51 – 2.74)**



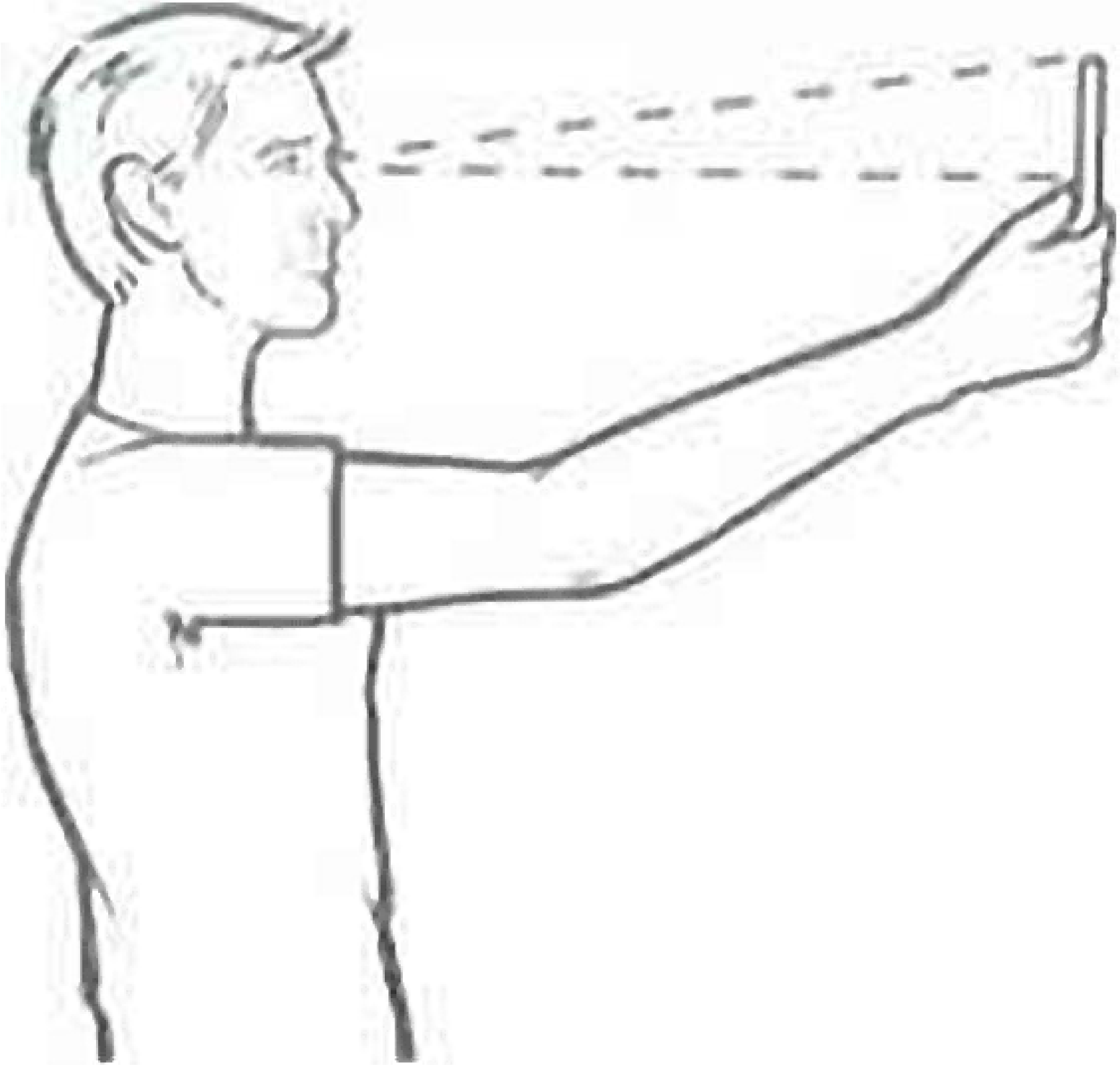
System III

Ratio DBT / DM:

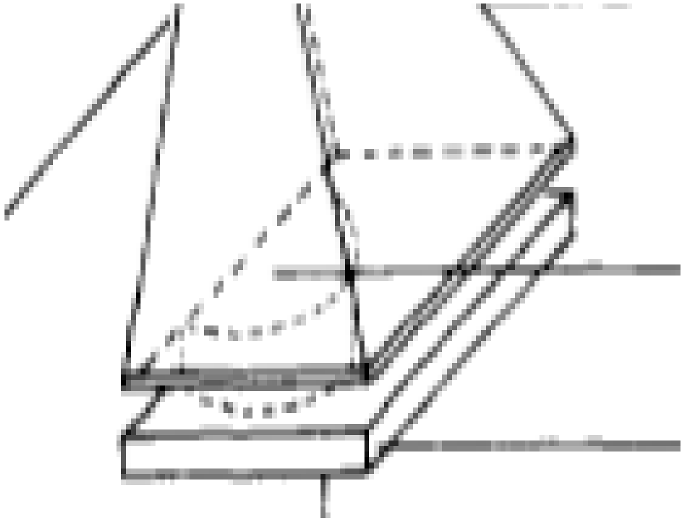
Mean = **1.90 (1.51 – 2.74)**



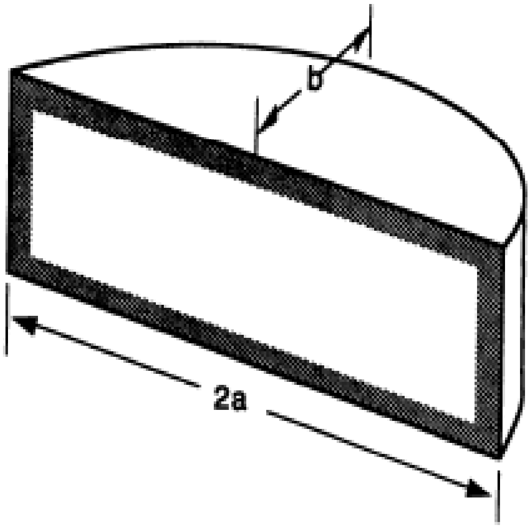
So where are the uncertainties?



Standard Breast Shape - CC View

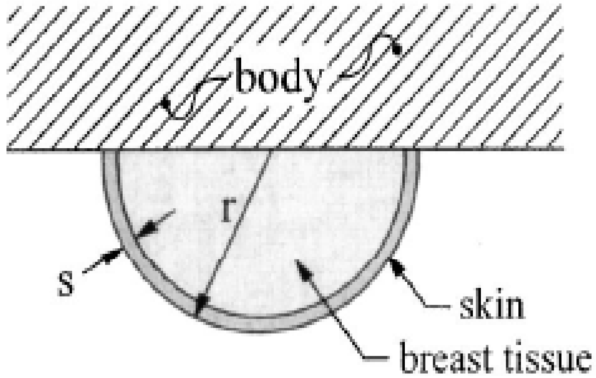


Dance, PMB, 1980; 25(1): 25-37



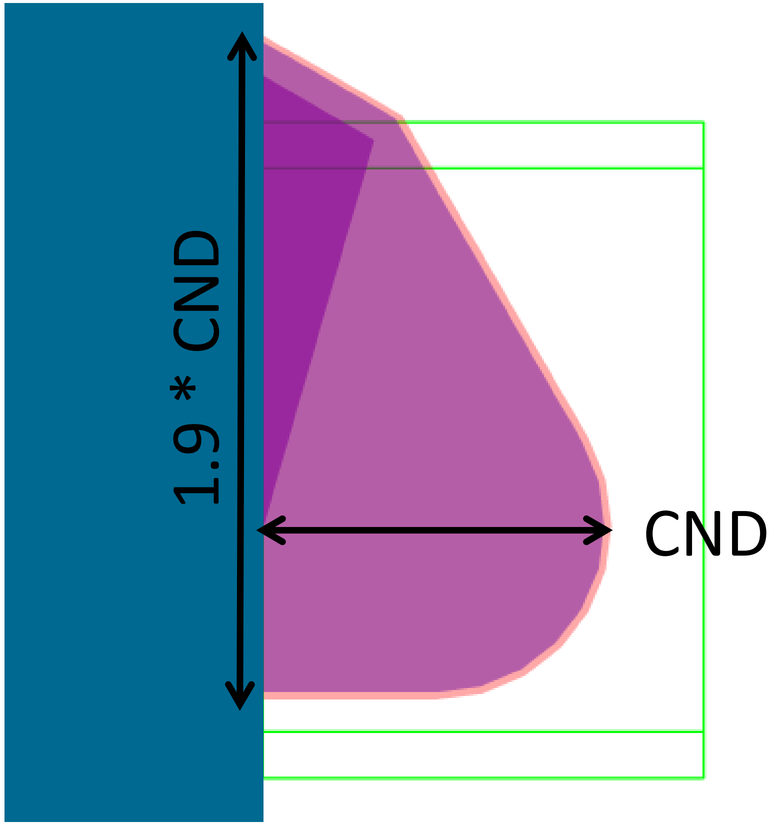
1.

Wu et al, Radiology, 1991; 179: 143-148



Boone, Med Phys, 2002; 29(5): 869-875

Standardized Breast Shape
MLO View

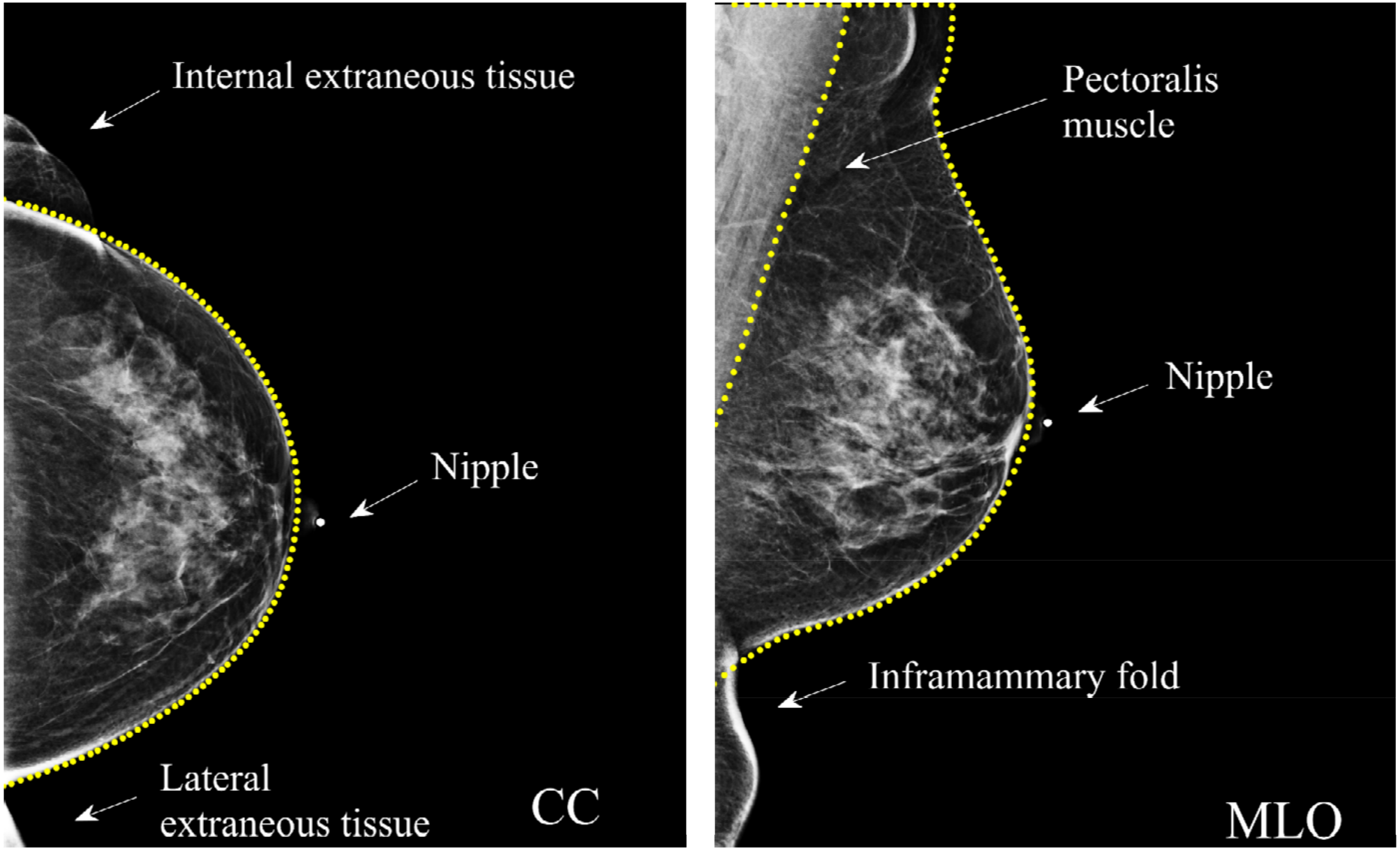


Sechopoulos et al, Med Phys, 2007; 3(1): 221-232
Sechopoulos et al, JACMP, 2008; 9(4): 161-171

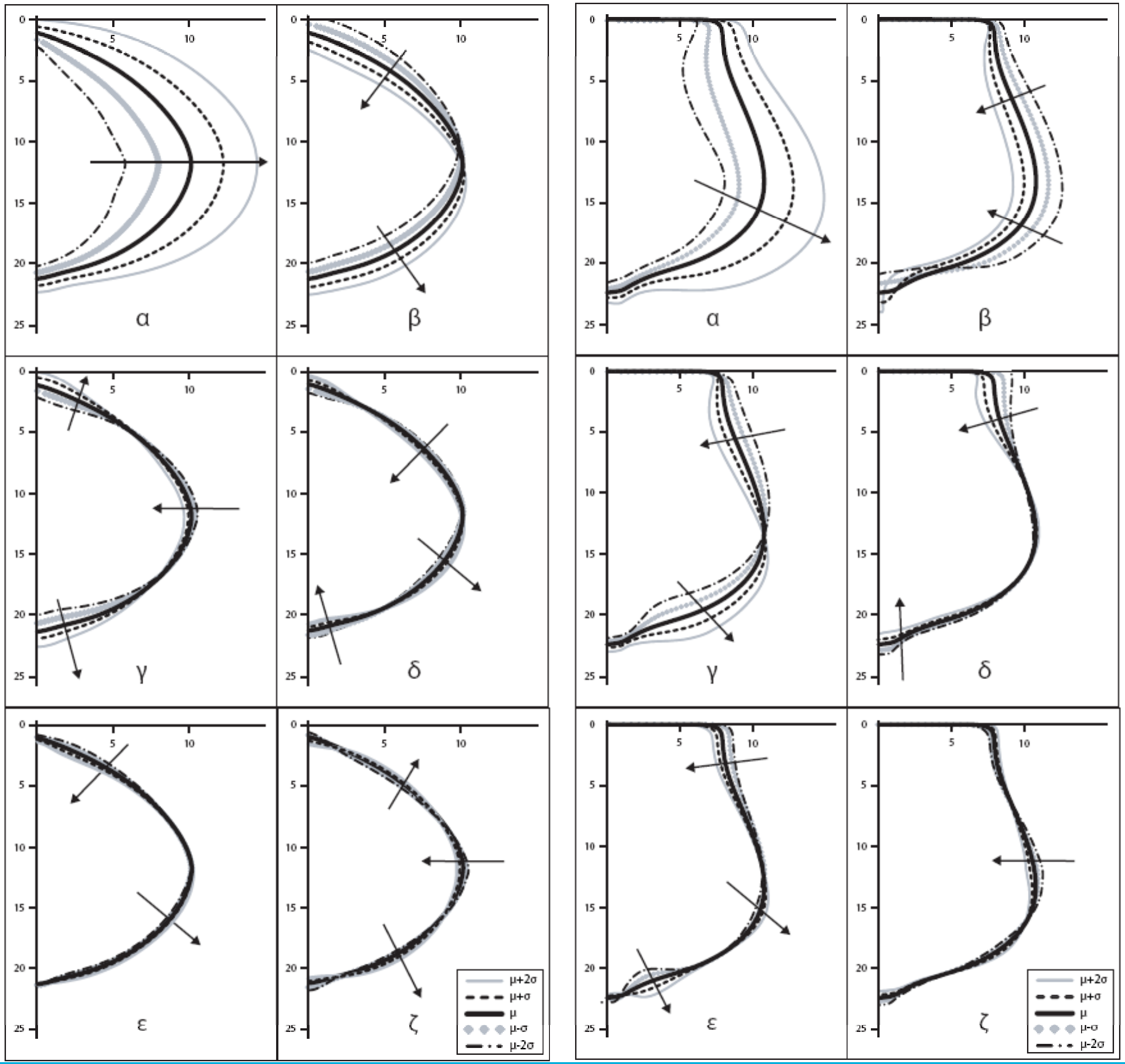
Can we be more objective?

