Patient Dosimetry in Mammography and Tomosynthesis:

What to measure, why and how

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Mammography and Tomosynthesis Dosimetry

Mammography

- Why measure breast dose?
- Basic Concepts of Breast Dosimetry (how)
- Mean Glandular Dose (MGD) (what)
- DgN coefficients
- Skin Thickness Issues
- Breast Density Issues

Tomosynthesis

- Differences between tomo and mammo

Summary

U.S. Breast Cancer Statistics (2006)

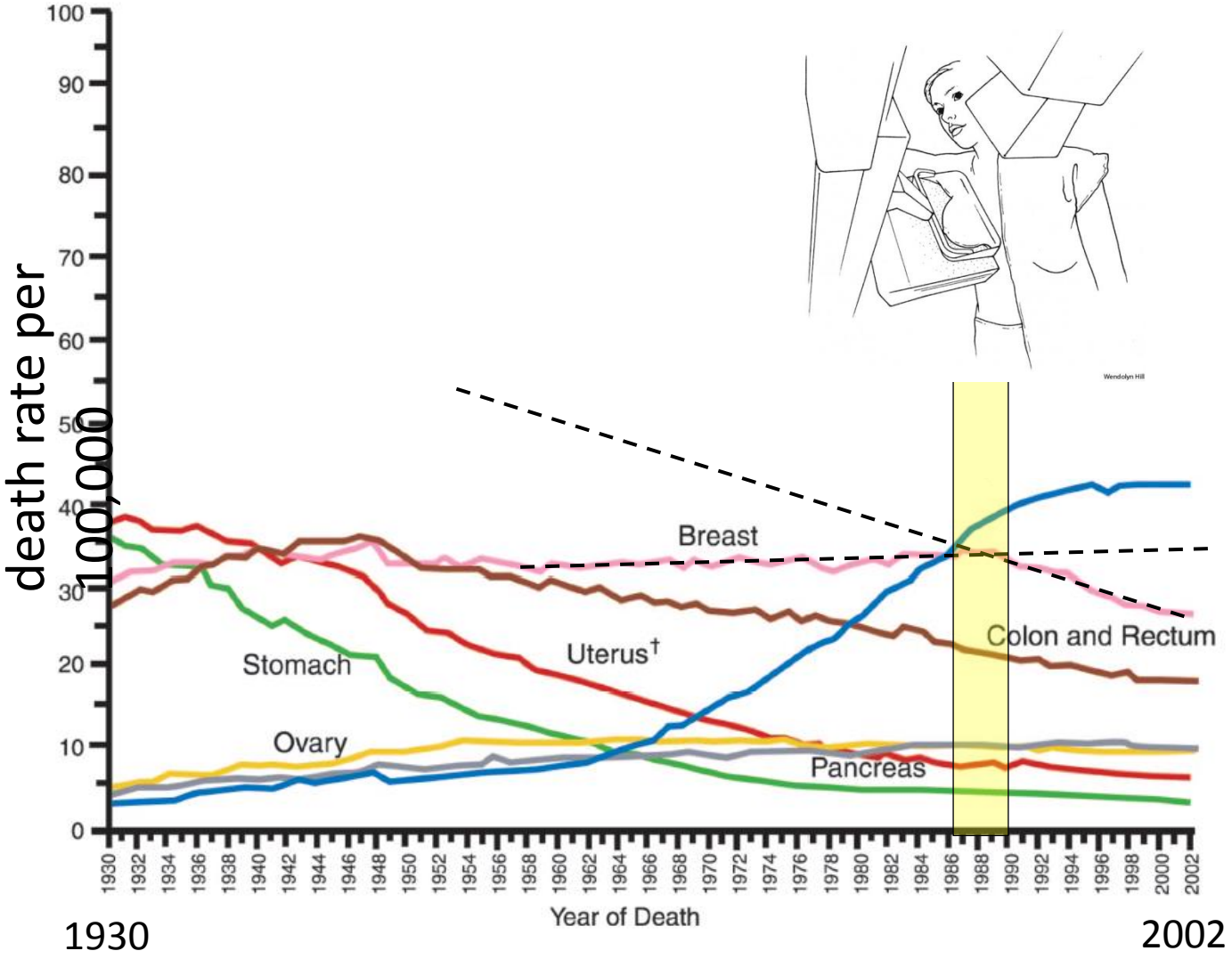
212,290 new cases
40,970 deaths
1 / 8 women will get breast cancer (12.5%)

	Incidence*	Mortality*
Breast Cancer	31%	15%
Lung Cancer	12%	26%

Ravdin, *et al*., NEJM 2004

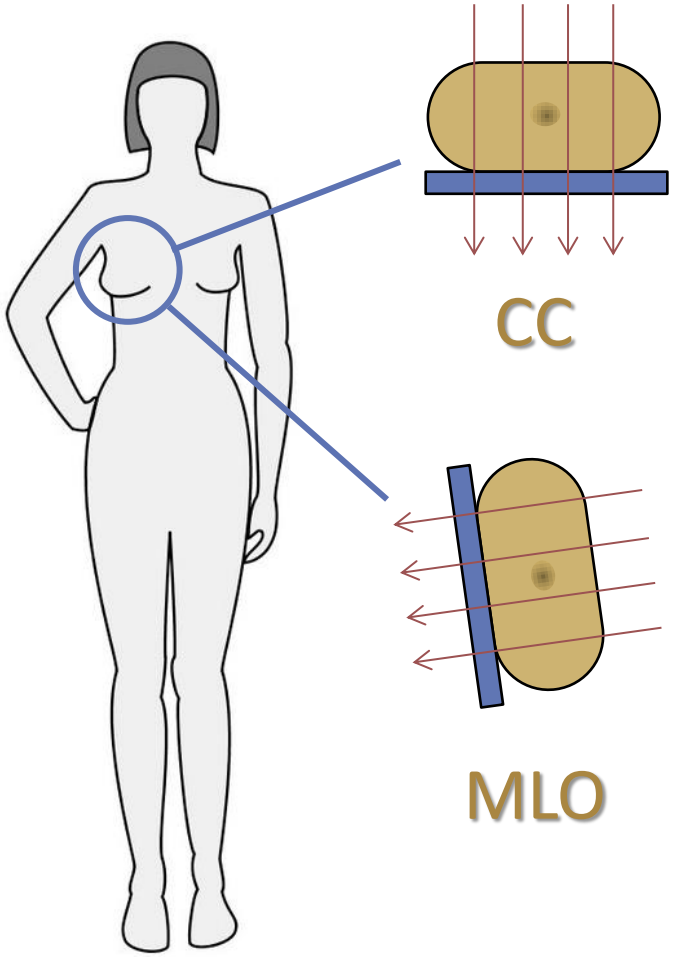
* of all cancers

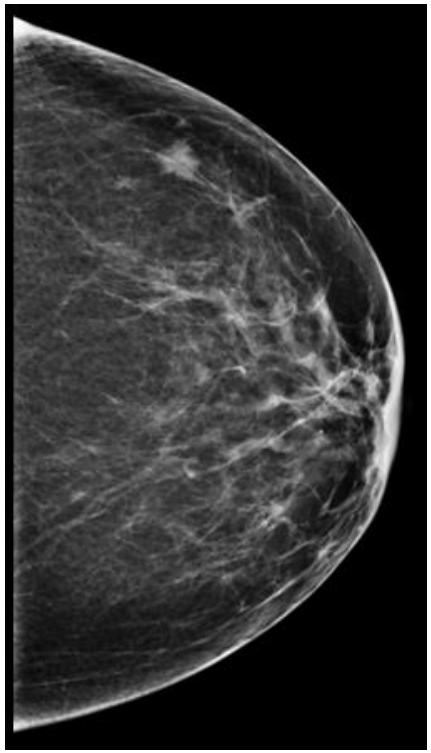
U.S. Cancer Mortality (1930-2002)



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

Mammography: Standard of Care

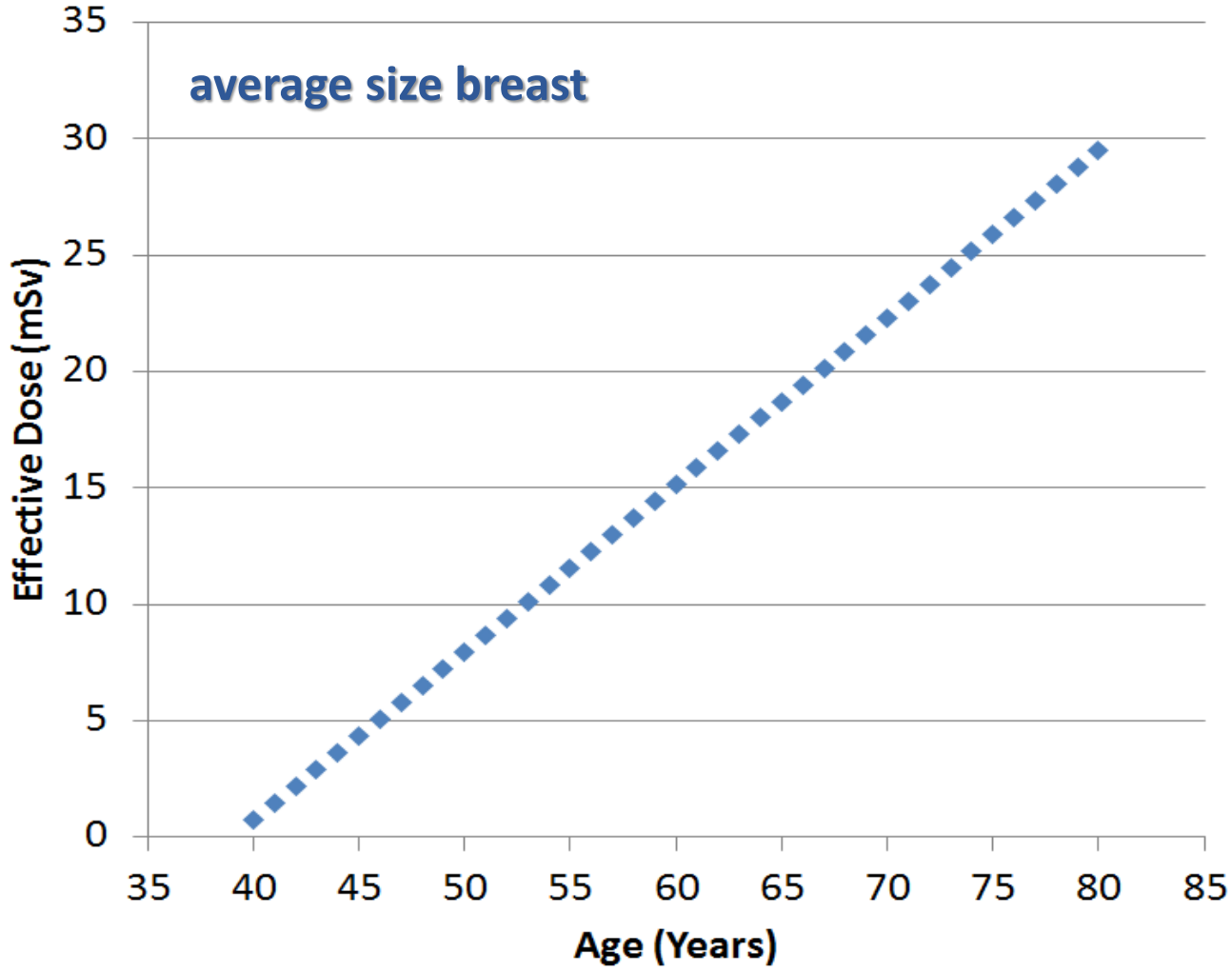




CC

MLO

Annual screening dose accumulation



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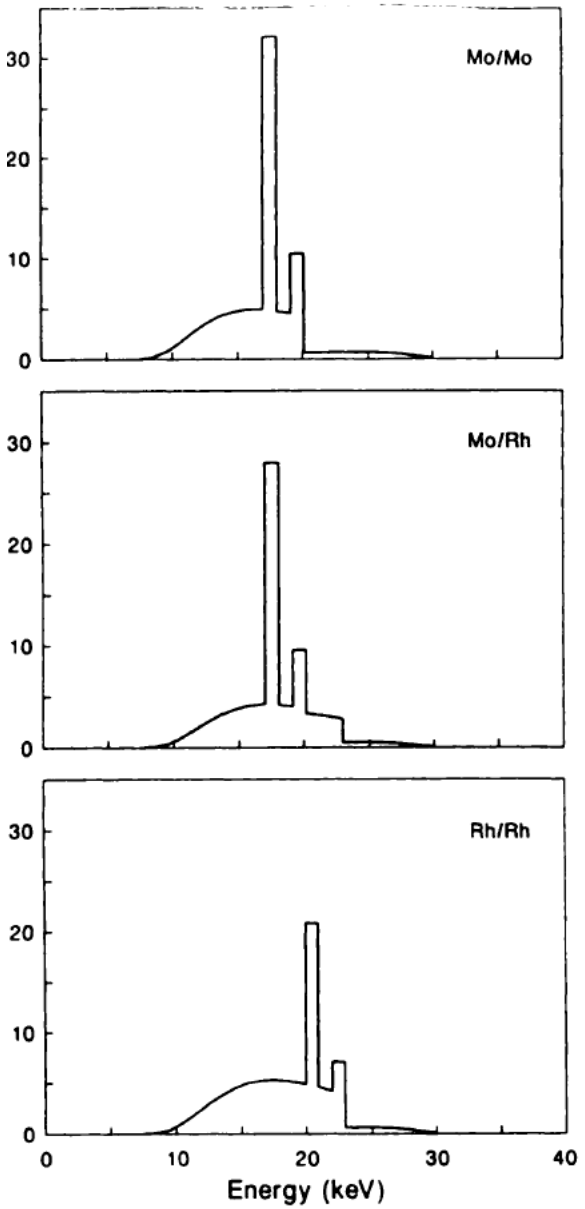
Summary