Principal Component Analysis

2D Model: From 1000 mammograms

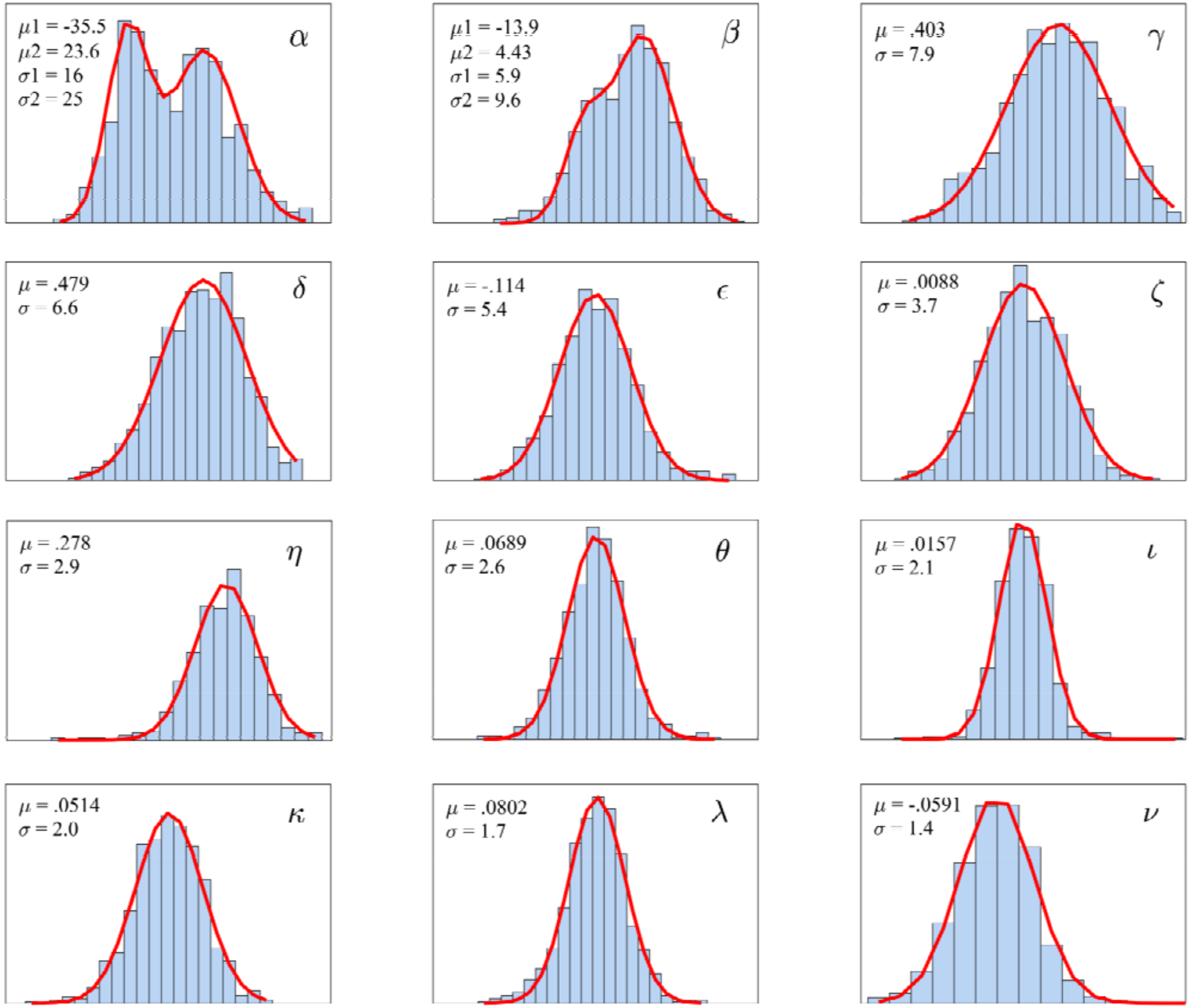


PCA Model Parameter Characterization



Feng et al, Medical Physics, 2013

Clinical Distribution of PCA Parameter Values



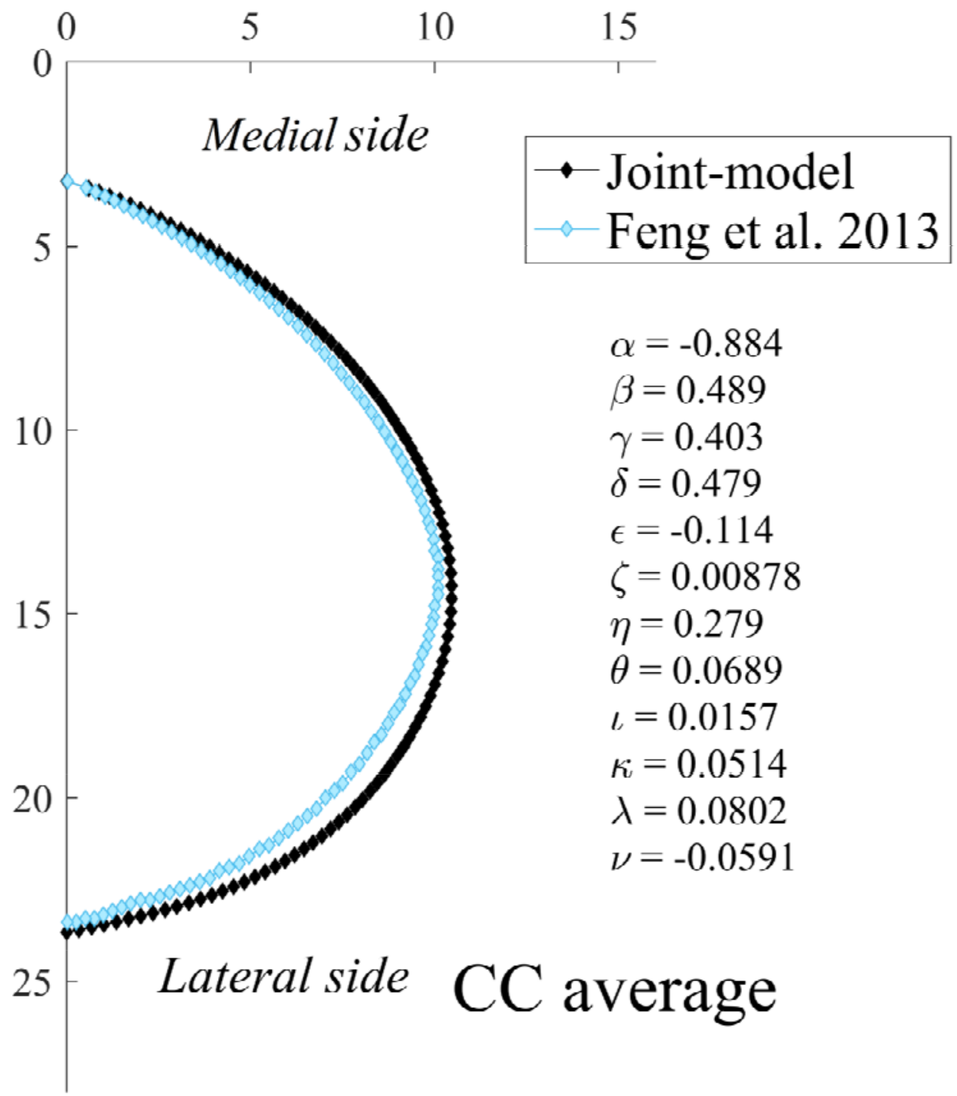
Rodriguez-Ruiz et al, Medical Physics, under review

Average CC view

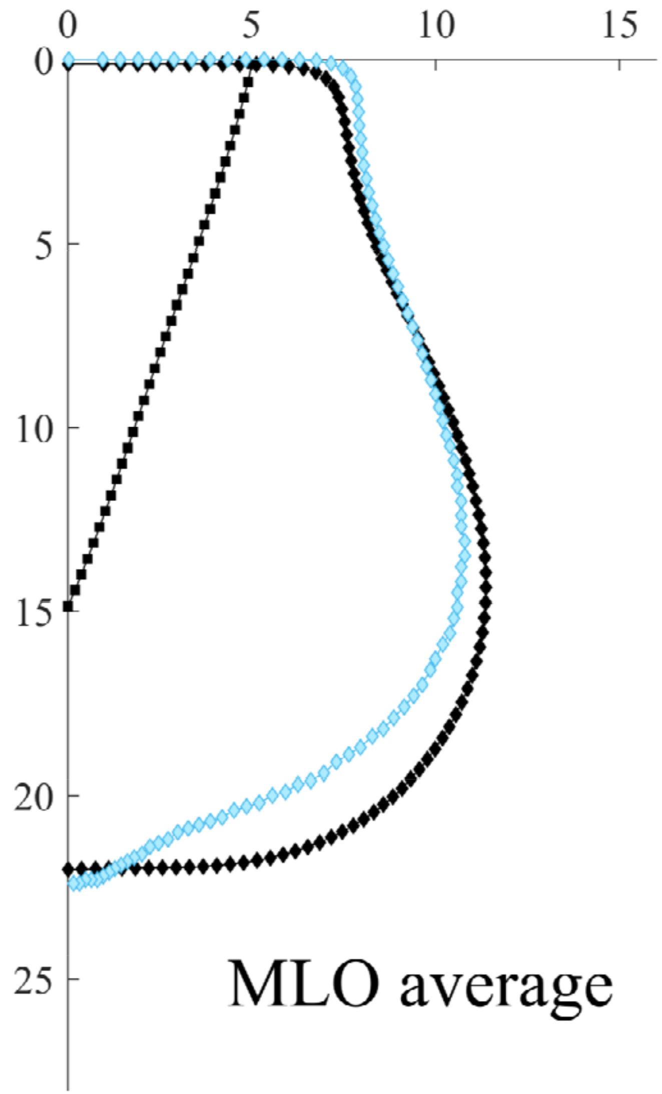
Area = 155.4 cm^2

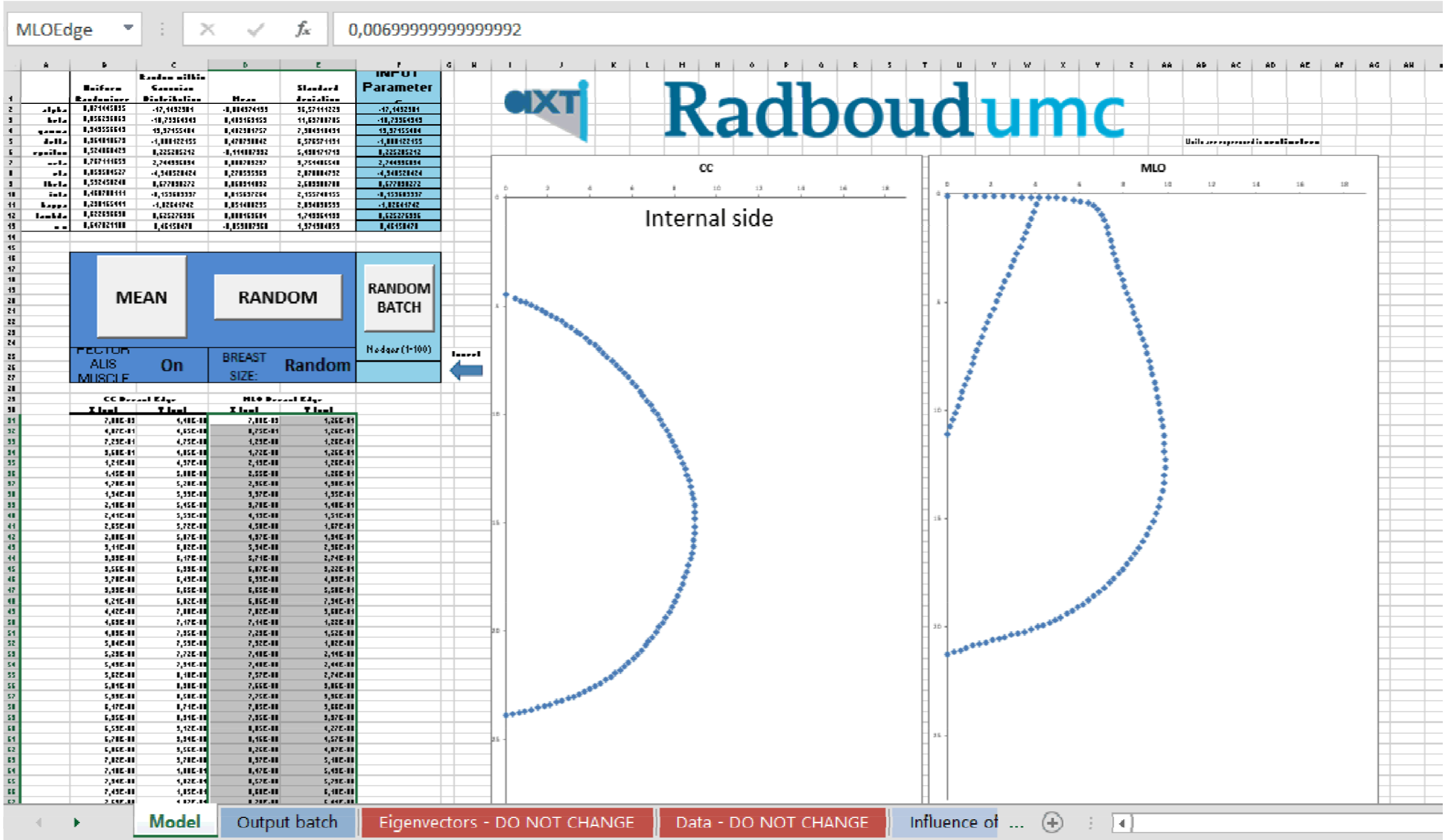
Patient average:[1]