Digital mammography unit at UC Davis

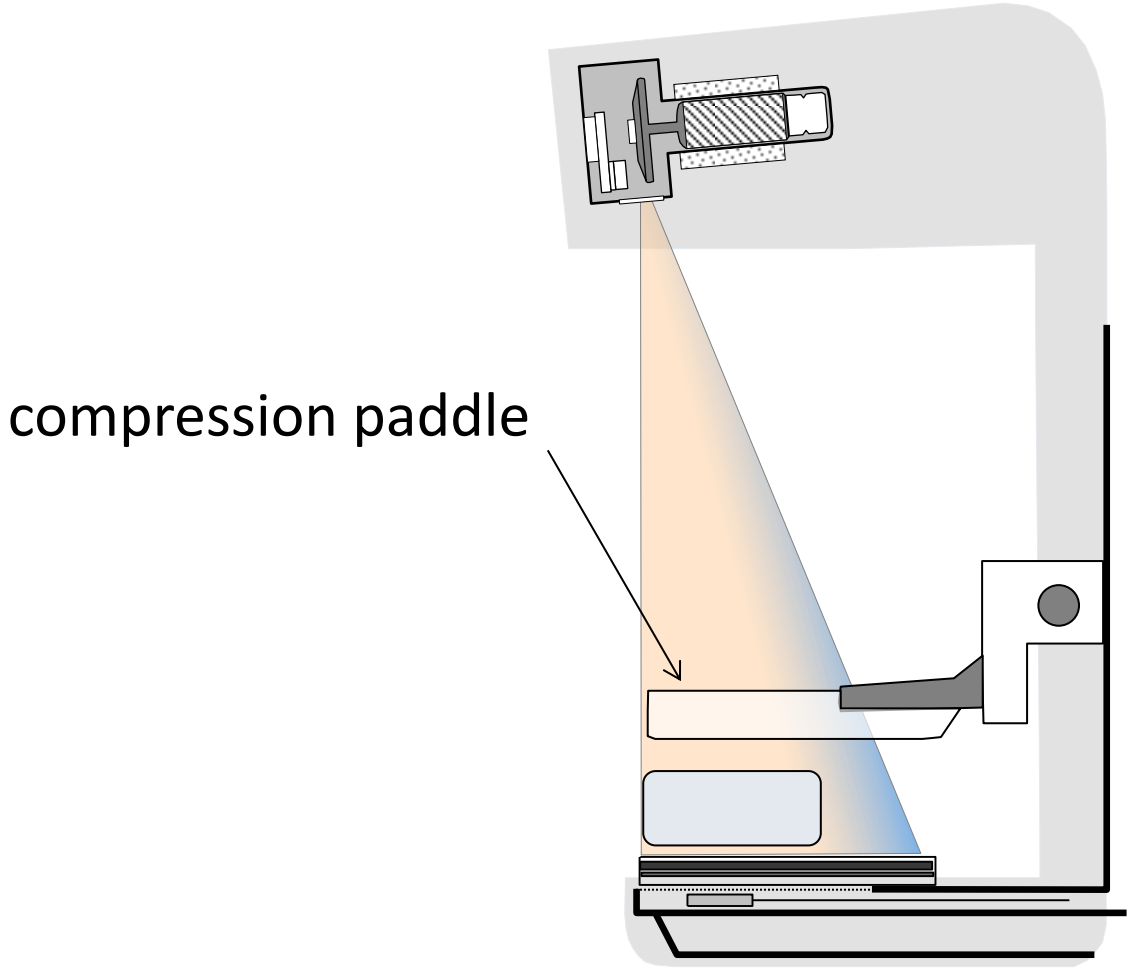
Breast Dose is highly dependent upon the x-ray spectrum used.

Different Anode/Filter combinations are used.

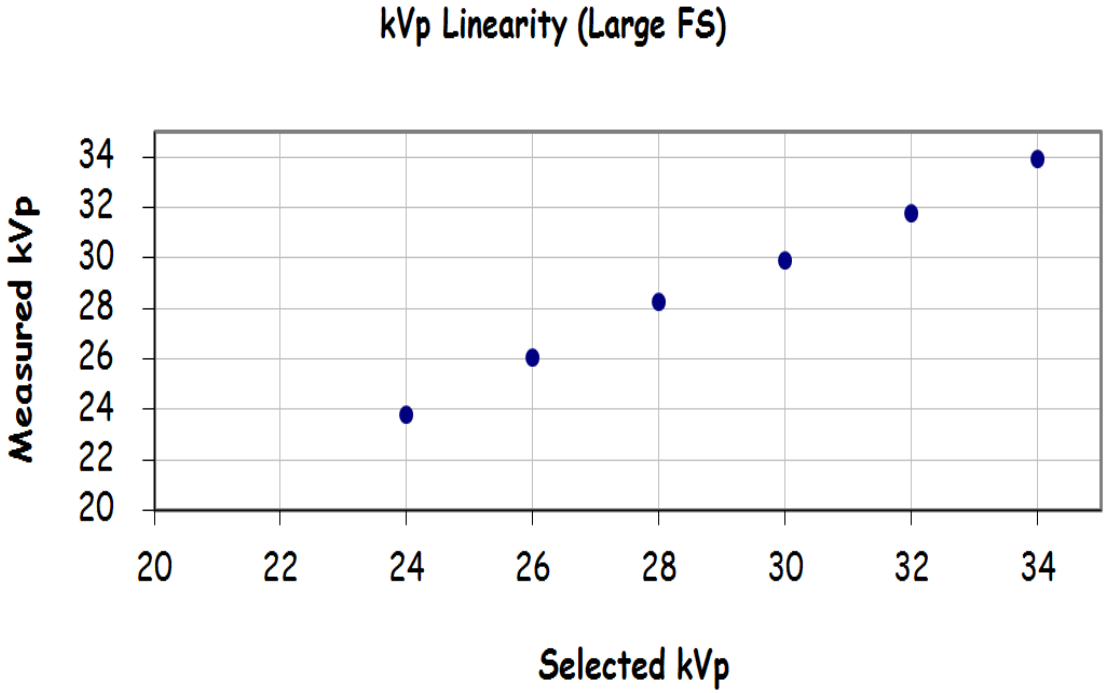
ANODE	FILTER	
Mo	Mo	S/F
Mo	Rh	
Rh	Rh	
W	Rh	Digital
W	Ag	
W	Al	Tomo

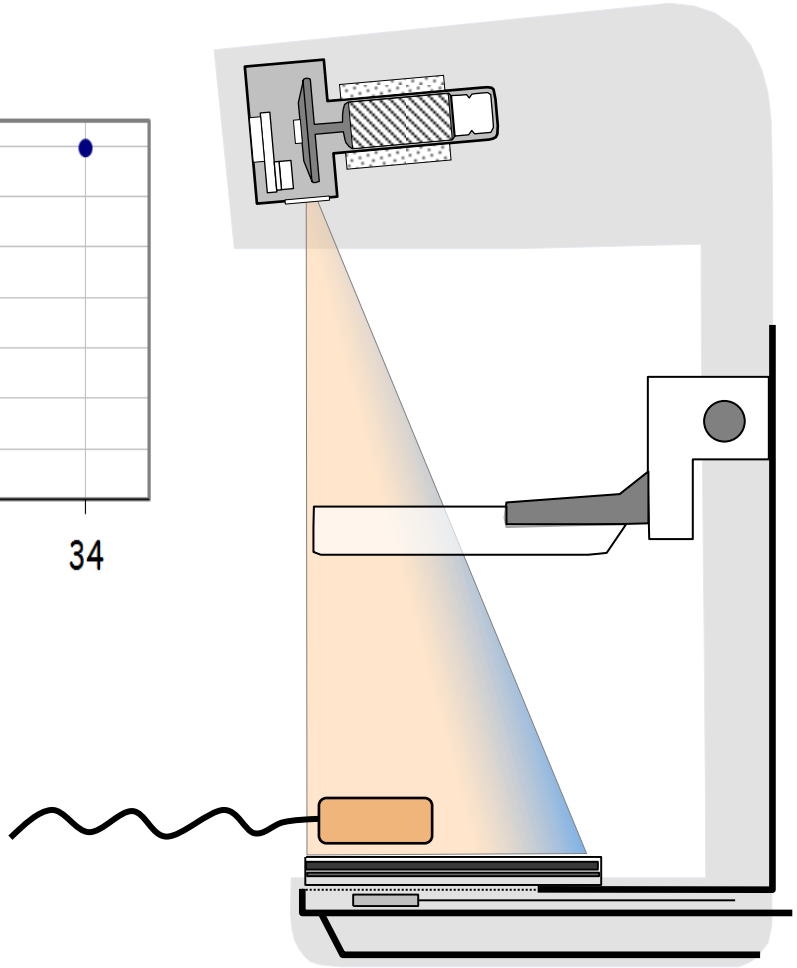


In addition to the Anode / Filter combo, the kV and HVL need to be well characterized