Area = 157.3 cm^2



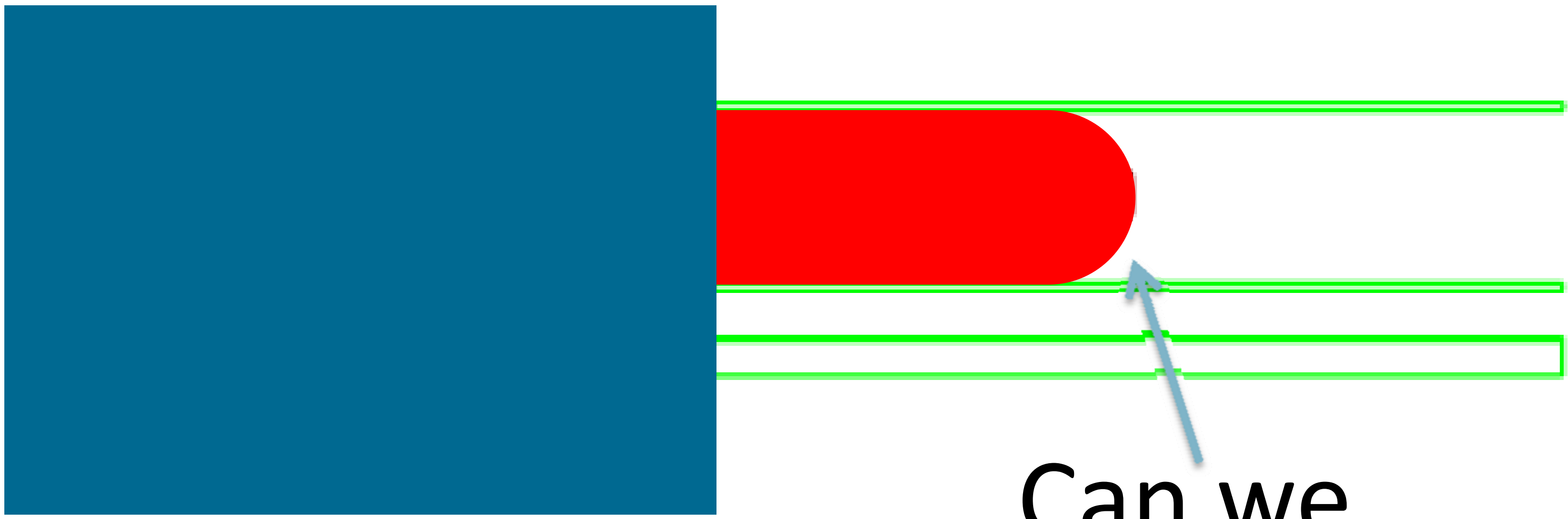
Average MLO view





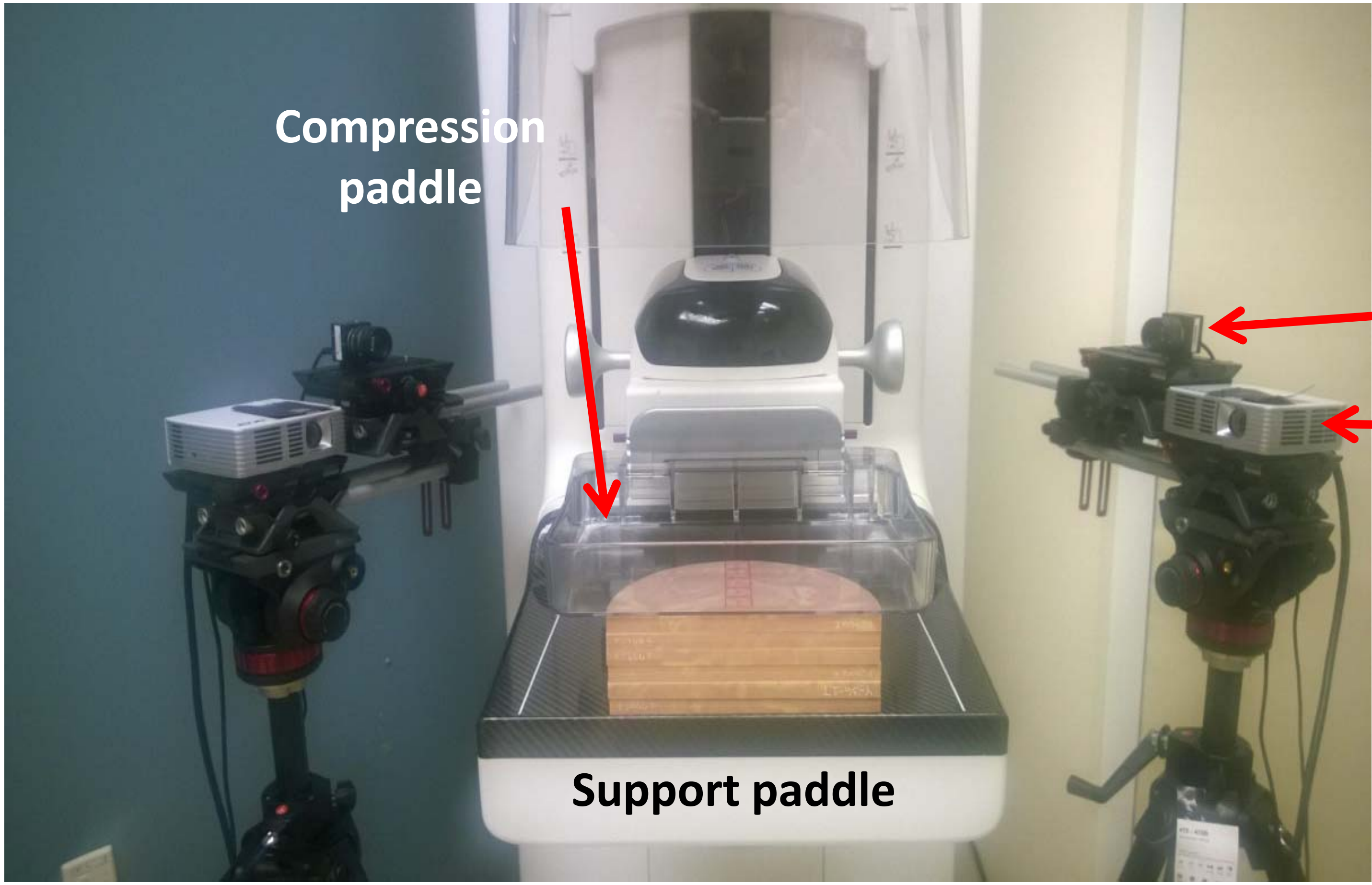
MLOEdge
0,00699999999999992
Parameter
MEAN
RANDOM
RANDOM BATCH
On
BREAST SIZE:
Random
CC
MLO
Internal side
Model
Output batch
Eigenvectors - DO NOT CHANGE
Data - DO NOT CHANGE
Influence of

How about the 3rd dimension?

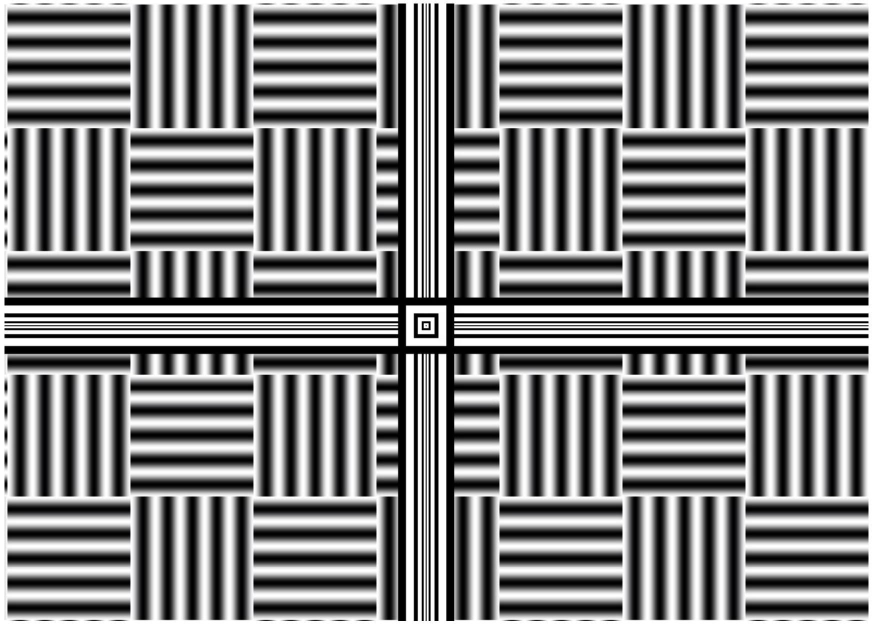


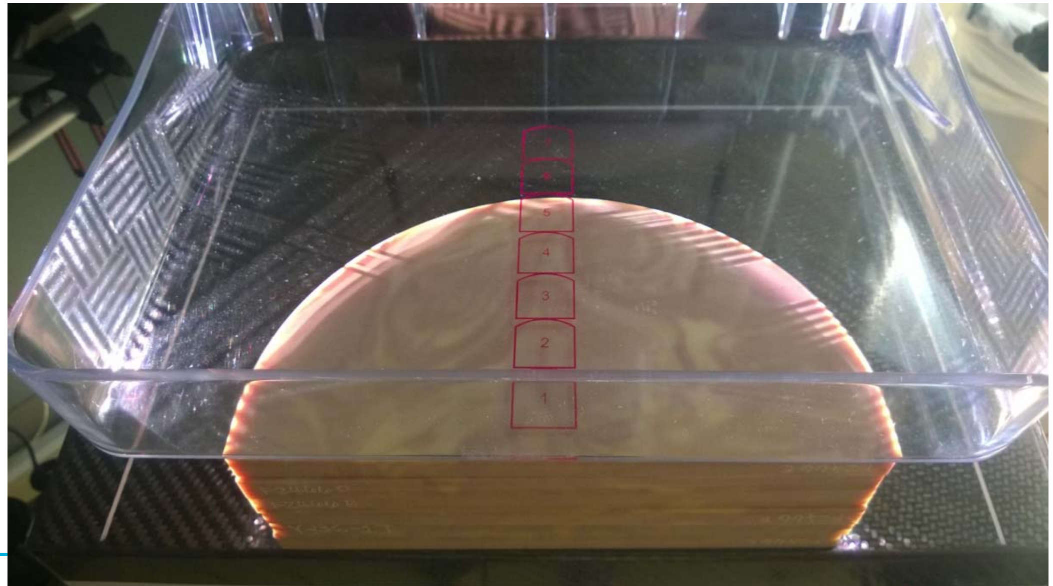
Can we characterize this?

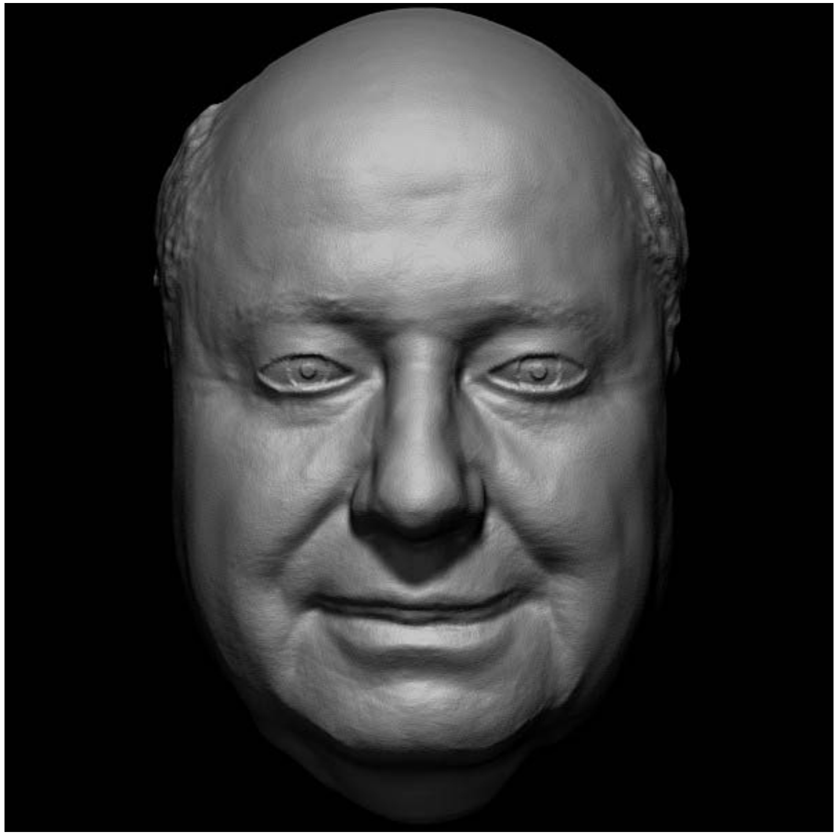
Acquisition of 3-D breast shape



3-D scanner

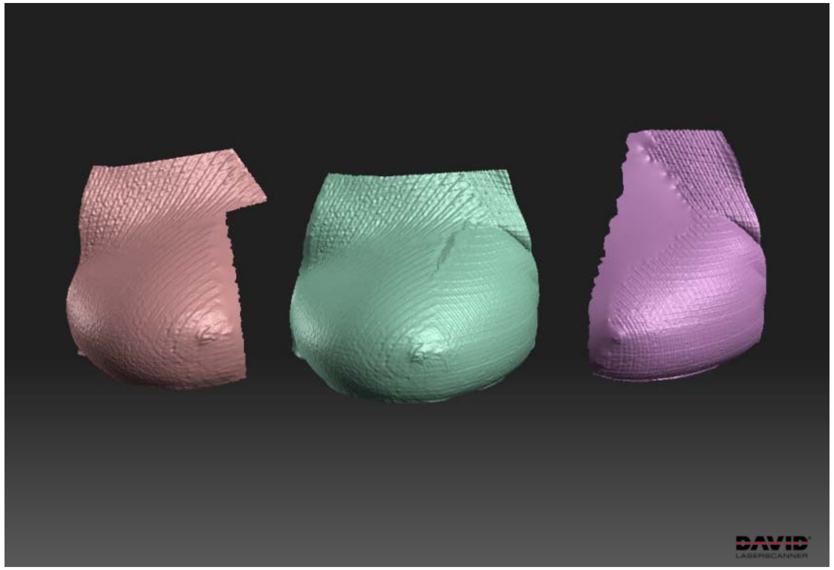


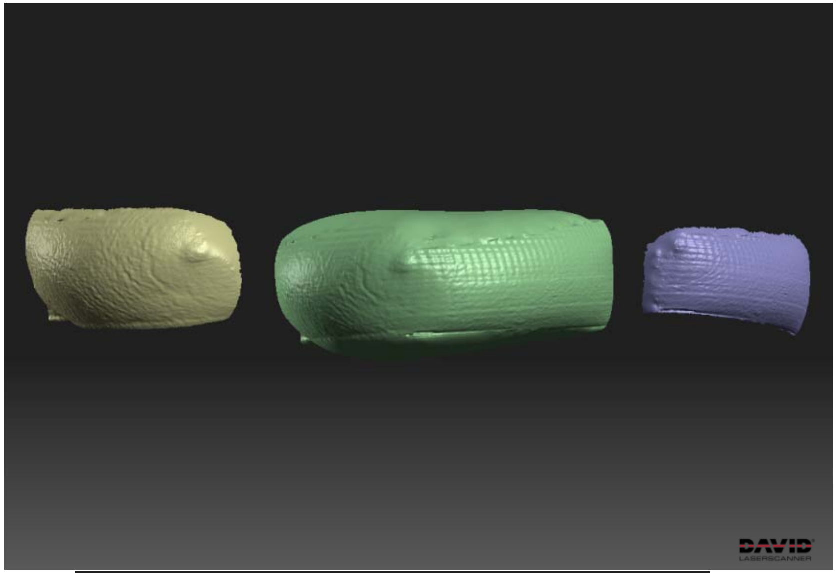


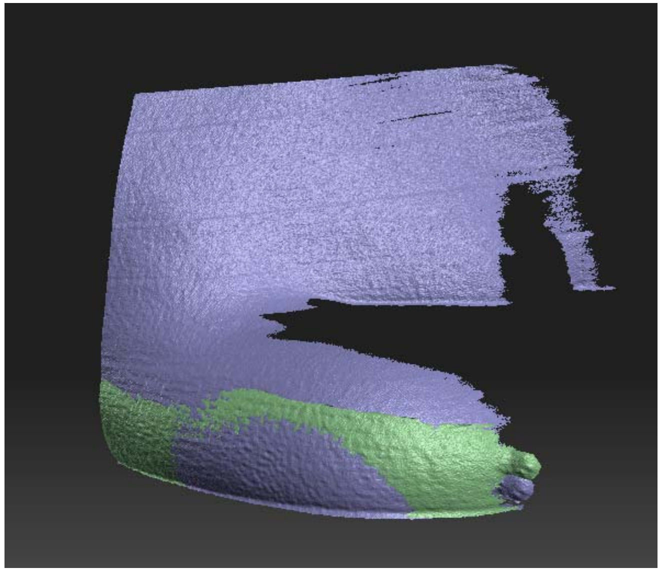


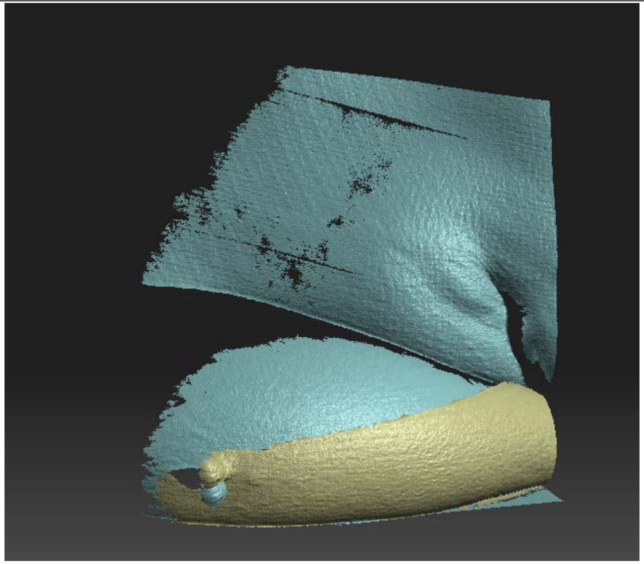
http://www.david-3d.com/?section=Gallery