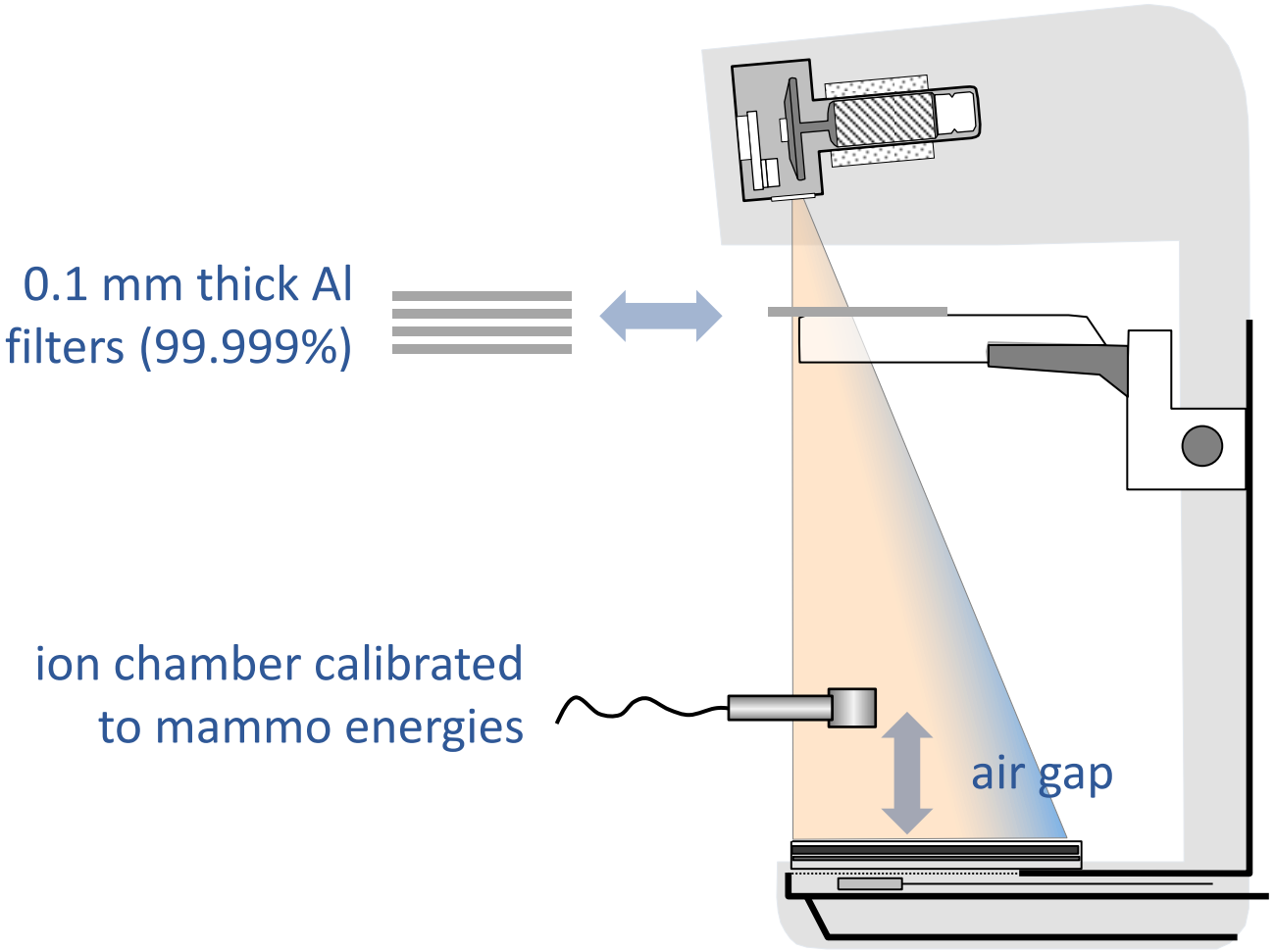
X-ray Tube Voltage Evaluation



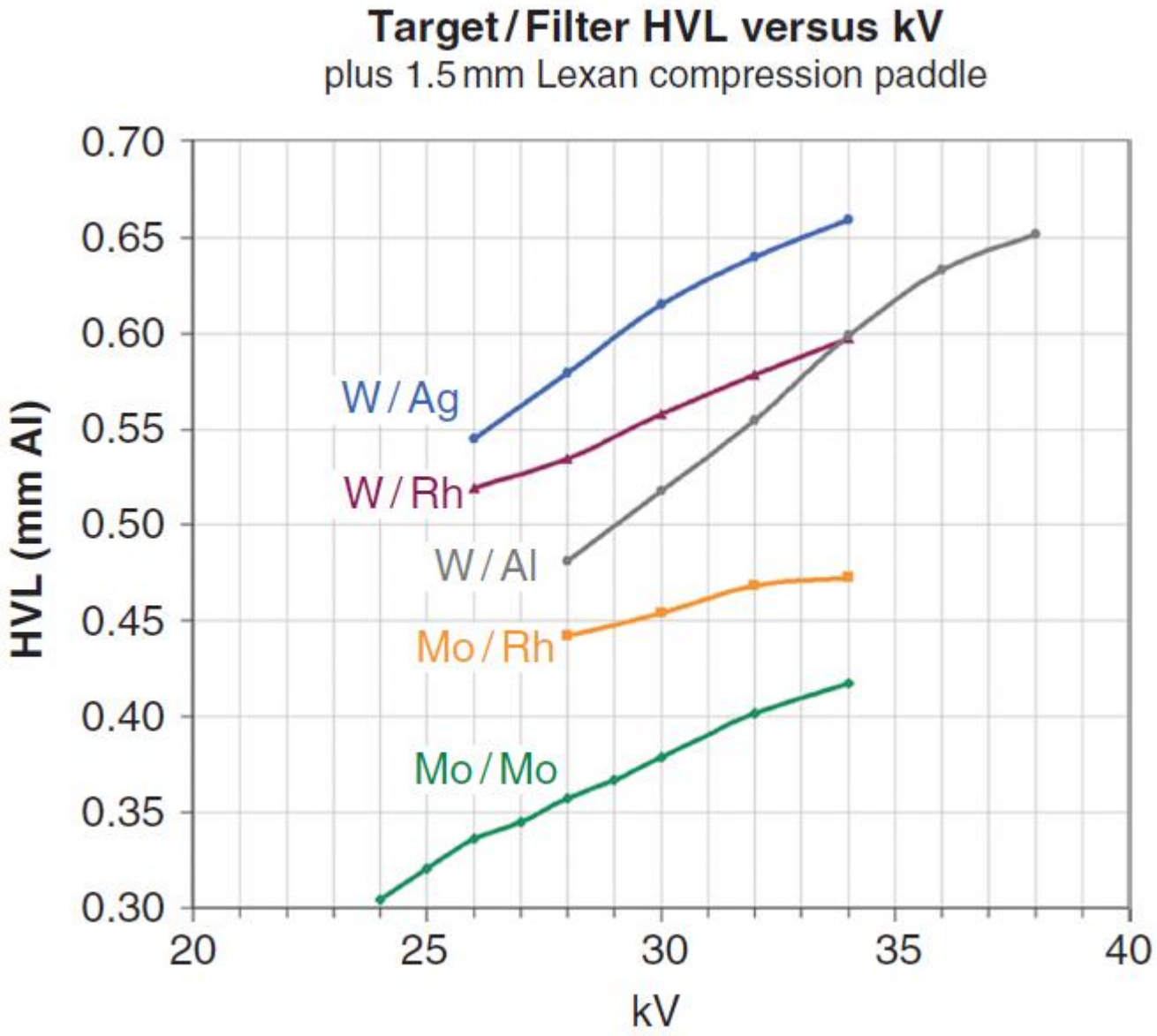


non-invasive kV meter

In addition to the Anode / Filter combo, the kV and HVL need to be well characterized

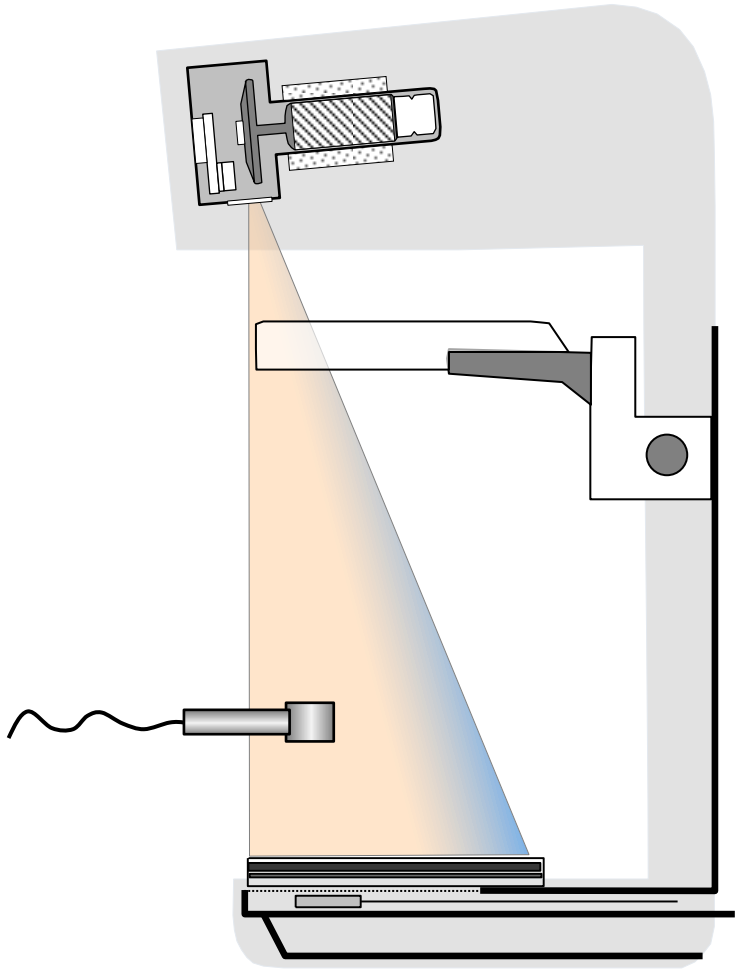


HVL as a function of tube voltage

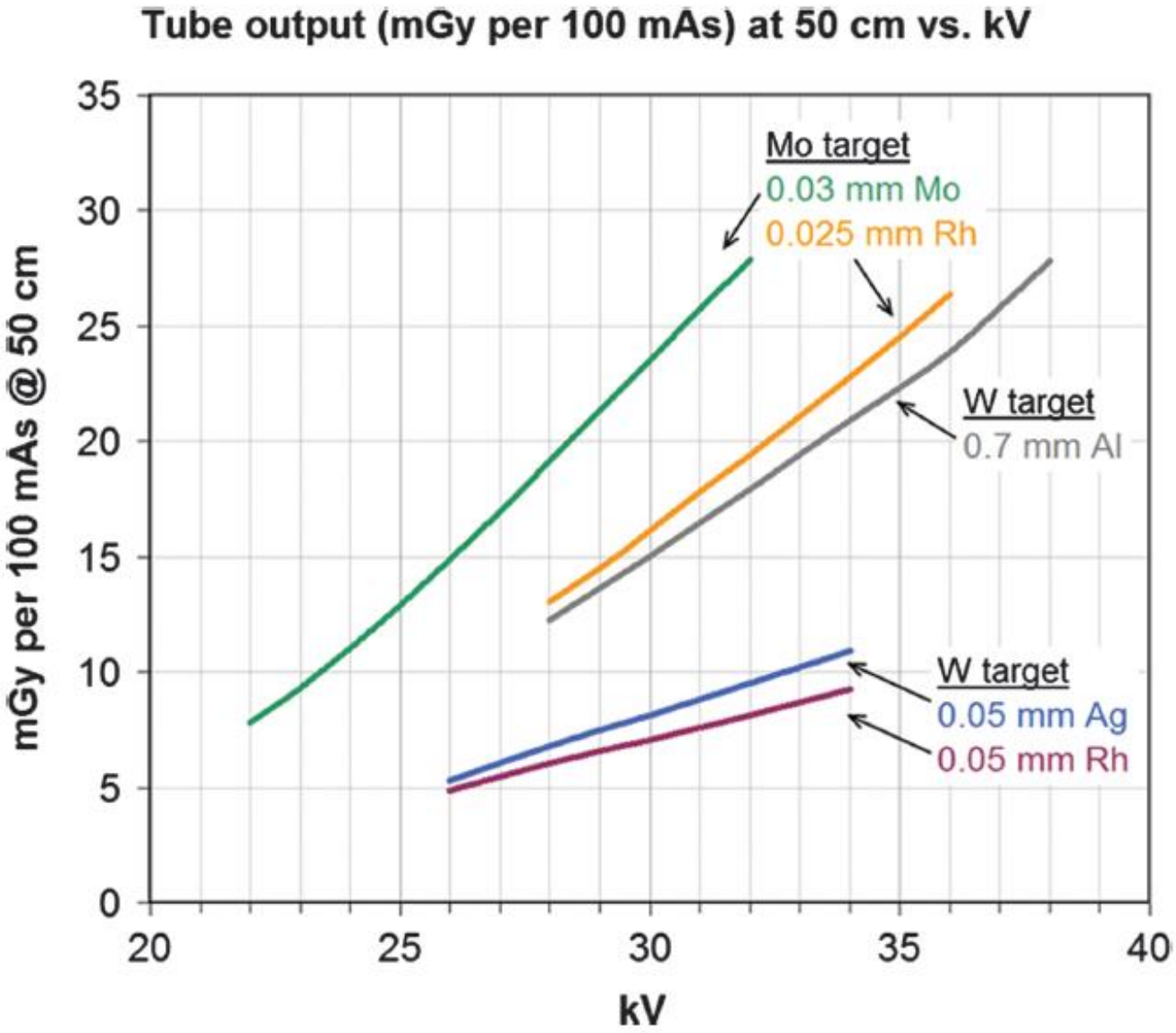


Establishing x-ray tube output

mGy air kerma per
100 mAs at 50 cm



X-ray output (@50 cm) versus tube voltage



anode / filter combo

glandular fraction

breast thickness

kV

HVL's

Table 3

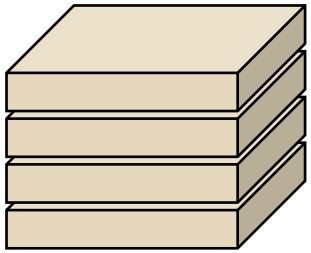
$\bar{D}_{gN}$ for Mo-Rh and 100% Glandular Breast: Glandular Tissue Dose (millirad) for 1-R Entrance Skin Exposure

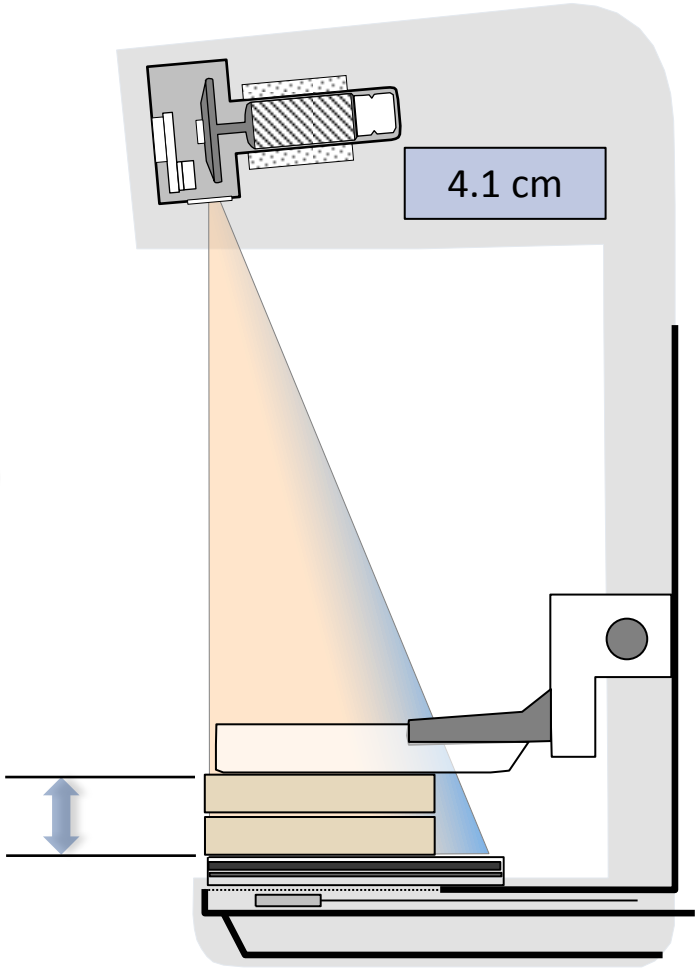
X-ray Tube Voltage/ HVL (mm Al)	Compressed Breast Thickness (cm)					
	3	4	5	6	7	8
25 kVp						
0.30	177	132	104	85	72	62
32	187	140	110	90	76	66
34	197	147	116	95	81	70
36	207	155	122	101	85	73
38	216	163	129	106	89	77
0.40	226	170	135	111	93	81
27 kVp						
0.34	200	150	119	98	83	71
0.36	209	158	125	102	87	75
	219	165	131	107	91	79
	228	172	137	112	95	82
	237	180	143	117	99	86
	247	187	149	122	104	90
29 kVp						
0.38	220	166	132	108	92	79
0.40	229	173	138	113	96	83
0.42	238	181	144	118	100	87
0.44	248	188	150	123	104	90
0.46	257	195	156	128	109	94
0.48	266	203	162	133	113	98
0.50	277	212	169	140	119	103
33 kVp						
0.42	241	183	146	121	102	89
0.44	250	191	152	126	107	92
0.46	259	198	158	131	111	96
0.48	268	206	164	136	116	100
0.50	278	213	171	142	120	104
0.52	287	221	178	147	125	109
35 kVp						
0.44	251	192	153	127	108	93
0.46	260	199	160	132	112	97
0.48	270	207	166	137	117	101
0.50	279	215	172	143	122	106
0.52	289	223	179	149	127	110
0.54	298	231	186	155	132	115

Note.—Doses are in conventional, not SI, units. Conversion factor: 1 mrad/R = 38.8 mGy/(C/kg).

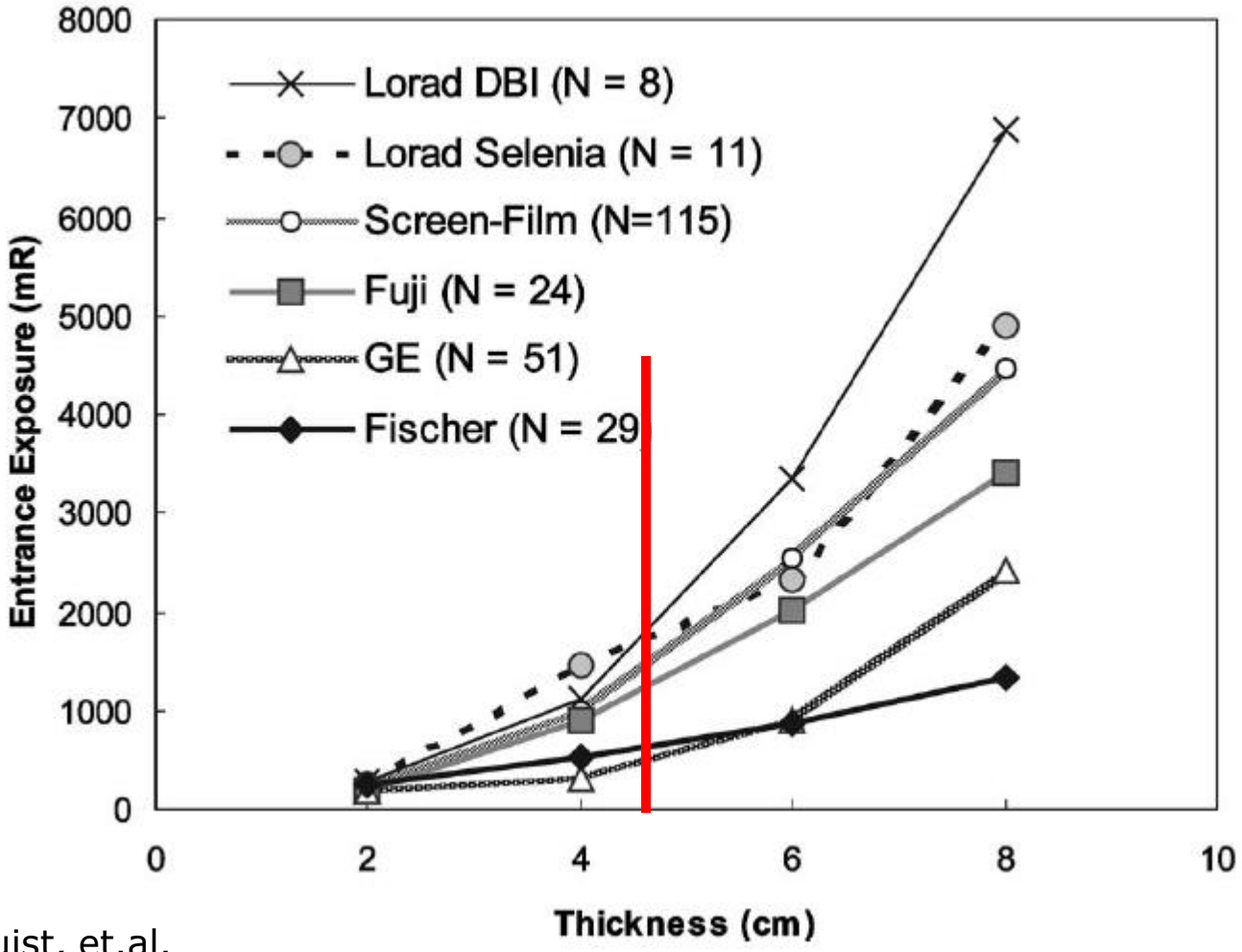
Validation of Breast Thickness Accuracy

breast phantoms (slabs)





Estimating Entrance Air Kerma

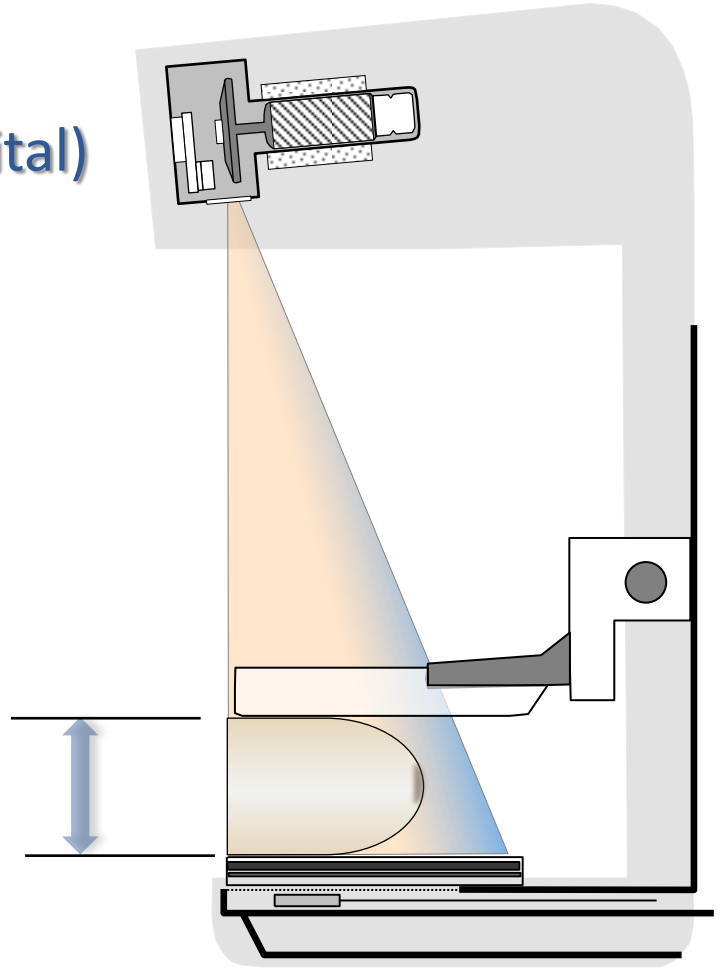


From Bloomquist, et.al.
Med Phys 33: 719-736, 2006

Estimating Entrance Air Kerma

Recorded in patient's record (digital)

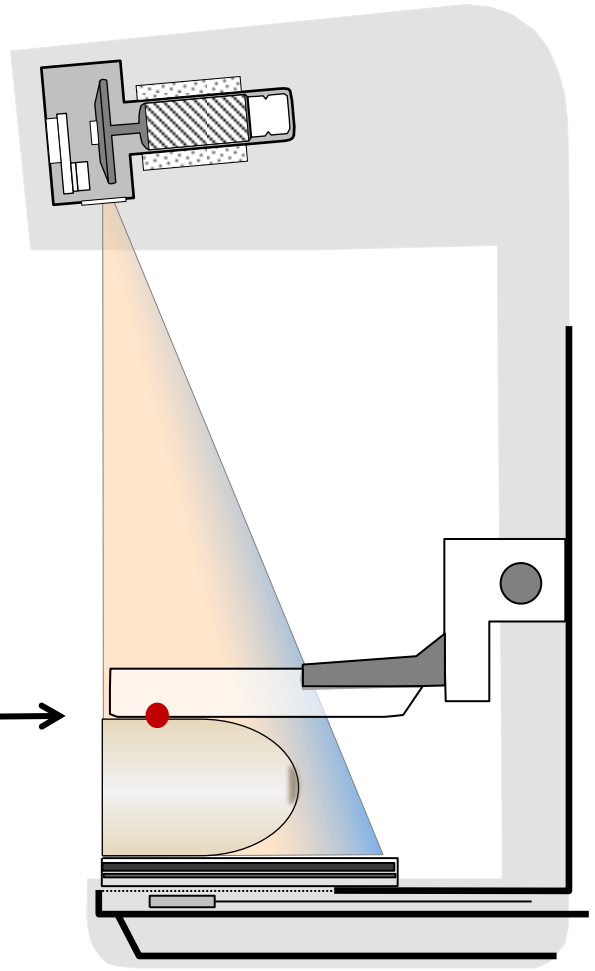
- anode
- filter
- kV
- mA
- exposure time
- compressed breast thickness



Estimating Entrance Air Kerma

dgN values

normalized glandular dose coefficients



Estimating Entrance Air Kerma

@ Anode/Filter kV:

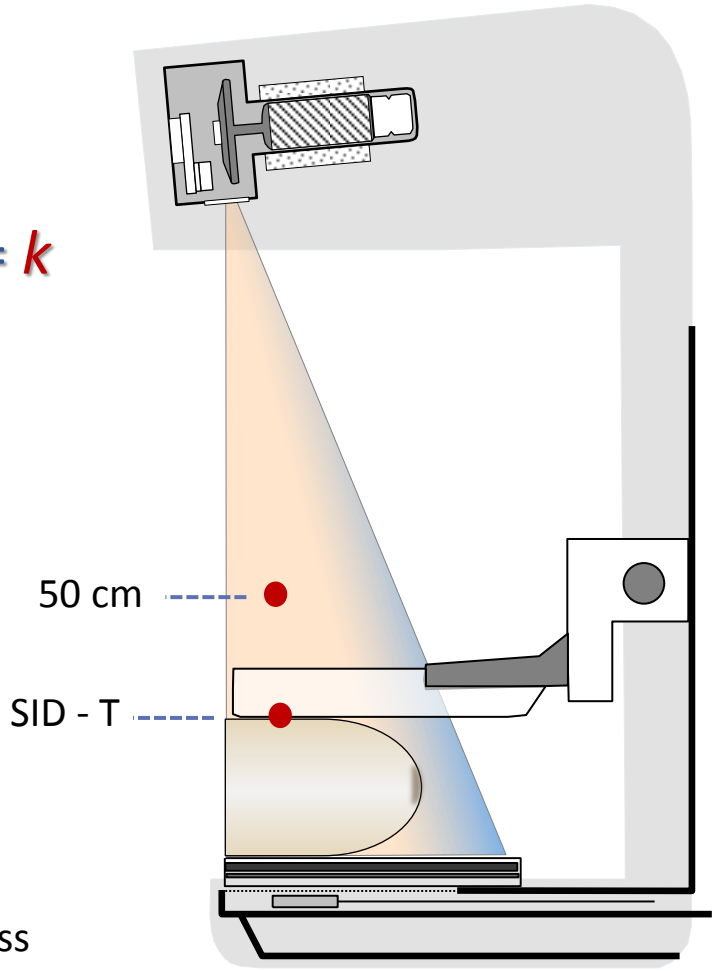
air kerma per 100 mAs @ 50 cm = *k*

ESK = *k* × (mAs/100) × ISL

$$ISL = \left[\frac{50}{SID - T}\right]^2$$

usually ~65 cm

breast thickness



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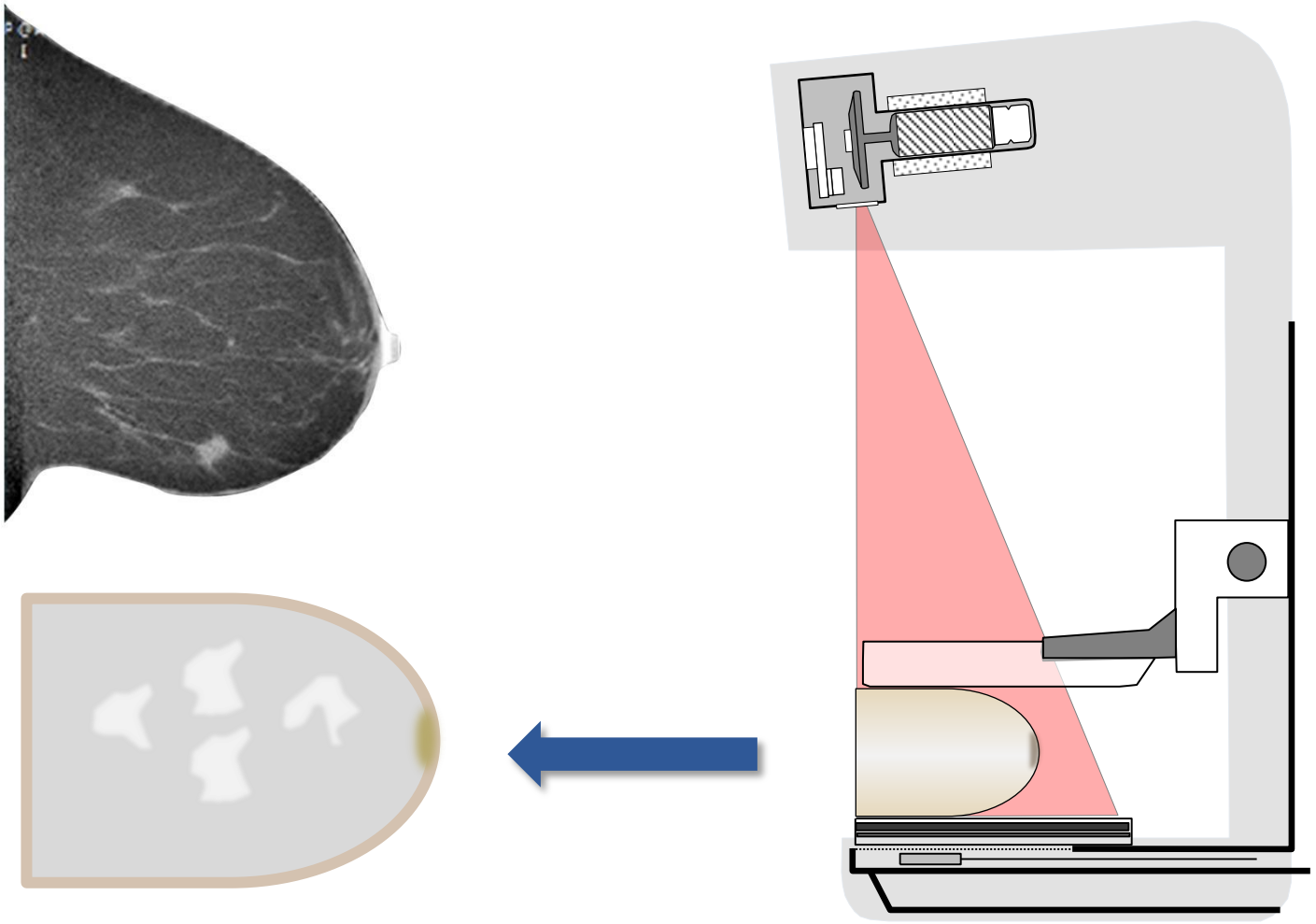
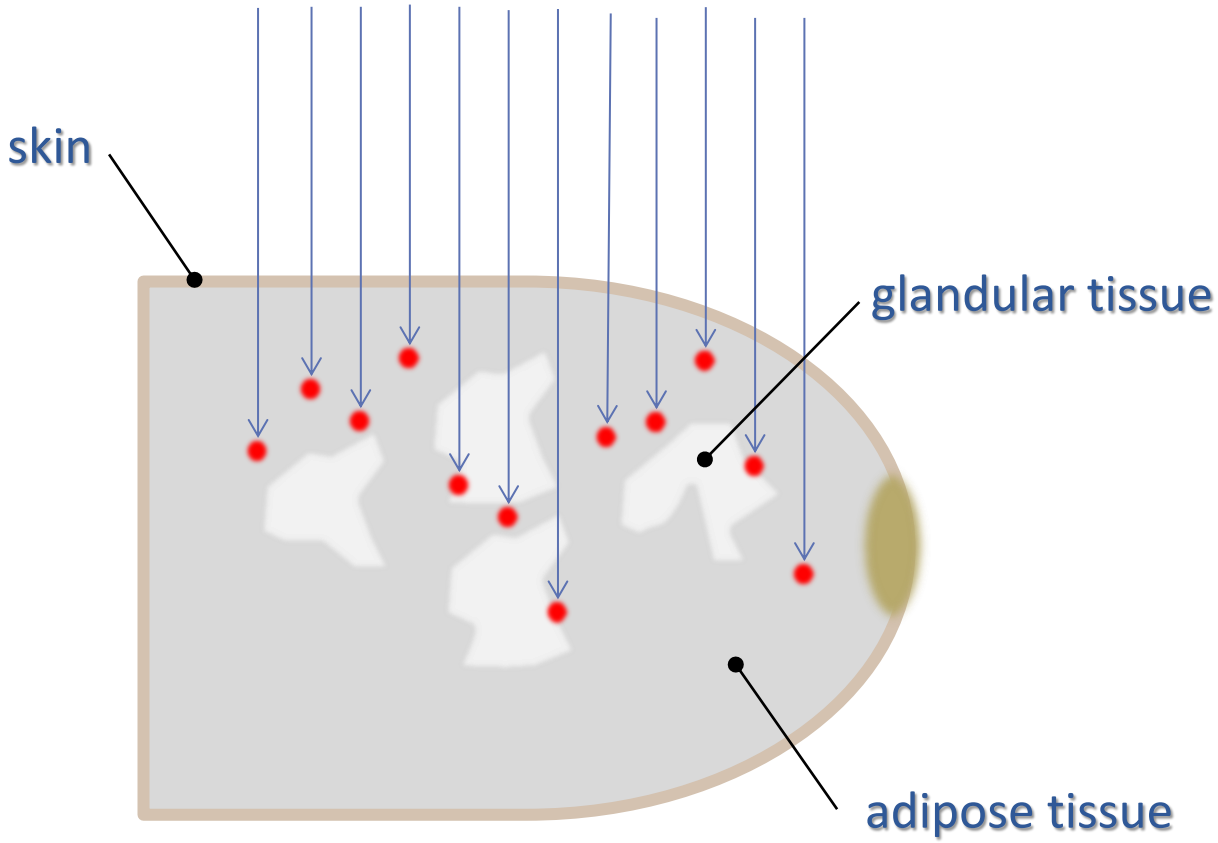
Summary

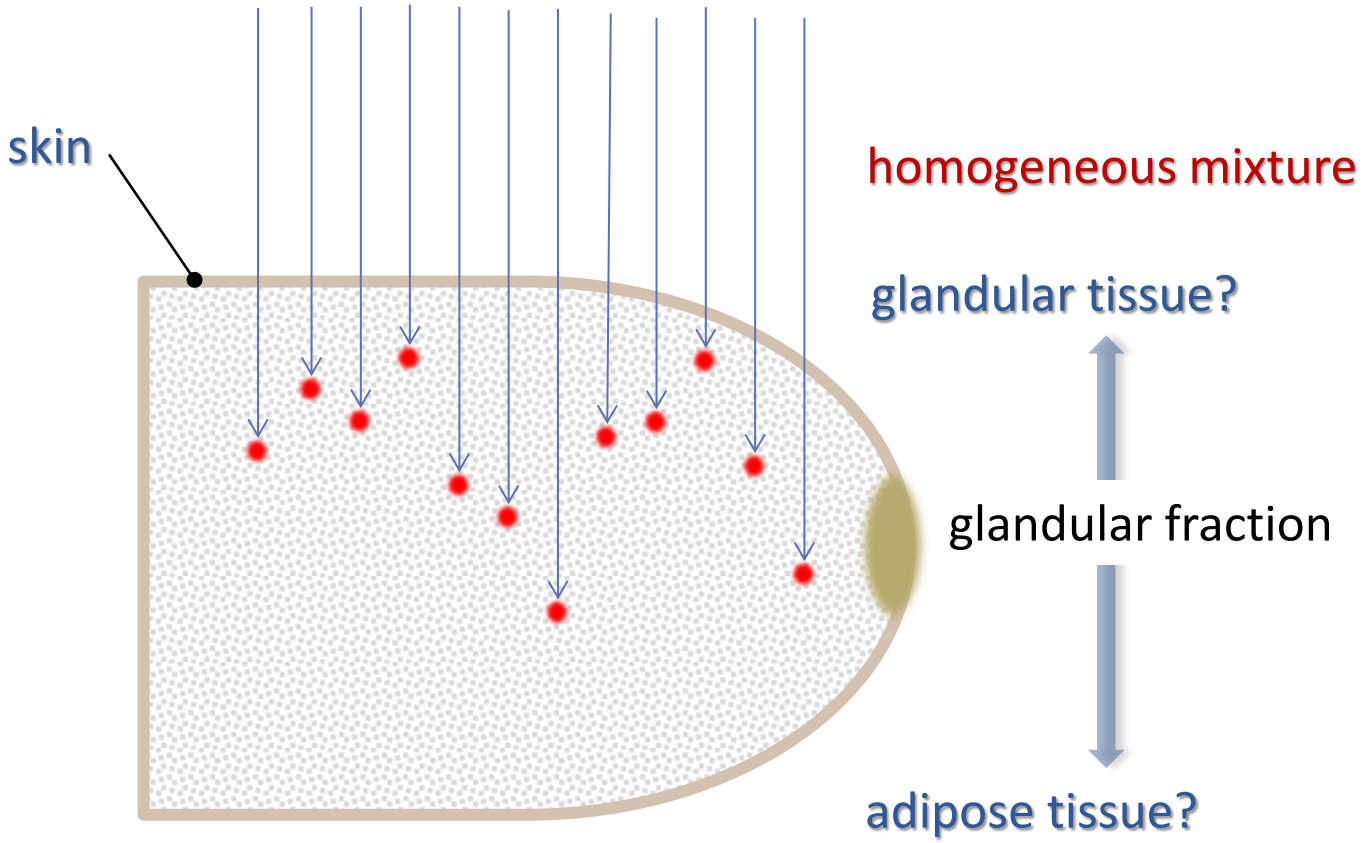
Mean Glandular Dose



Mean Glandular Dose



Mean Glandular Dose
(Monte Carlo Calculations)



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Summary

DgN values are based on MC Studies

Medical Physics

Xizeng Wu, PhD • Eric L. Gingold, PhD • Gary T. Barnes, PhD • Douglas M. Tucker, PhD

Normalized Average Glandular Dose in Molybdenum Target–Rhodium Filter and Rhodium Target–Rhodium Filter Mammography[1]

$\bar{D}_{gN}$ for Mo-Rh and 100% Glandular Breast: Glandular Tissue Dose (millirad) for 1-R Entrance Skin Exposure