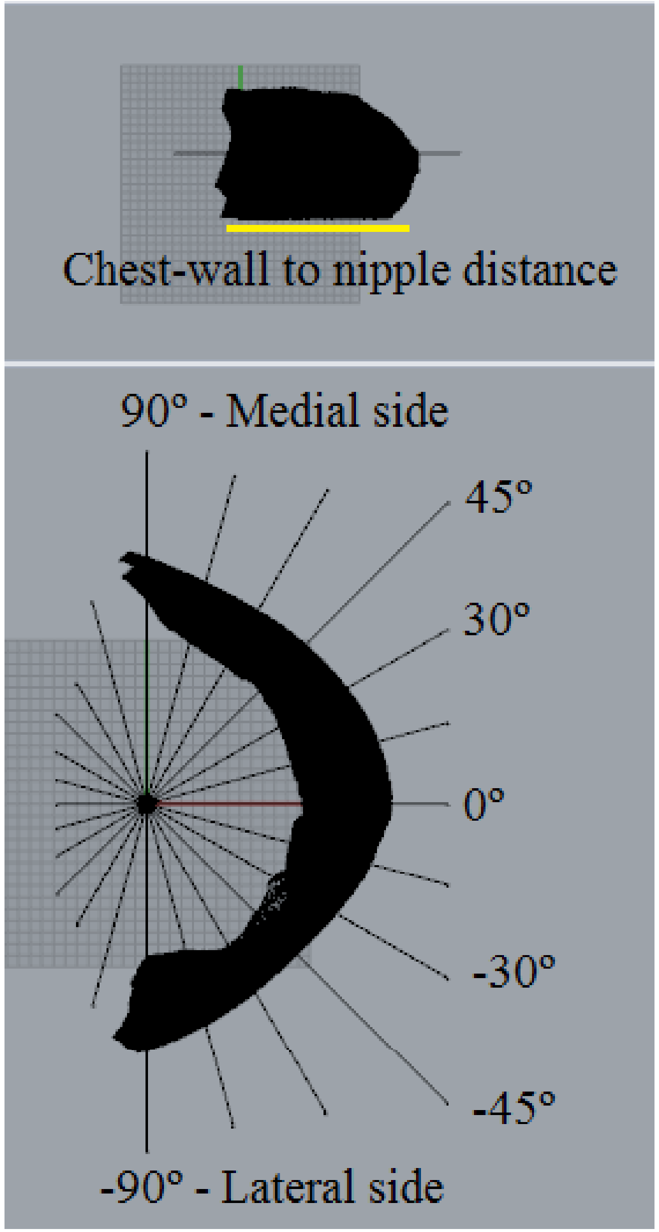
Patient scans

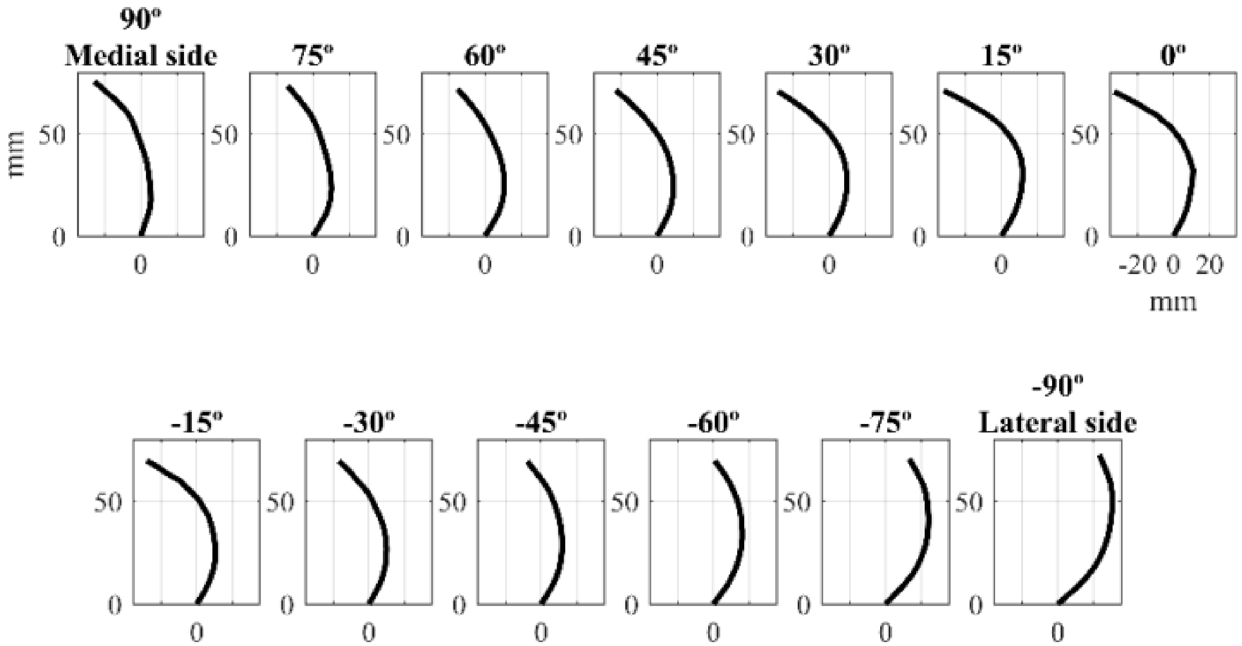


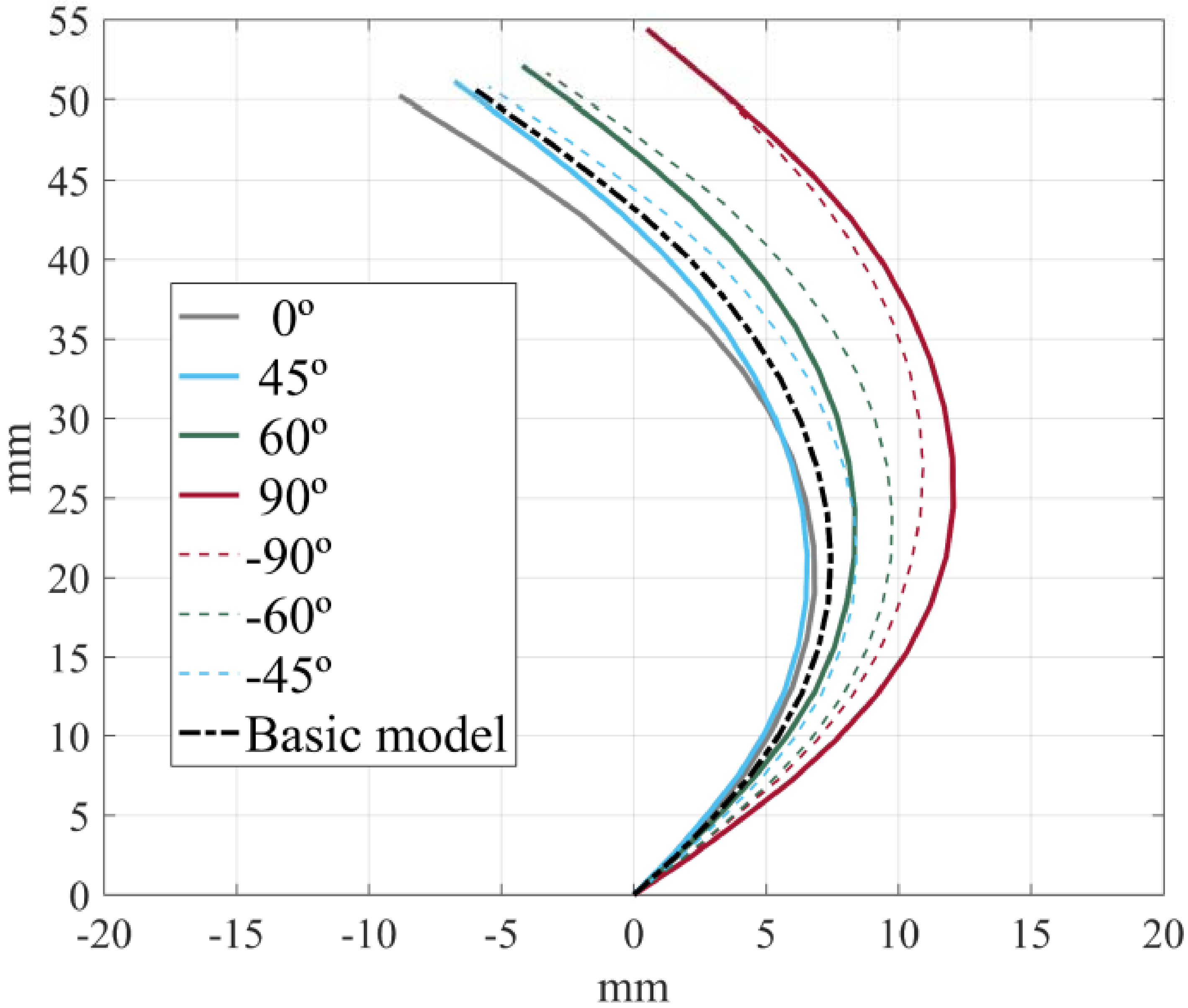




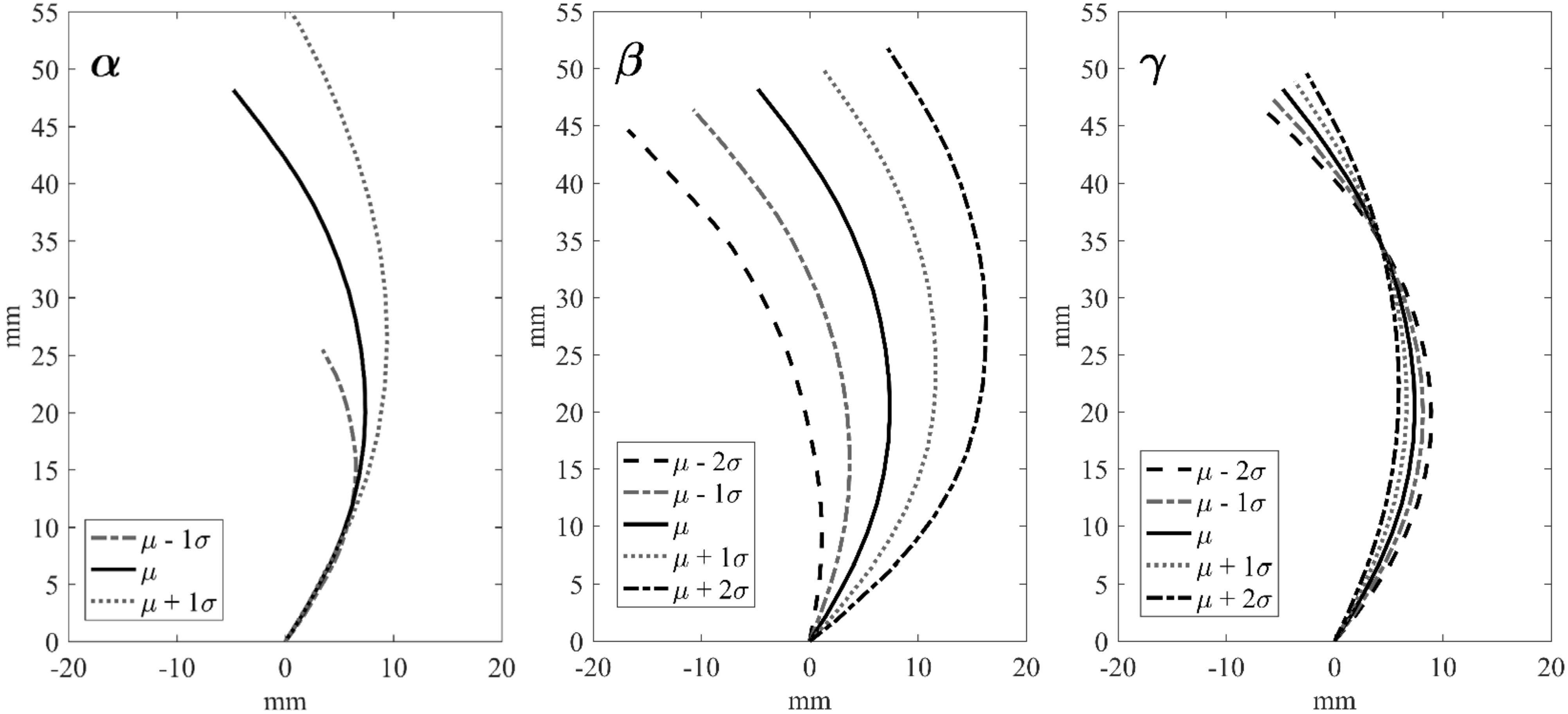



Chest-wall to nipple distance
90° - Medial side
45°
30°
0°
-30°
-45°
-90° - Lateral side


90°
Medial side
75°
60°
45°
30°
15°
0°
mm
50
0
-20 0 20
mm
-15°
-30°
-45°
-60°
-75°
-90°
Lateral side

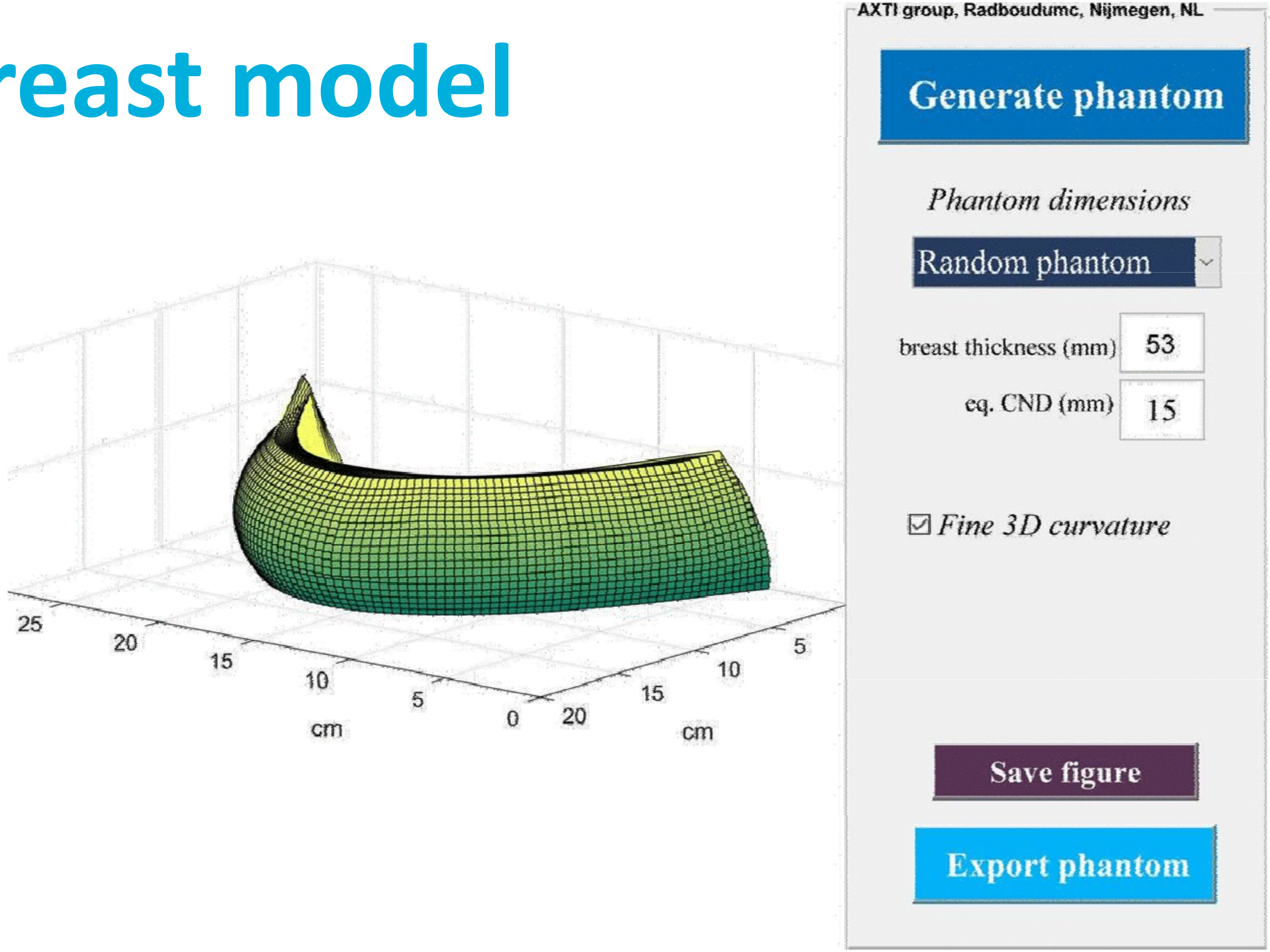


0º
45º
60º
90º
-90º
-60º
-45º
Basic model
mm
mm
55
50
45
40
35
30
25
20
15
10
5
0
-20
-15
-10
-5
0
5
10
15
20

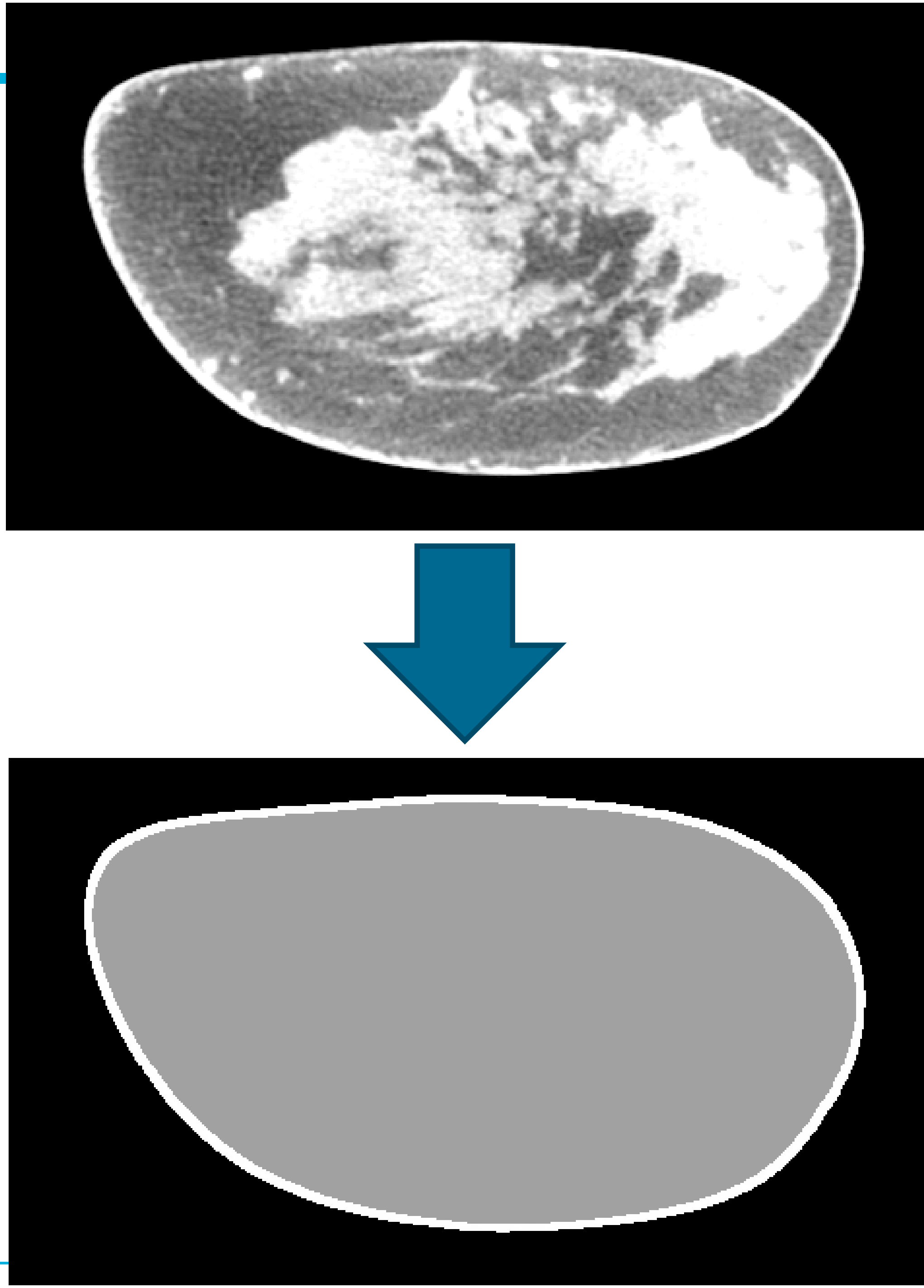


α
β
γ
μ - 2σ
μ - 1σ
μ
μ + 1σ
μ + 2σ
mm

Breast model



But what do these values of AGD mean?