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0.48	266	203	162	133	113	98

assumed 4 mm skin thickness

DgN values are based on MC Studies

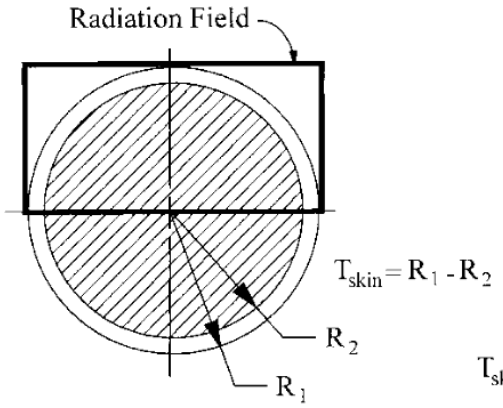
Medical Physics

John M. Boone, PhD

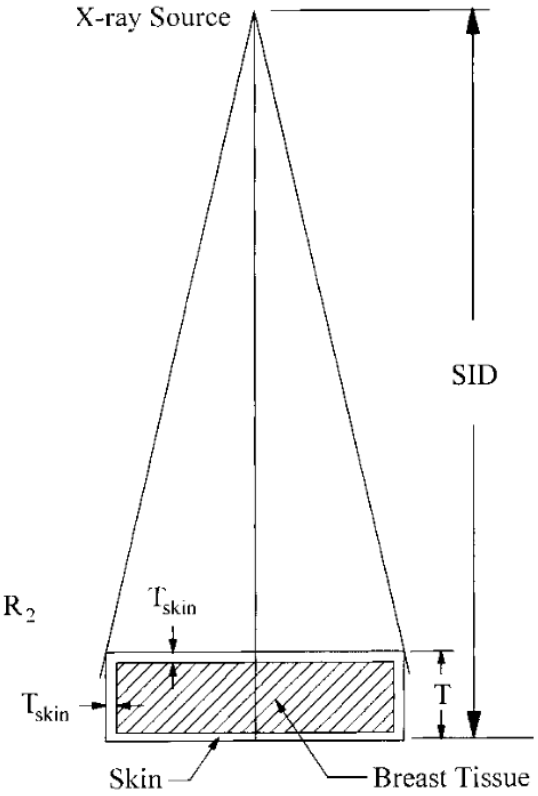
Index terms:
Breast radiography, radiation dose, 00.47, 0.99
Breast radiography, technology, 00.12
Breast radiography, utilization, 00.99
Physics

Glandular Breast Dose for Monoenergetic and High-Energy X-ray Beams: Monte Carlo Assessment[1]

assumed 4 mm skin thickness

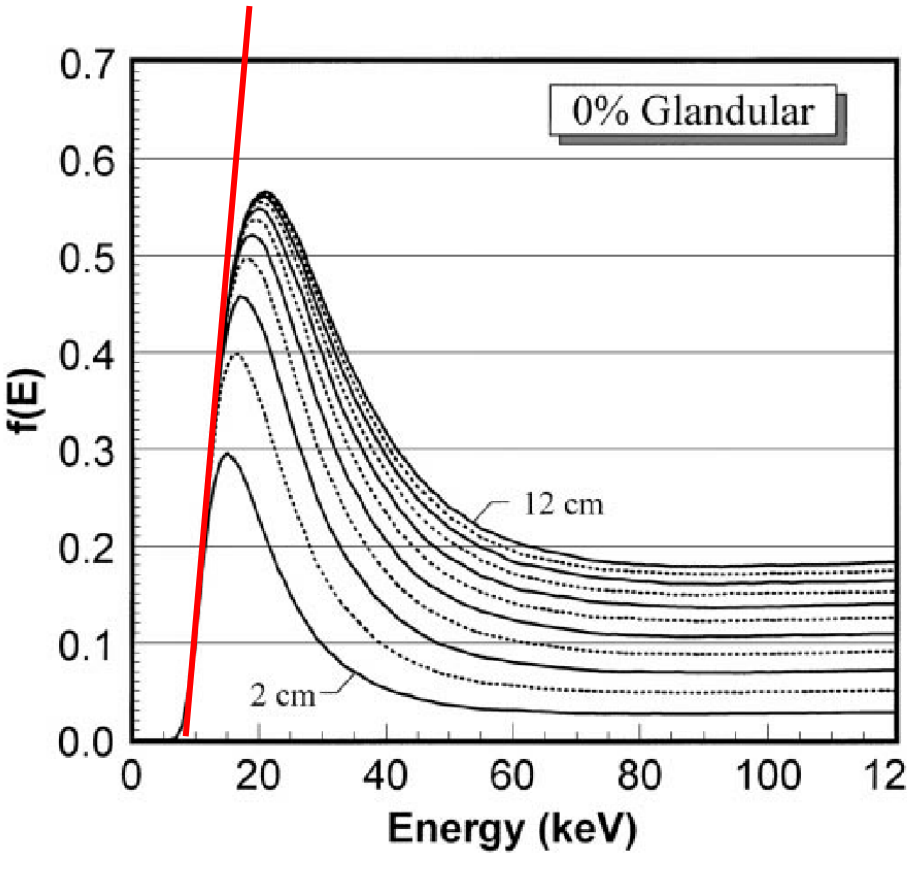


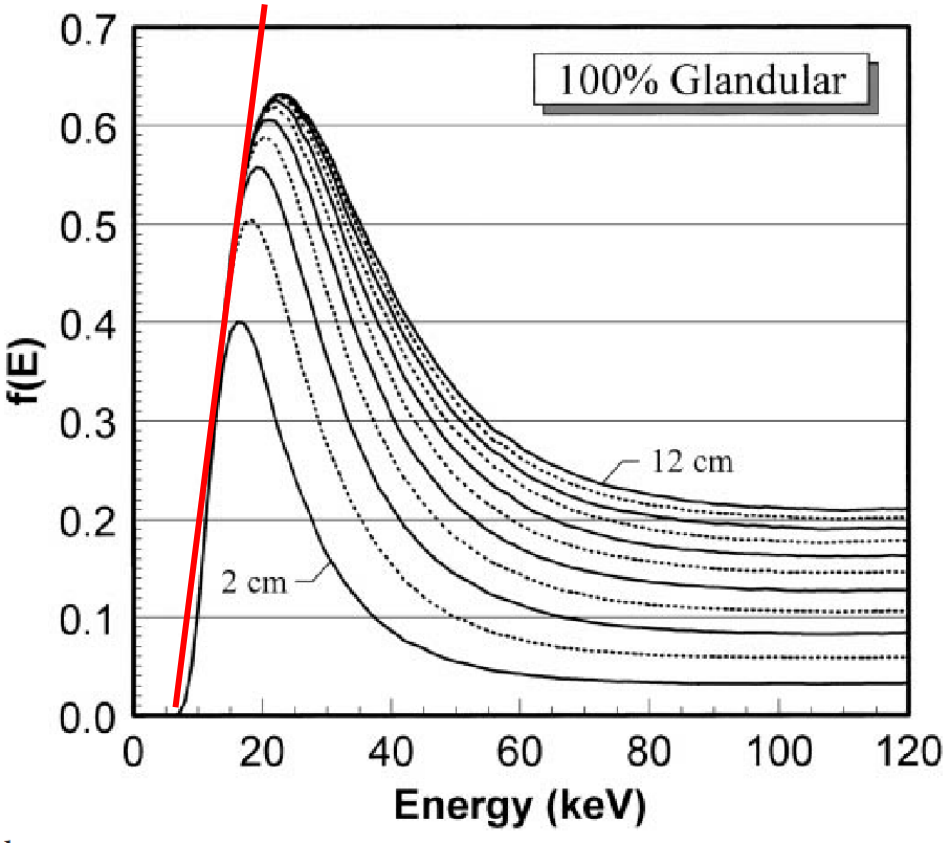
Top View



Side View

Monoenergetic MC eval of E deposition





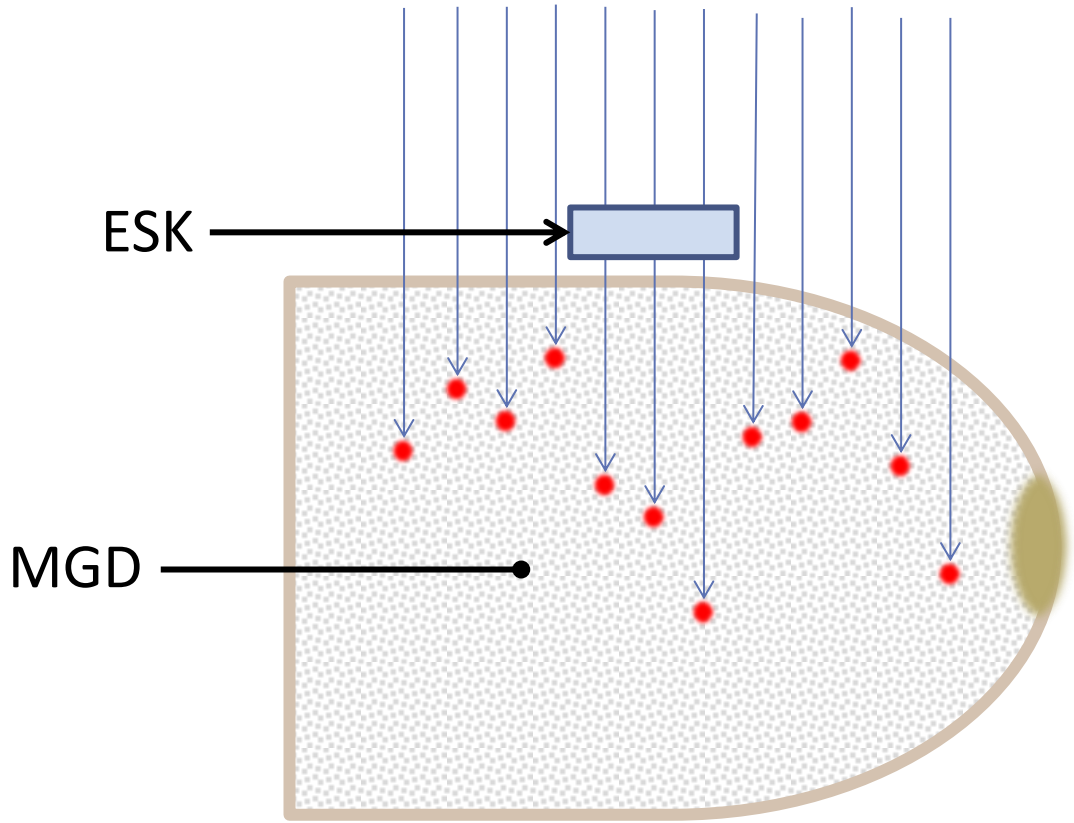
$$f(E) = \frac{\text{energy absorbed per incident photon}}{\text{photonenergy}}.$$

Converting Energy imparted to dose….

$$MGD = \frac{\left[\frac{\mu_{en}}{\rho}\right]_{glandular}}{\left[\frac{\mu_{en}}{\rho}\right]_{breast\ comp}} \frac{\text{Energy Imparted}}{\text{Mass}}$$

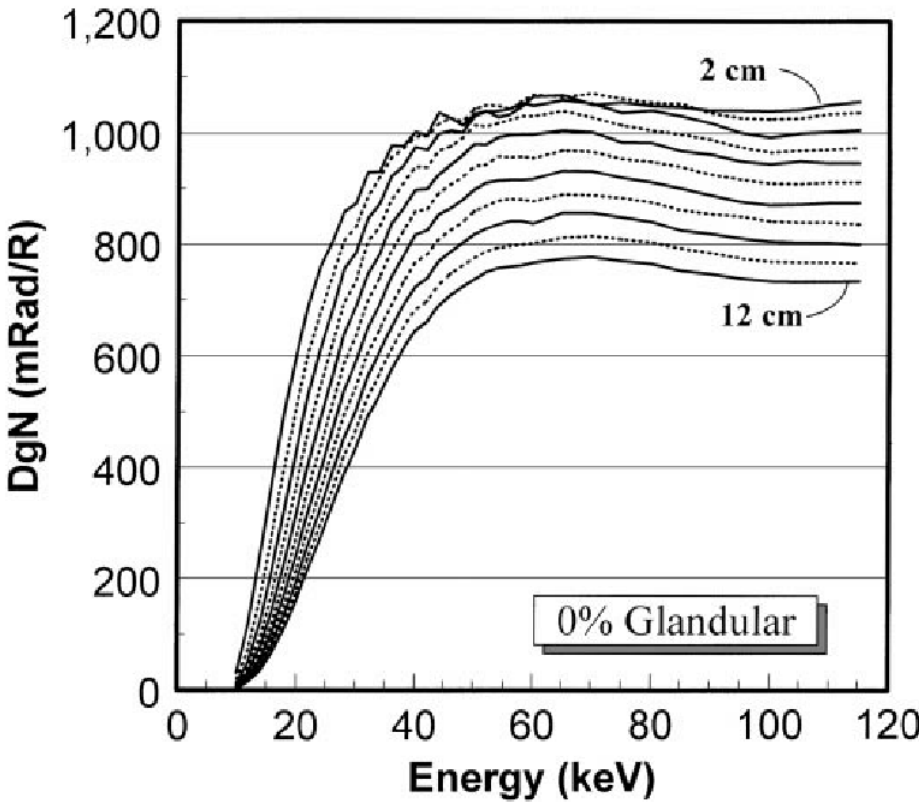
f-factor (SI)