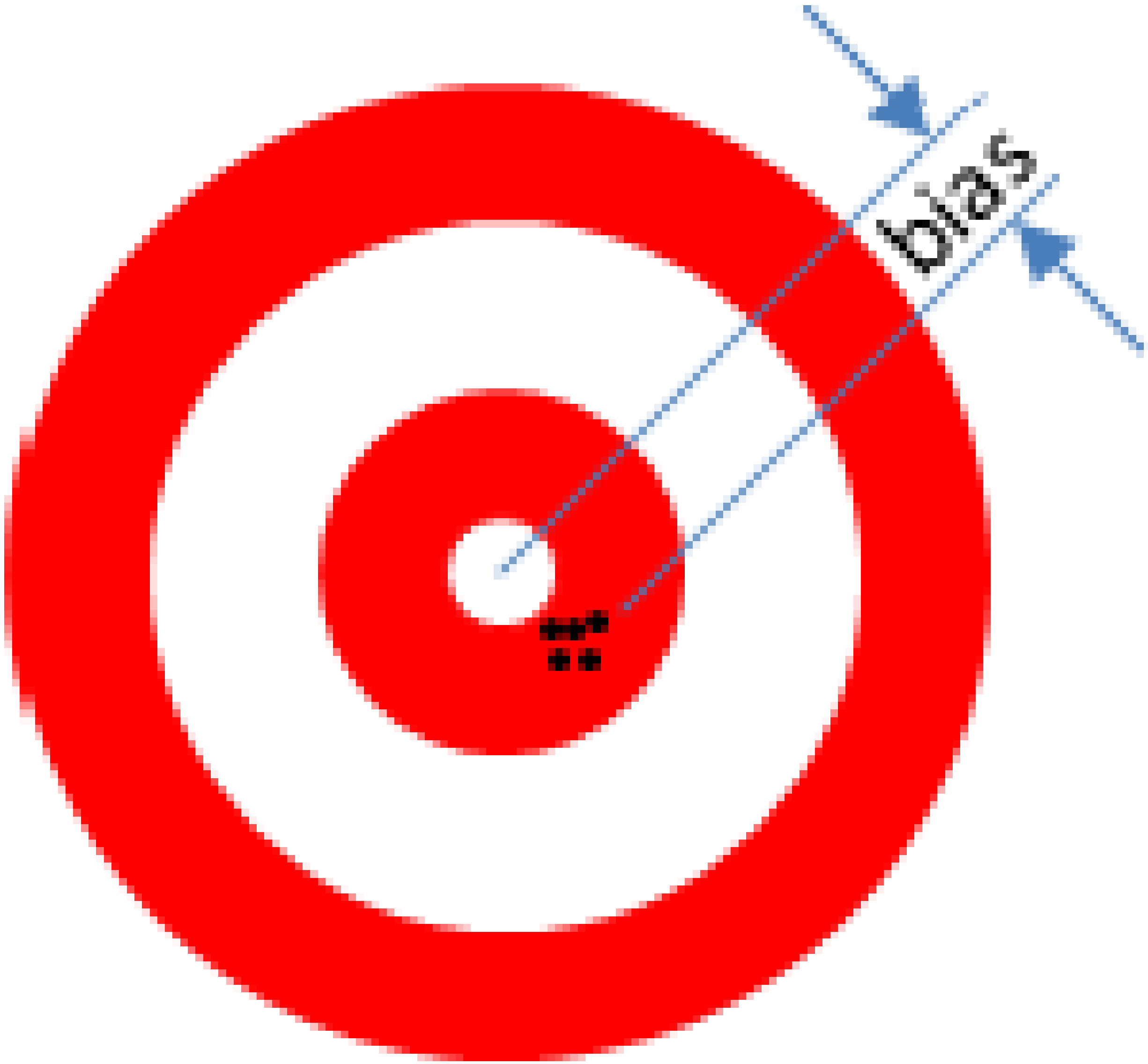
Hammerstein et al, Radiology, 1979; 130, 485–491.


NATIONAL
GEOGRAPHIC
What the average human will look like in
2050 according to National Geographics.

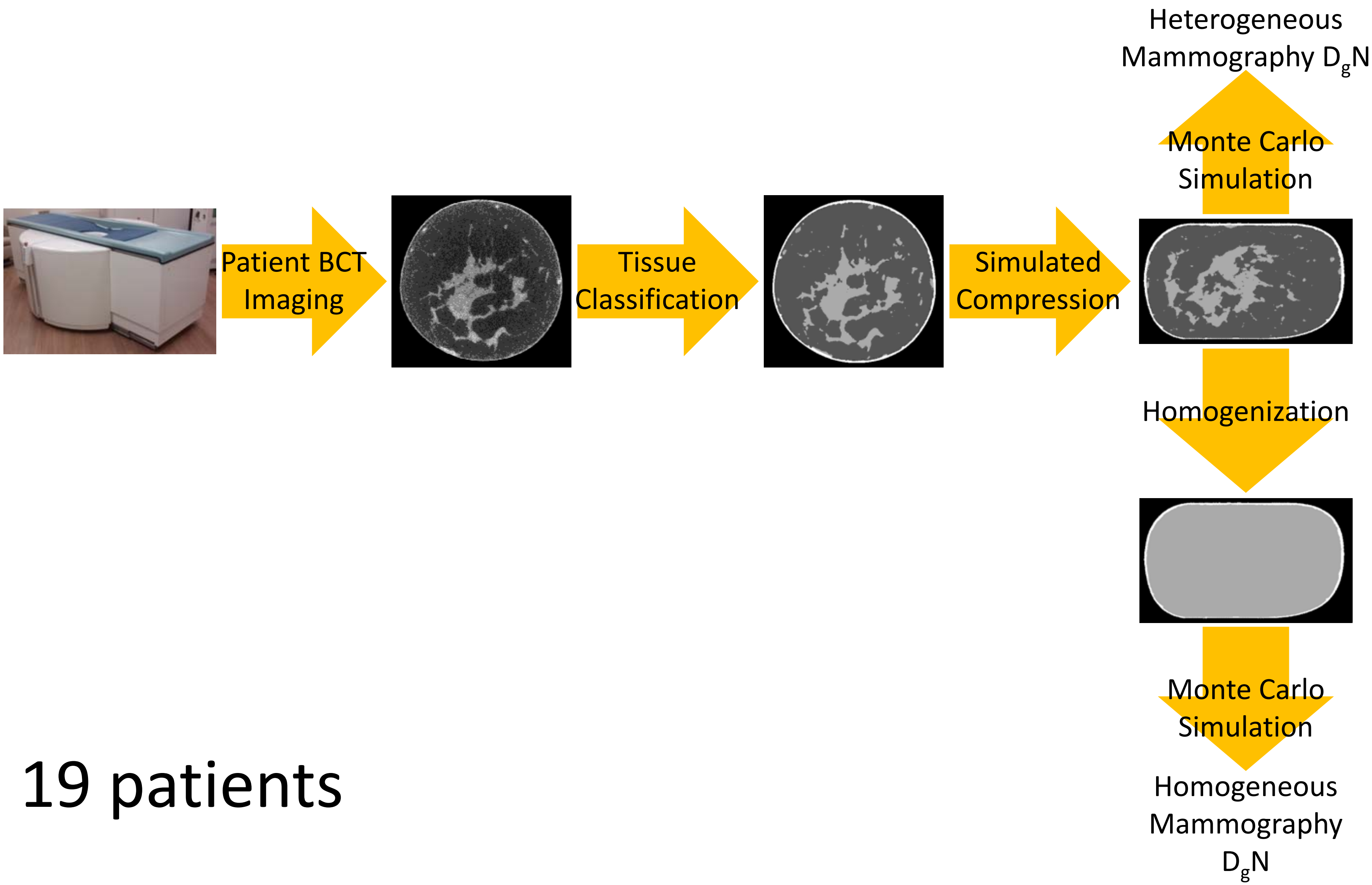
So…

“detailed information will have to be obtained on the amount and distribution of gland tissue in many individual cases” before individual risk estimates can be made.

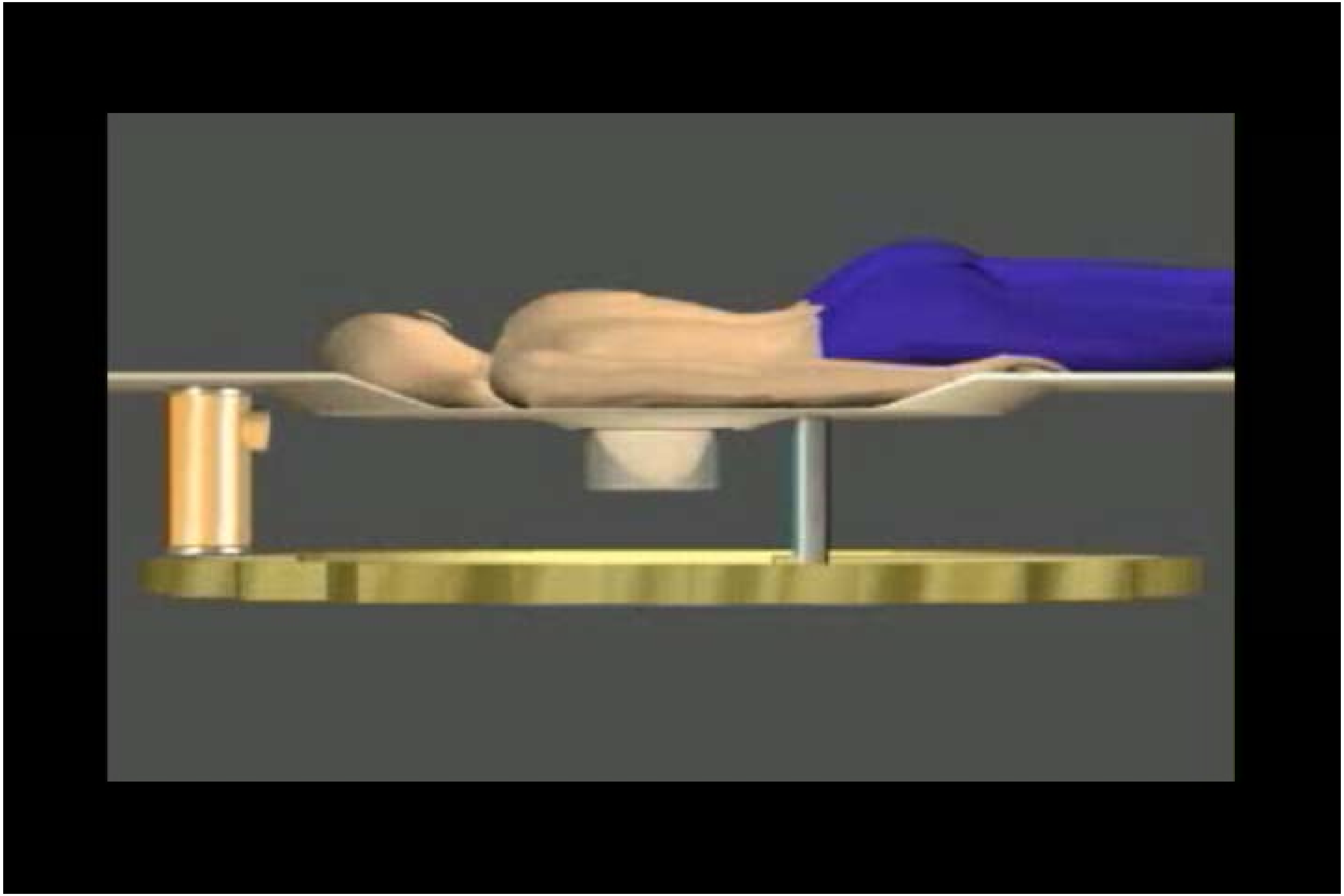
Hammerstein et al, Radiology, 1979


bias

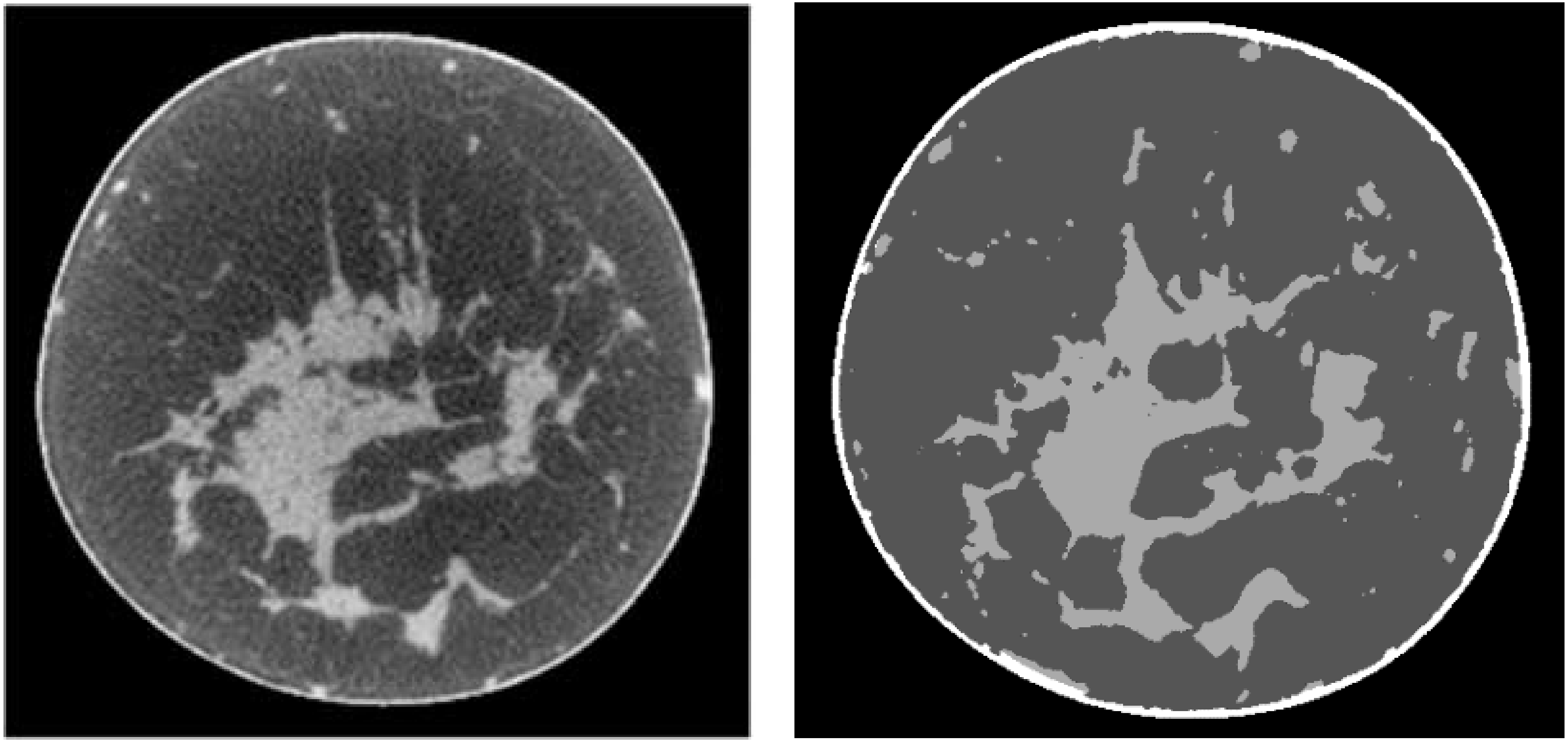
What is the error introduced by the homogeneous tissue approximation in breast dosimetry?


Heterogeneous Mammography D_gN
Monte Carlo Simulation
Patient BCT Imaging
Tissue Classification
Simulated Compression
Homogenization
Monte Carlo Simulation
Homogeneous Mammography D_gN

19 patients

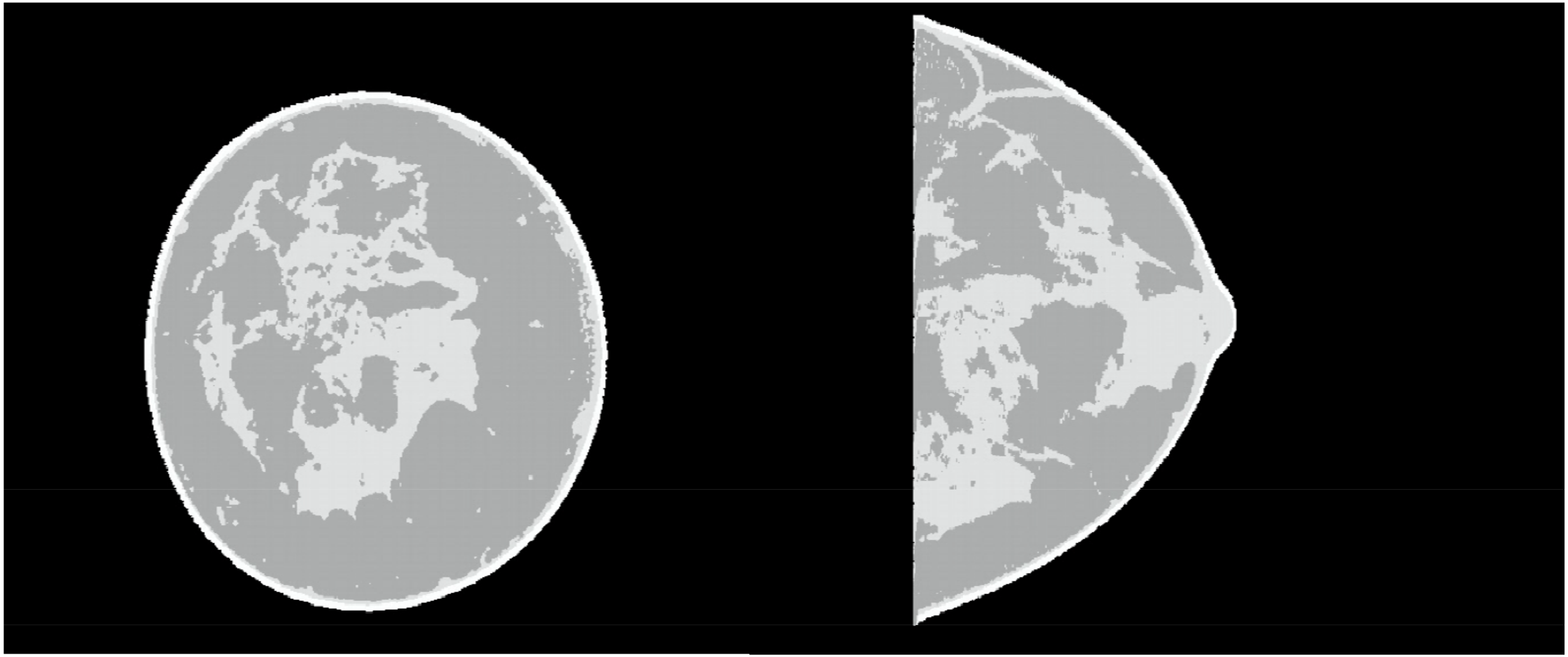


Automated Tissue Classification



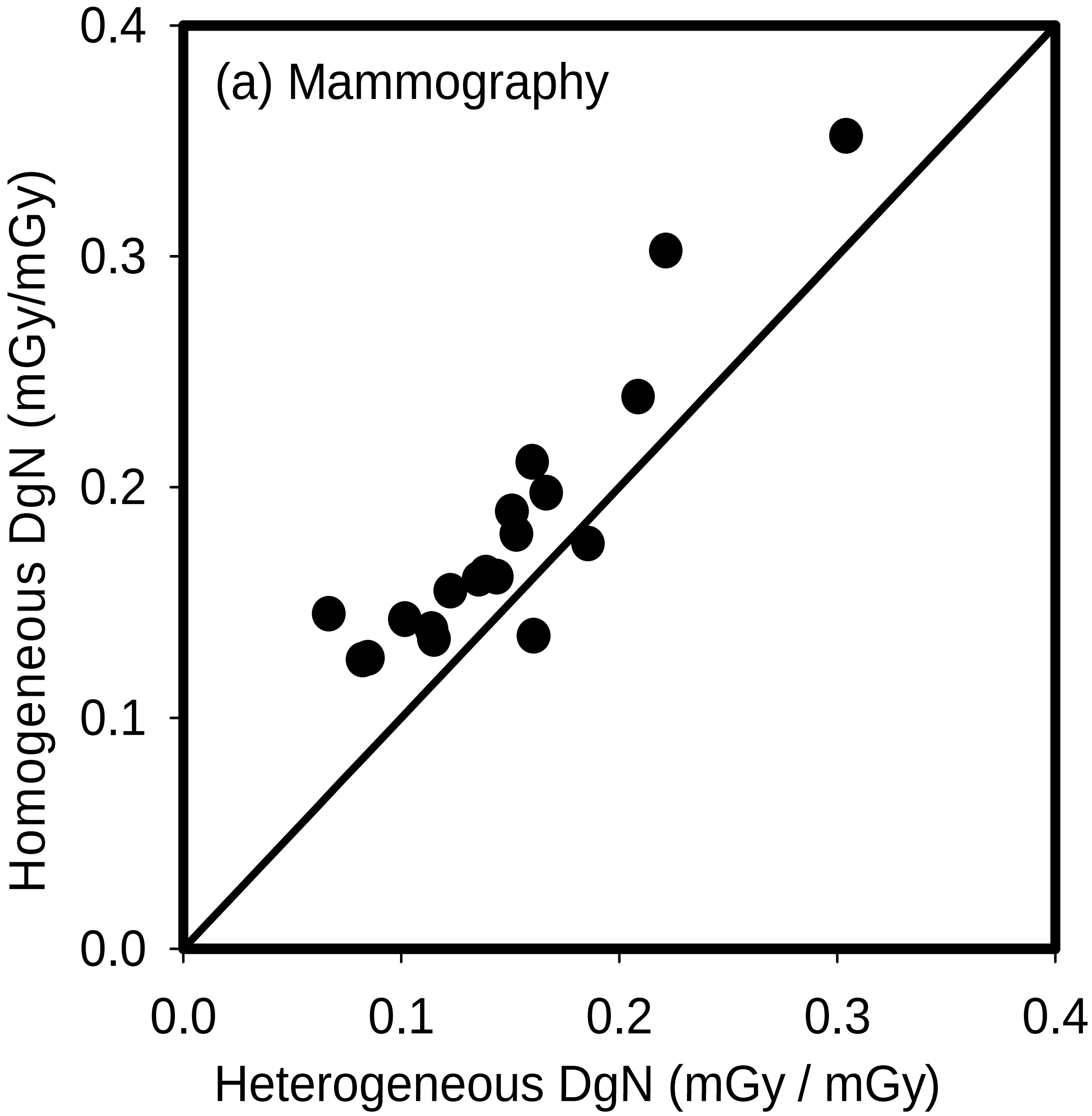
Yang et al, Medical Physics, 2012, 39(10), 6397-6406.

Mechanical Breast Compression

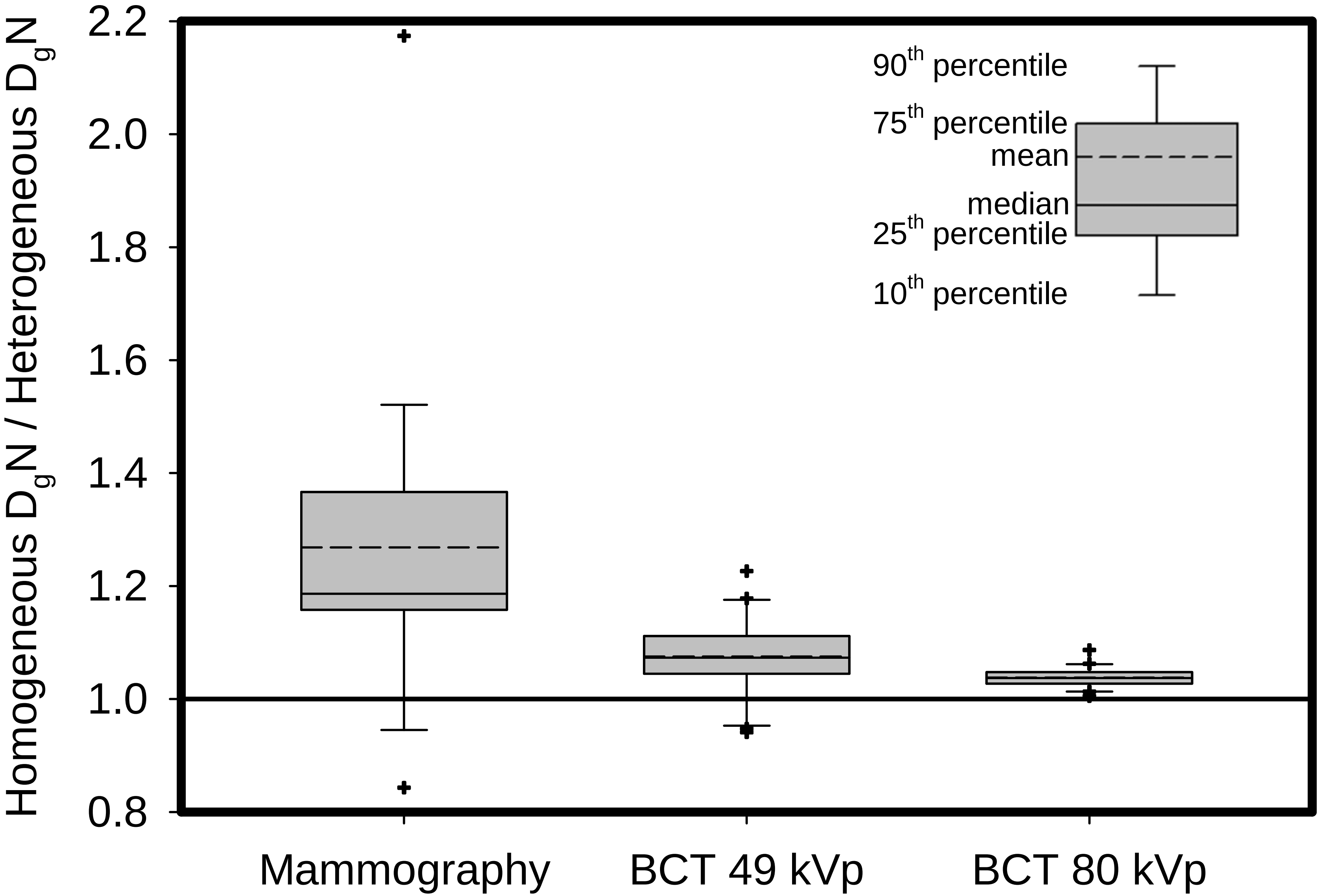


Zyganitidis et al, Med. Biol. Eng. Comput. 2007, 45, 661-669.

Monte Carlo simulations



(a) Mammography
Homogeneous DgN (mGy/mGy)
Heterogeneous DgN (mGy / mGy)
0.0
0.1
0.2
0.3
0.4



Sechopoulos et al, Medical Physics, 2012, 39(8), 5050-5059

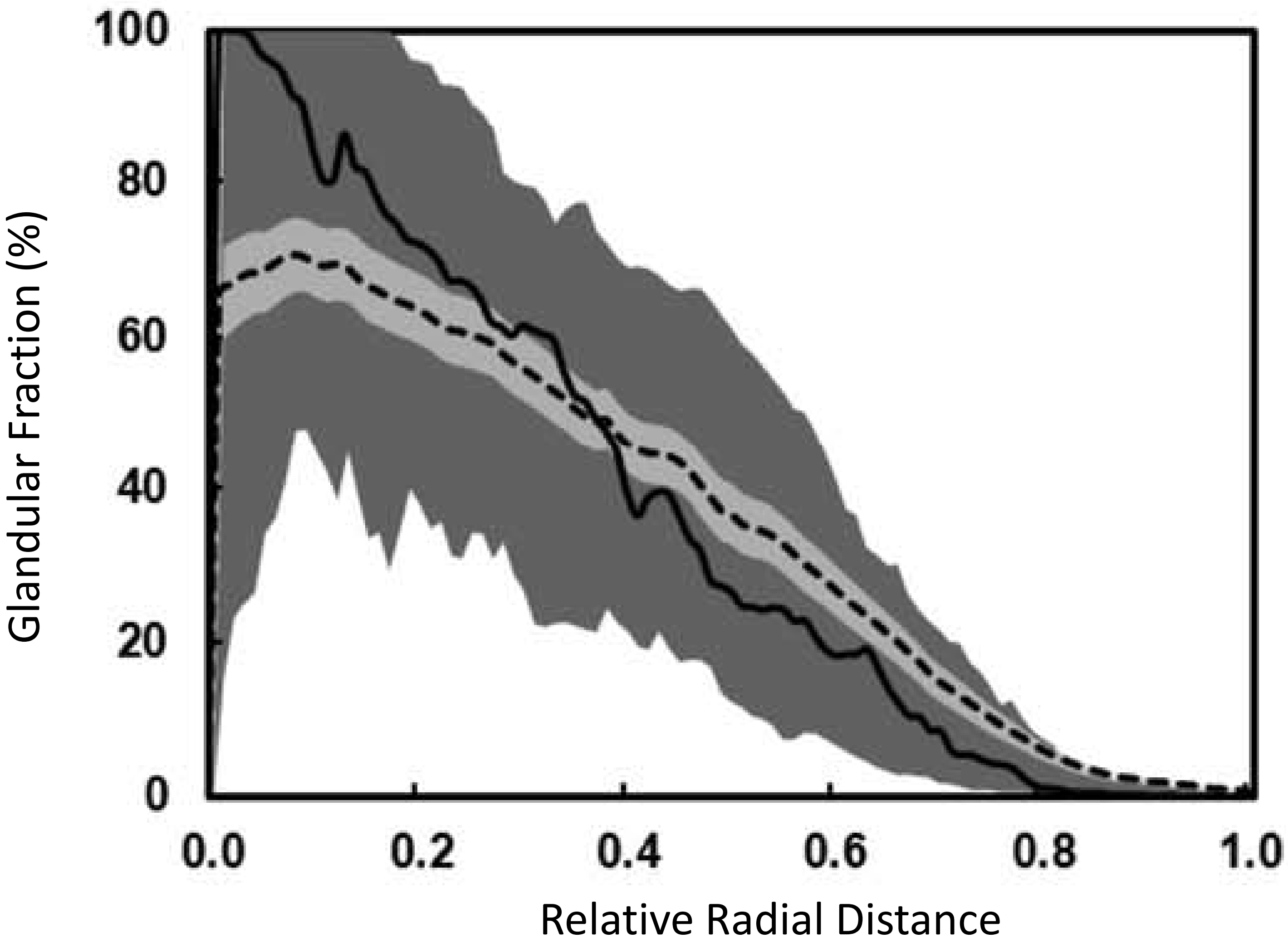
Radboudumc

Model-based Confirmation (N=219)

Mo anode: −35.3% (SD = 4.1)