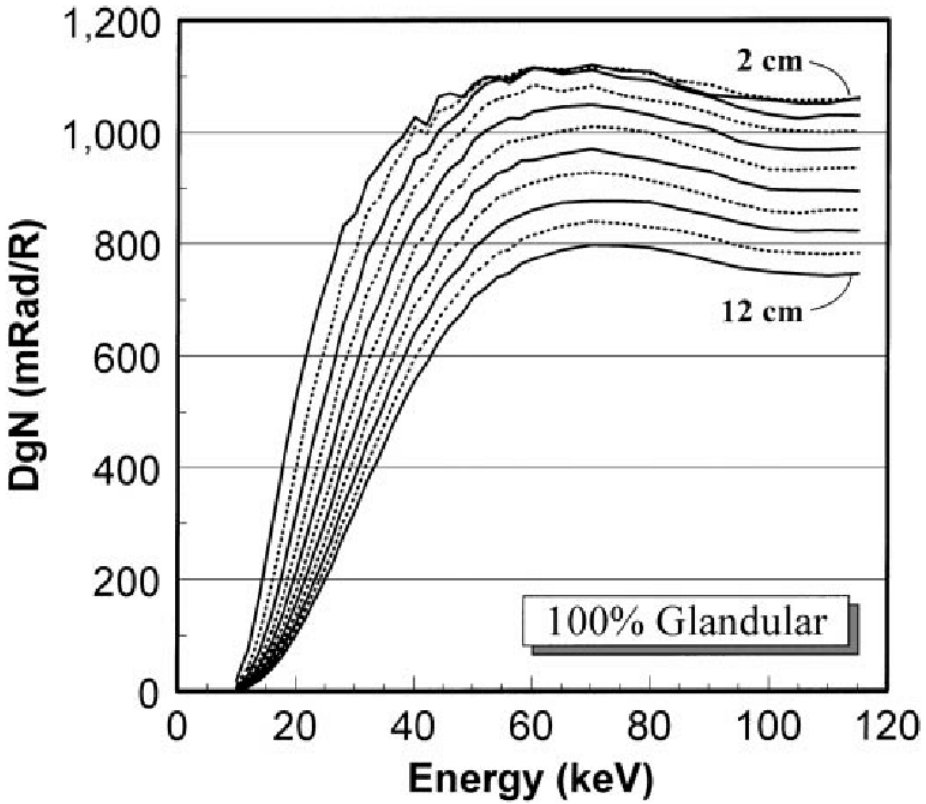
Mean Glandular Dose
(Monte Carlo Calculations)



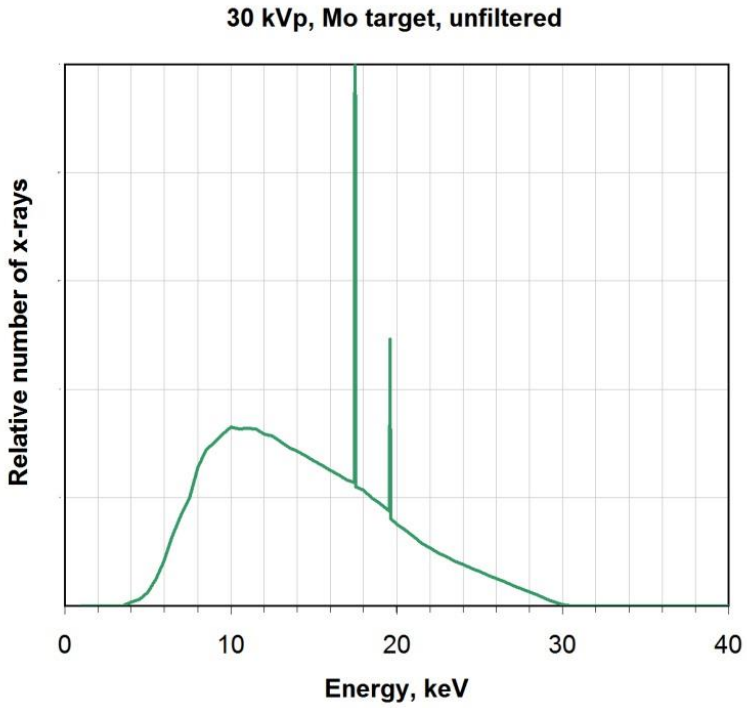
$$DgN = \frac{MGD}{ESK}$$

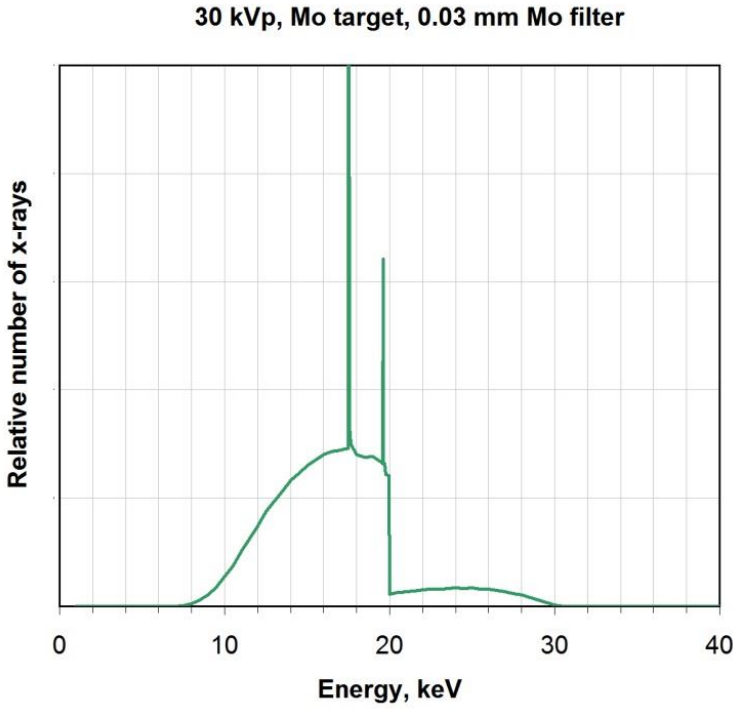
Dose Calc with Normalization by ESE





To convert the monoenergetic DgN values to realistic polyenergetic values, spectral models are used to weight the monoenergetic values





DgN Tables (poly)

TABLE 7
D_{gN} Values for W-Rh (50-μm-thick) Anode-Filter Combination and a 0% Glandular Breast

Energy (kV)	HVL	Breast Thickness (cm)										
		2	3	4	5	6	7	8	9	10	11	12
20	0.338	342	258	202	164	136	116	101	89	79	71	65
21	0.365	368	282	224	183	153	131	114	100	90	81	74
22	0.392	392	306	245	202	170	146	127	112	101	91	83
23	0.420	415	328	266	221	187	161	140	124	111	101	92
24	0.444	434	347	284	237	201	174	152	135	121	109	100
25	0.462	447	360	296	248	211	183	160	142	128	116	106
26	0.477	457	370	305	257	219	190	167	148	133	120	110
27	0.489	465	378	313	264	226	195	172	153	137	124	113
28	0.500	472	385	320	270	231	200	176	157	141	128	116
29	0.509	478	391	326	275	236	205	180	160	144	131	119
30	0.518	484	397	331	280	241	209	184	164	147	134	122
31	0.527	489	403	336	285	245	213	188	168	151	137	125
32	0.535	494	408	342	290	250	218	192	171	154	140	128
33	0.544	499	413	347	295	254	222	196	175	158	143	131
34	0.552	504	418	352	300	259	226	200	179	161	146	134
35	0.560	509	424	357	306	264	231	205	183	165	150	137
36	0.569	514	429	363	311	269	236	209	187	169	154	141
37	0.577	519	434	368	316	275	241	214	192	173	158	144
38	0.585	524	440	373	321	280	246	218	196	177	161	148
39	0.593	528	444	379	327	285	251	223	200	181	165	152
40	0.601	532	449	383	331	289	255	227	204	185	169	155

Note.—D_{gN} values are expressed in millirad per roentgen. To convert to SI units (mGy · mGy^{-1}), multiply by 873^{-1}.

The units used in DgN Tables have varied over the years and by the country of origin. These units are mRad / R, but mGy/mGy is in more common usage today

Normalized glandular dose (DgN) coefficients for arbitrary x-ray spectra in mammography: Computer-fit values of Monte Carlo derived data

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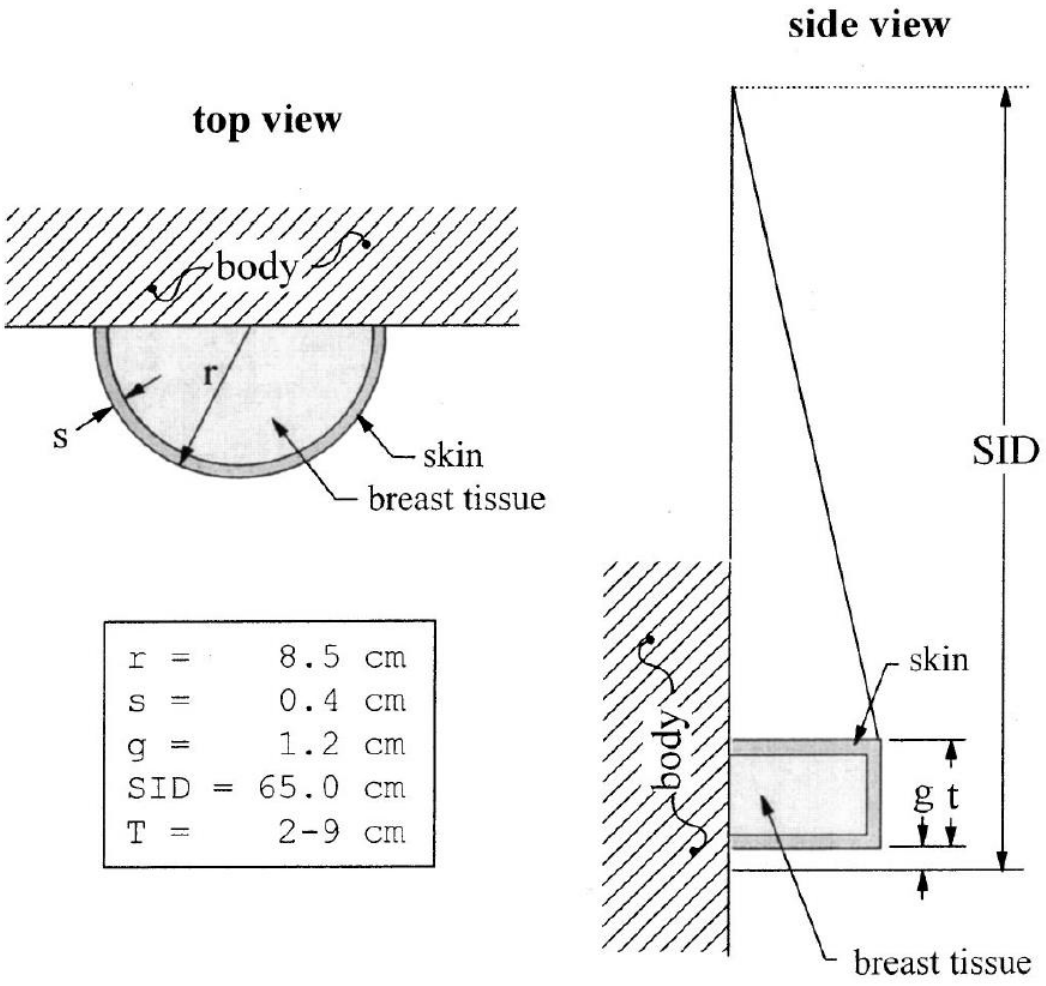
Department of Radiology, University of California, Davis, Sacramento, California 95817

(Received 1 November 2001; accepted for publication 28 February 2002; published 19 April 2002)



DgN versus monoenergetic x-ray energy

TABLE II. Fit equations for 50% glandular breast compositions.