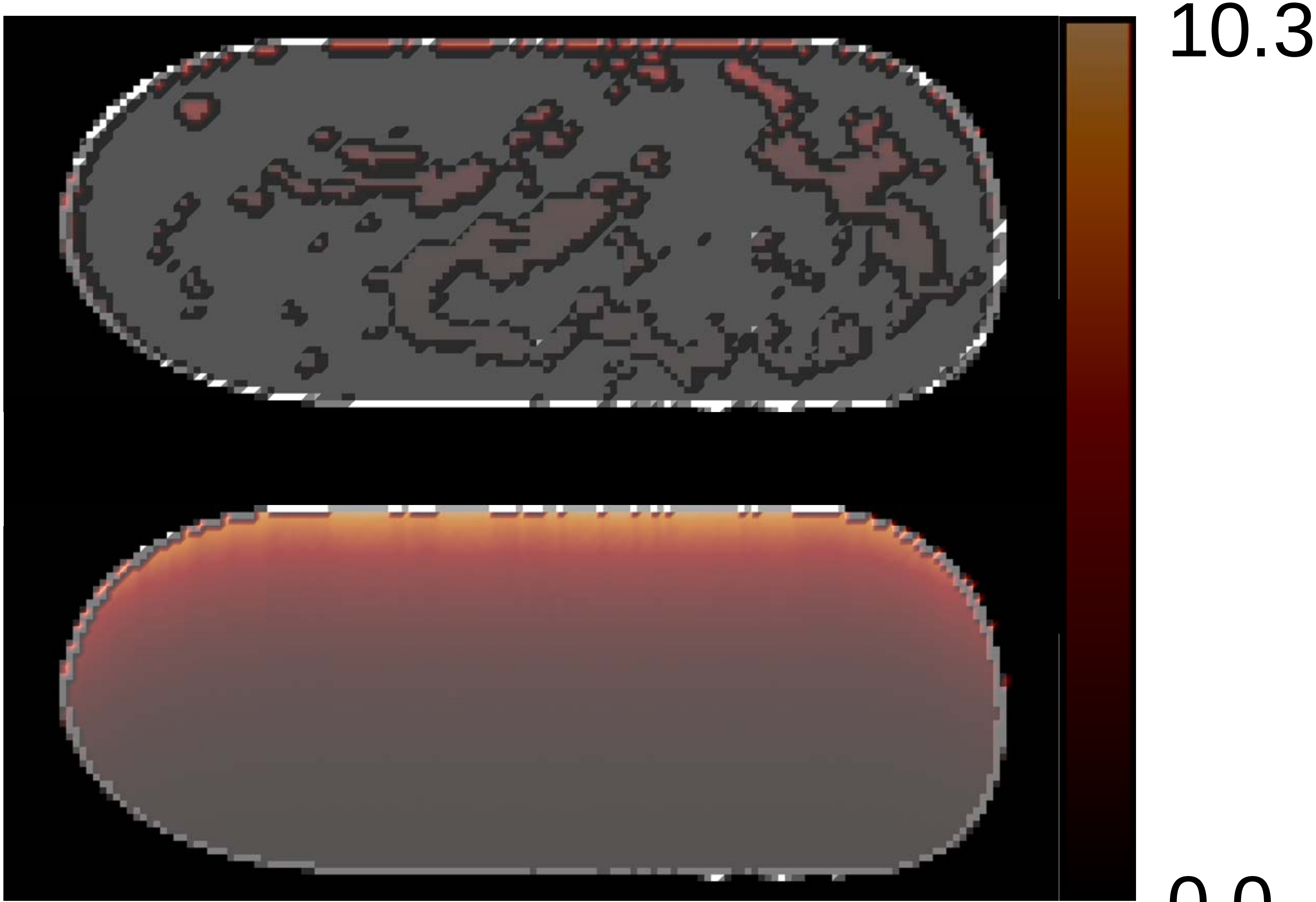
W anode: −24.2% (SD = 3.0)

Glandular tissue distribution

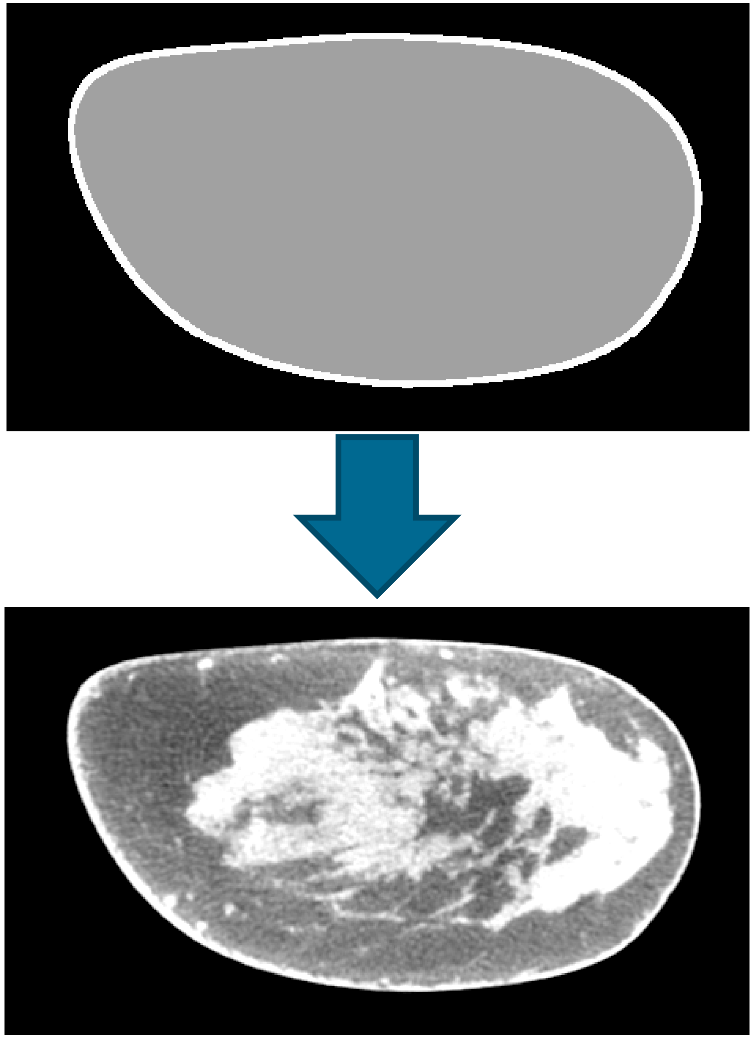


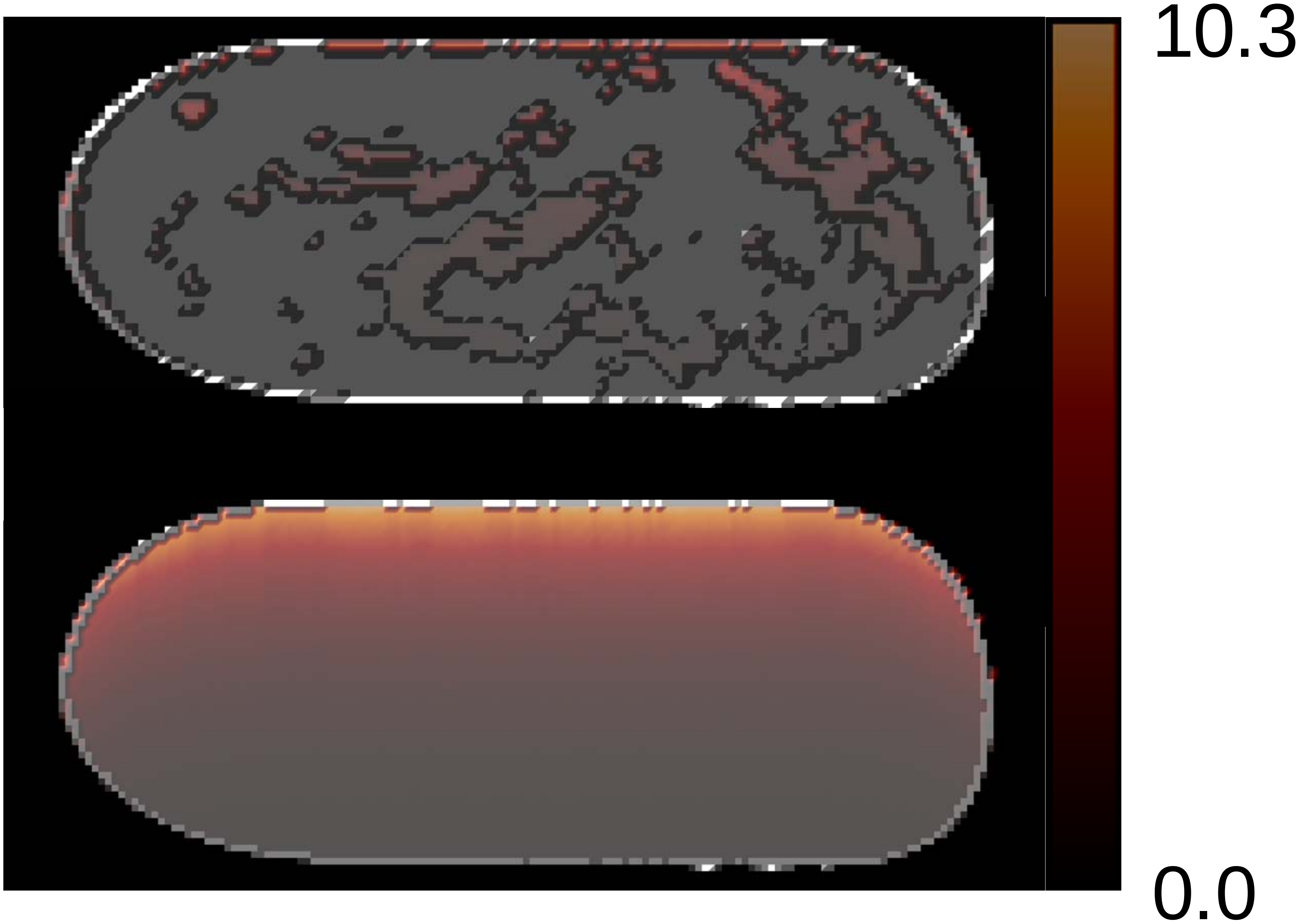
Huang et al, Med. Phys. 38(4), 2180, 2011

Radboudumc


10.3
0.0

Patient-Specific Breast Dosimetry

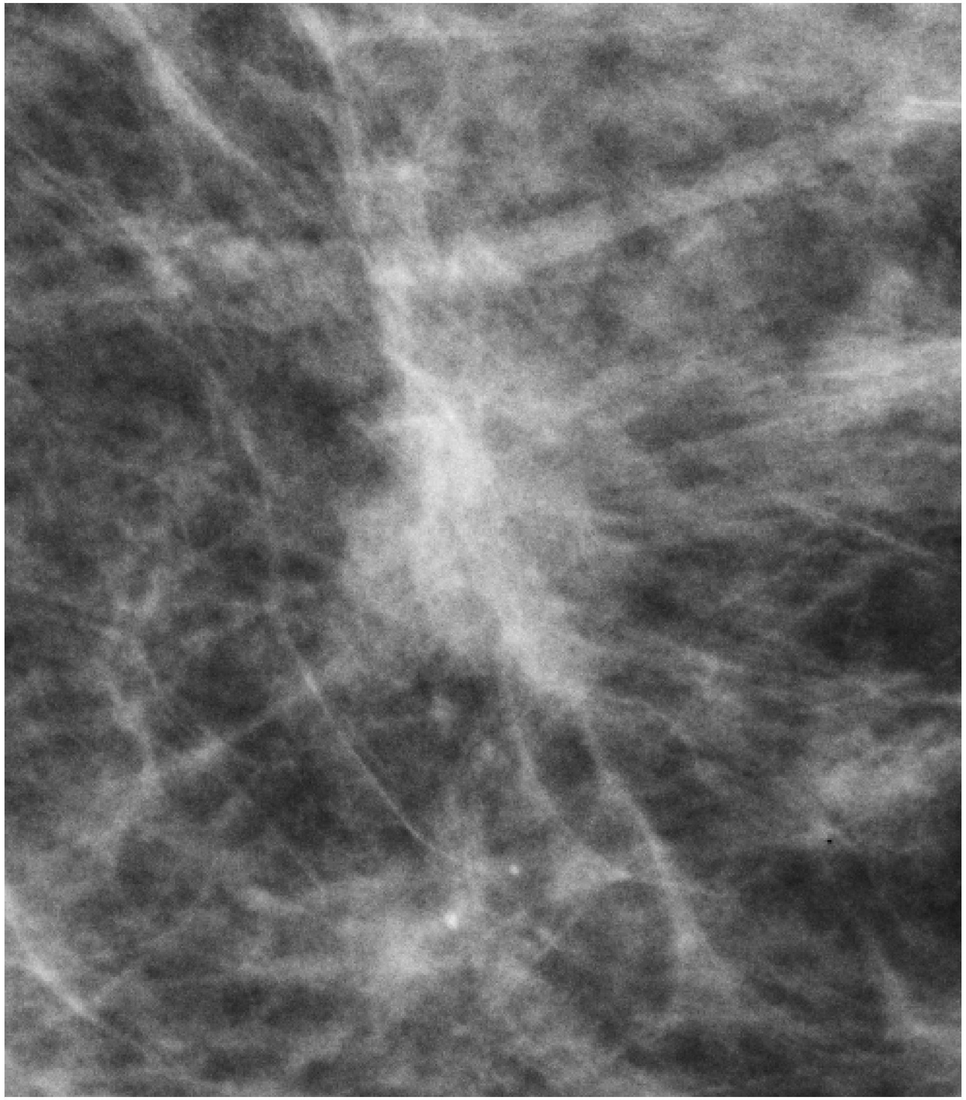



10.3
0.0

DIGITAL BREAST TOMOSYNTHESIS

https://www.youtube.com/watch?v=qju-rw8MmHs

Courtesy of Hologic Inc.



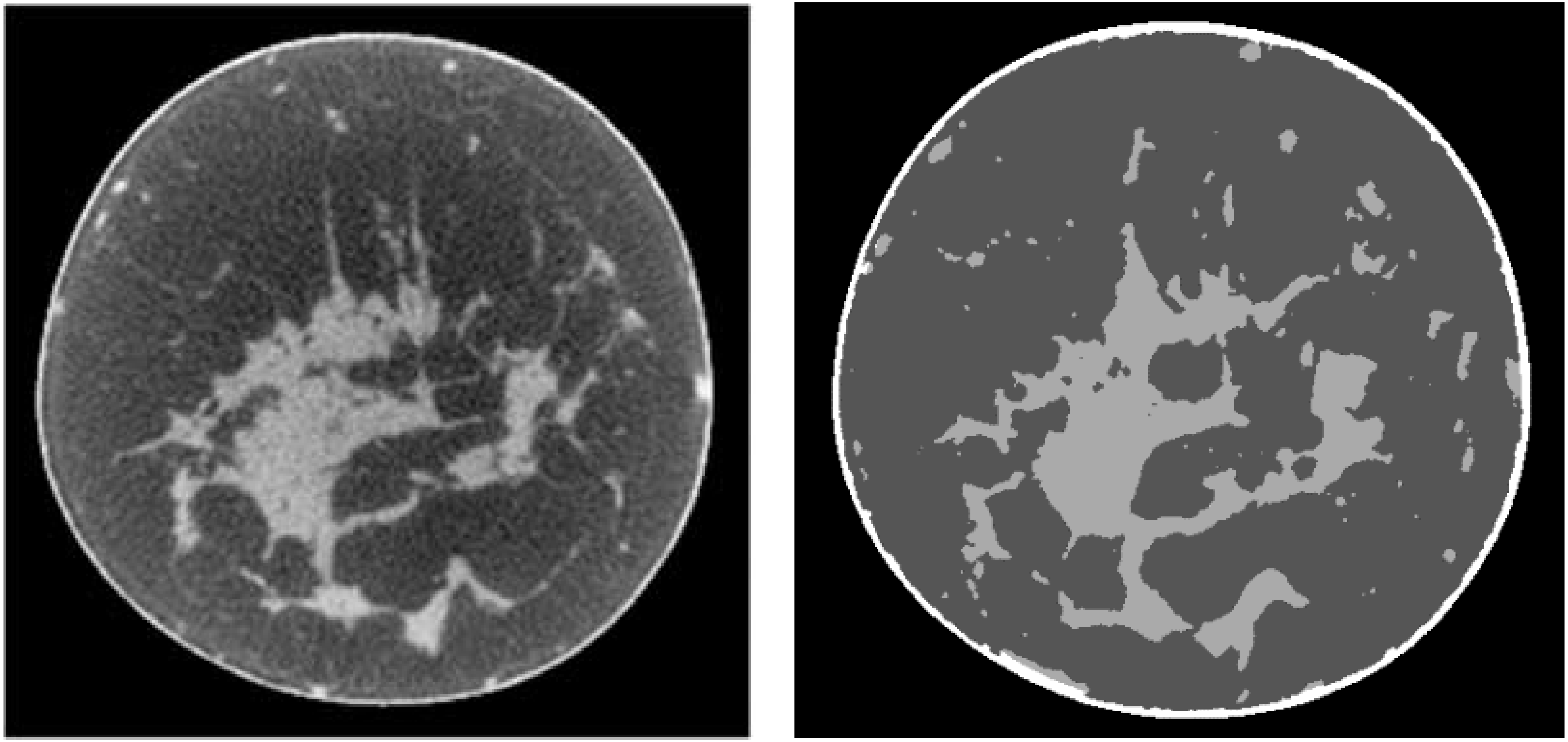
Courtesy of Hologic Inc.

Radboudumc

Patient-Specific Breast Dosimetry

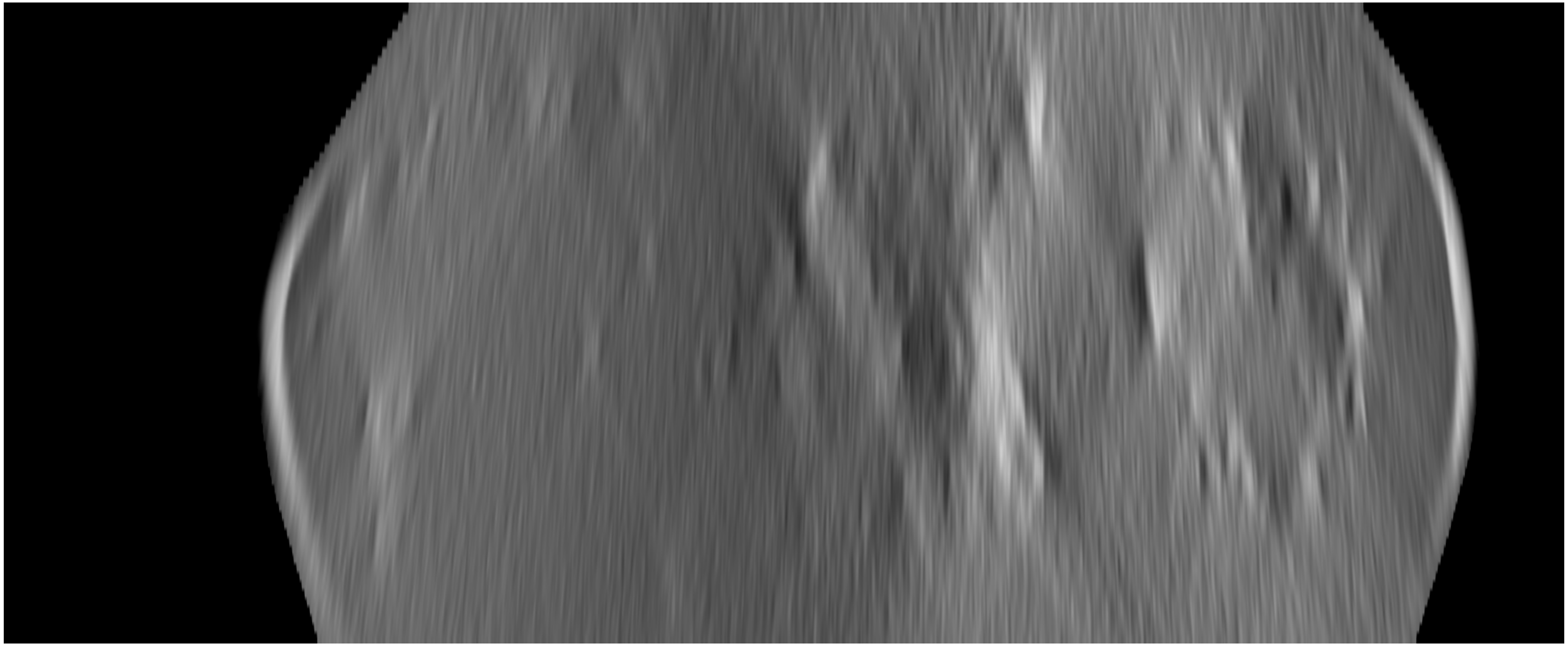
Need a tomosynthesis image classification algorithm

Automated Tissue Classification



Yang et al, Medical Physics, 2012, 39(10), 6397-6406.

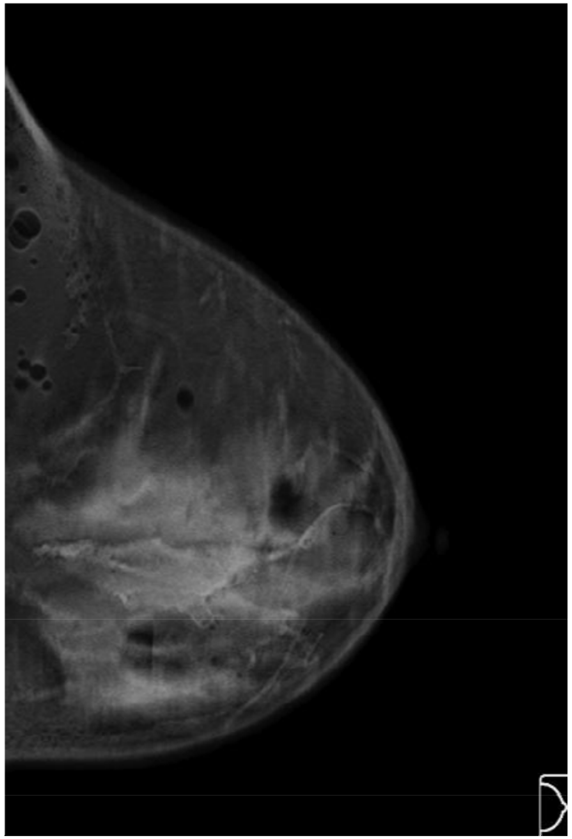
Image in the “wrong” direction



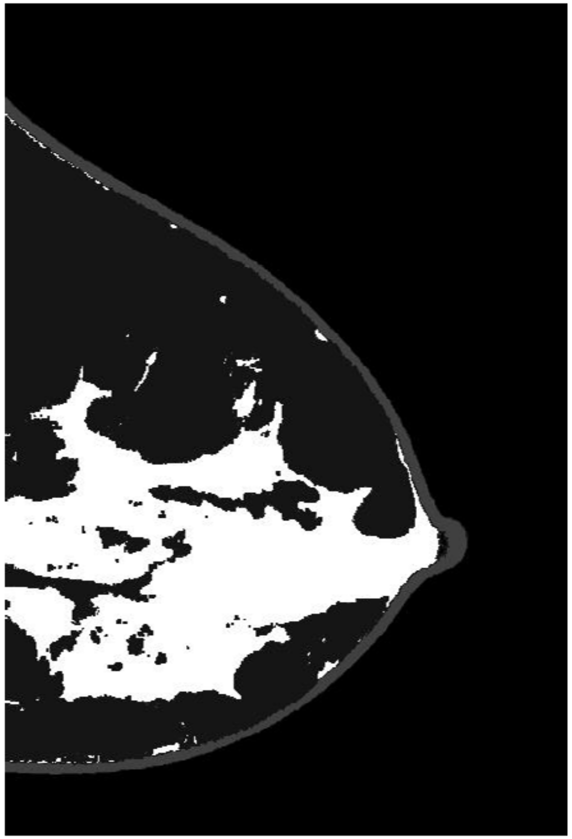
Option 1

Classify the reconstructed tomosynthesis image

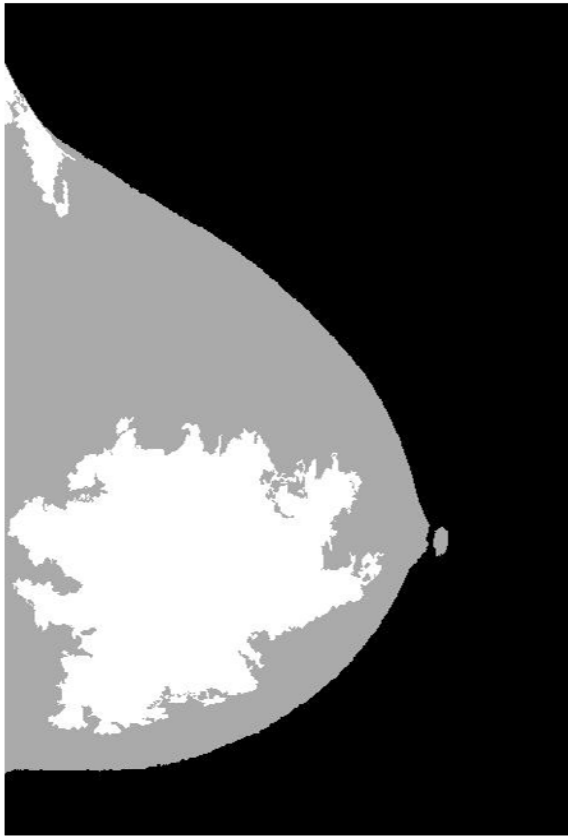
Representative Classification - Fuji



Tomography

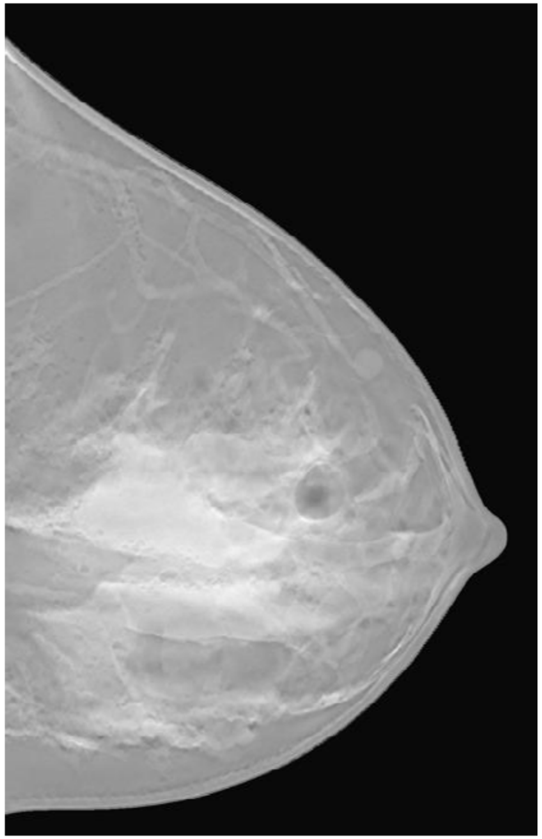


Gold Standard

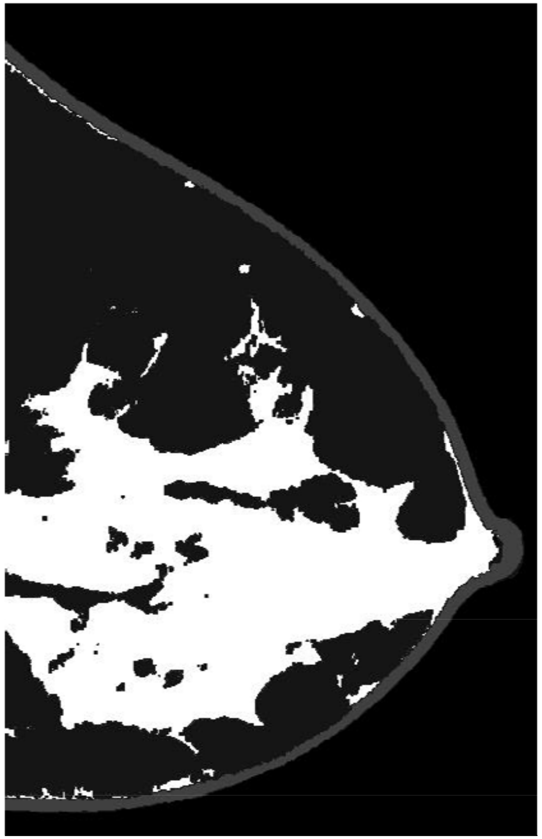


Classification

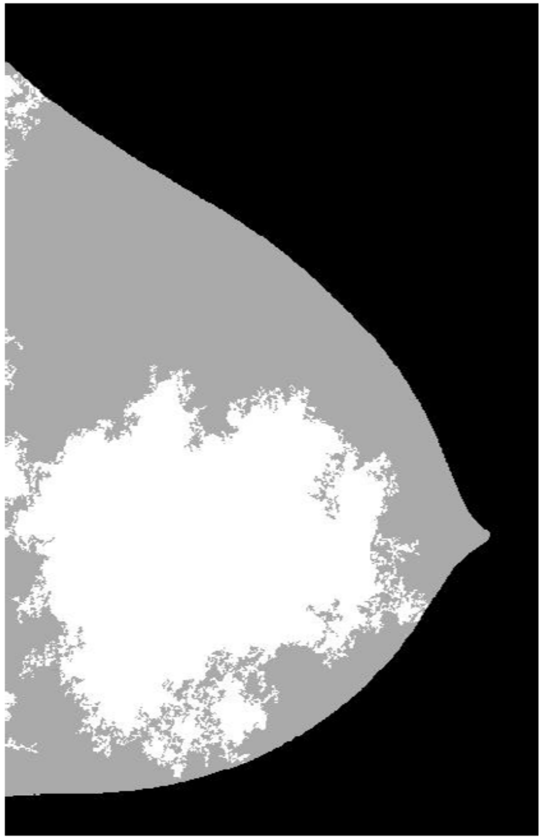
Representative Classification - Phillips



Tomography



Gold Standard

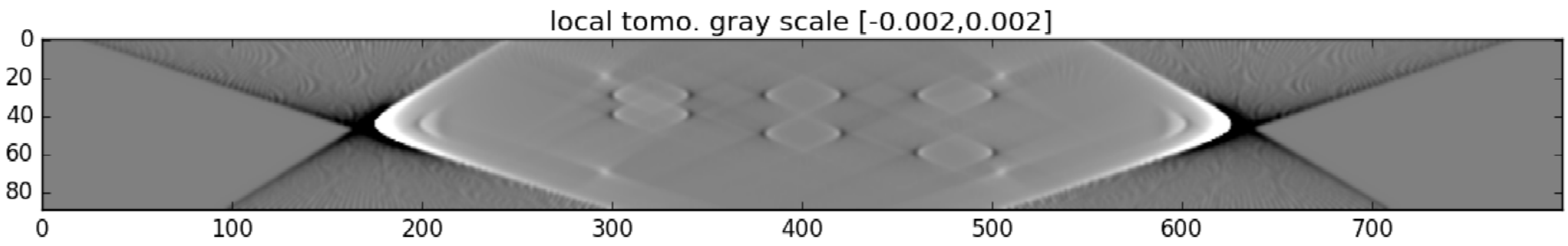


Classification

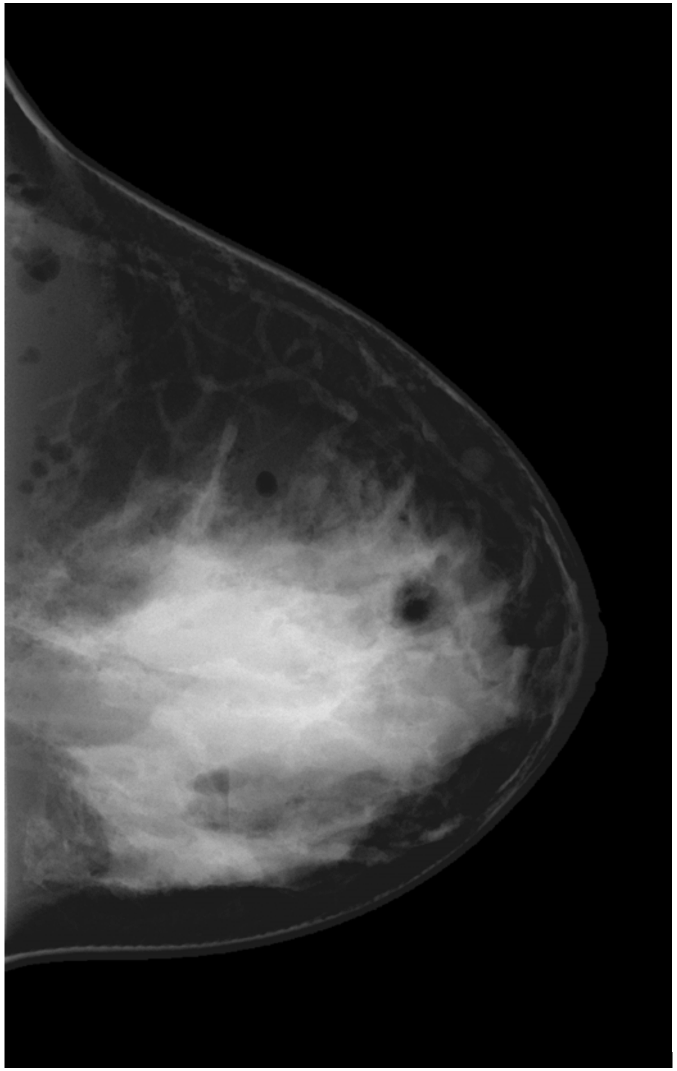
Option 2

Reconstruct to a binary (trinary?) image

Local tomography



Density maps




WORK IN
PROGRESS

Patient-Specific Breast Dosimetry

4-year project funded by the Susan G. Komen Foundation for the Cure

How does dose translate to risk?

In short...

Breast dosimetry for QA/QC is well understood

So are its shortcomings

Patient-specific dose

Possible with (pseudo-)3D imaging

Questions?