Composition = 50% glandular, compressed breast thickness = 2 cm

$$\mathrm{DgN}(E) = \exp\left(a + \frac{b\ln(E)}{E^2} + \frac{c}{E^2}\right)$$

$a = 2.391\ 926\ 241\ 342\ 124$
$b = 144.613\ 662\ 310\ 9463$
$c = -698.408\ 499\ 945\ 4397$

Composition = 50% glandular, compressed breast thickness = 3 cm

$$\mathrm{DgN}(E) = \exp\left(a + \frac{b}{E^{0.5}} + \frac{c}{E^2}\right)$$

$a = 2.144\ 310\ 706\ 434\ 551$
$b = 2.756\ 318\ 009\ 819\ 883$
$c = -502.795\ 387\ 923\ 8766$

Composition = 50% glandular, compressed breast thickness = 4 cm

$$\mathrm{DgN}(E) = \exp\left(a + \frac{b}{E^{0.5}} + \frac{c \times \ln(E)}{E^2}\right)$$

$a = 1.716\ 433\ 088\ 631\ 987$
$b = 7.179\ 067\ 281\ 599\ 553$
$c = -271.371\ 867\ 296\ 2624$

Composition = 50% glandular, compressed breast thickness = 5 cm

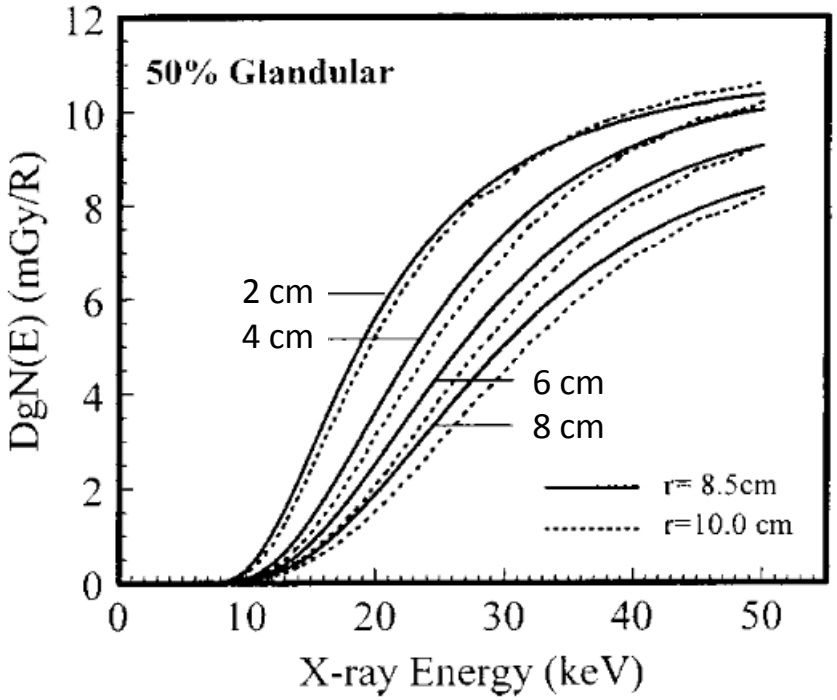
$$\mathrm{DgN}(E) = \exp\left(a + b \times \{\ln(E)\}^2 + \frac{c \times \ln(E)}{E^2}\right)$$

$a = 3.456\ 584\ 050\ 727\ 194$
$b = -0.051\ 521\ 196\ 269\ 344\ 88$
$c = -252.814\ 966\ 844\ 1184$

Composition = 50% glandular, compressed breast thickness = 6 cm

$$\mathrm{DgN}(E) = \exp\left(a + \frac{b}{E^{0.5}} + \frac{c}{E}\right)$$

$a = 0.174\ 992\ 526\ 996\ 0791$
$b = 33.686\ 852\ 918\ 469\ 66$
$c = -135.572\ 672\ 463\ 385$



Mammography and Tomosynthesis Dosimetry

Mammography

- Why measure breast dose?
- Basic Concepts of Breast Dosimetry (how)
- Mean Glandular Dose (MGD) (what)
- DgN coefficients
- → Skin Thickness Issues
- Breast Density Issues

Tomosynthesis

- Differences between tomo and mammo

Summary

The effect of skin thickness determined using breast CT on mammographic dosimetry

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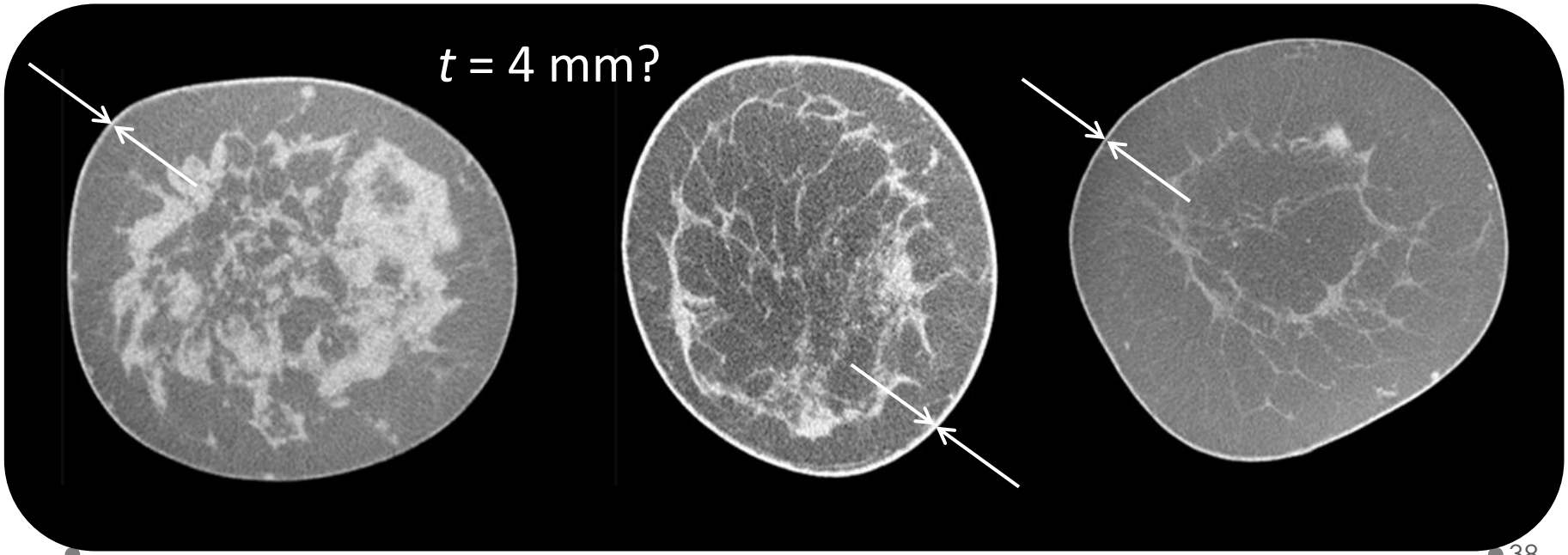
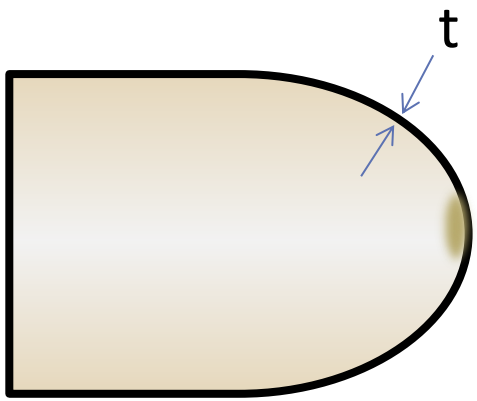
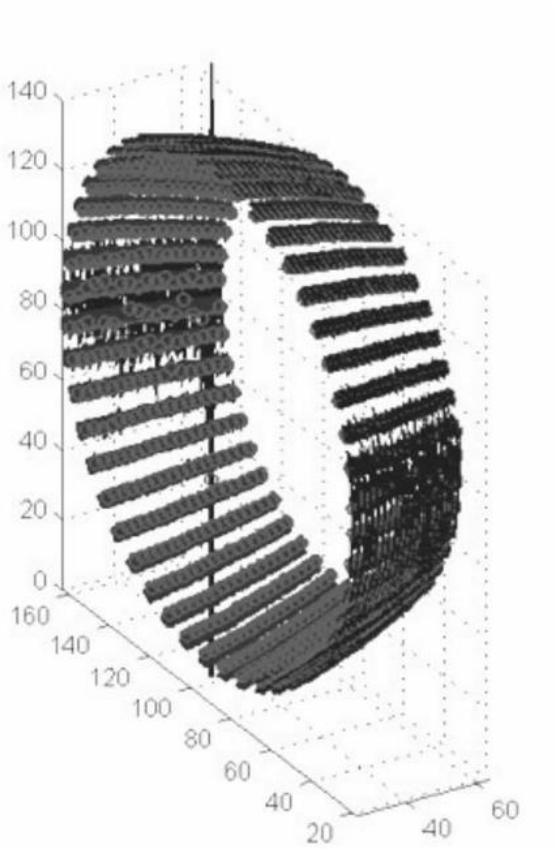
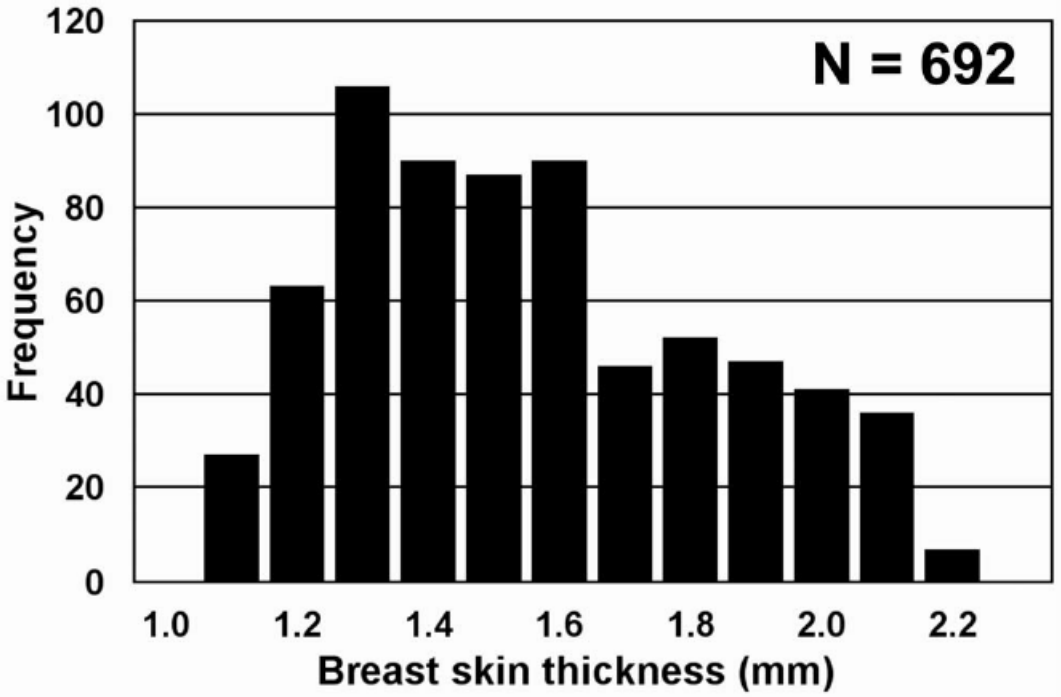


Developed algorithms to segment skin from breast CT images and measure thickness





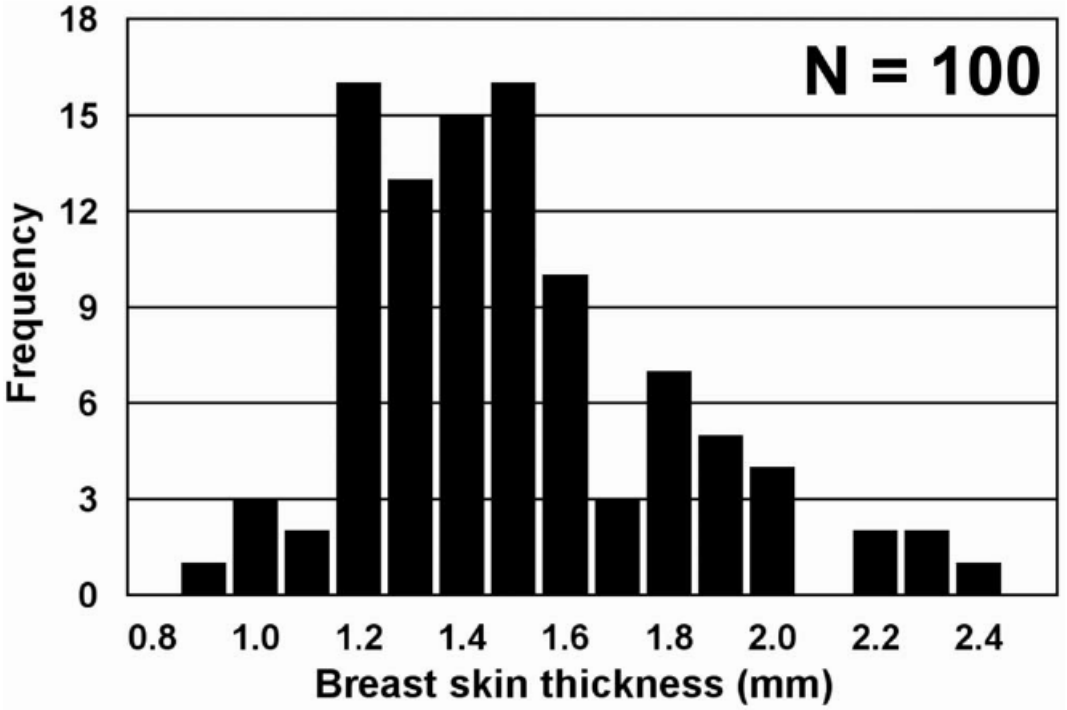
Skin Thickness measurements were relatively precise for each women (18%)



Measurements from the same women

FIG. 7. A histogram of breast skin thickness using the three-dimensional surface-fit approach with one single bCT volume data set. Among the skin thickness measured from 692 breast surface patches, the mean skin thickness (±intra-breast standard deviation) was 1.51 ± 0.28 mm, with a range of 1.1–2.1 mm.

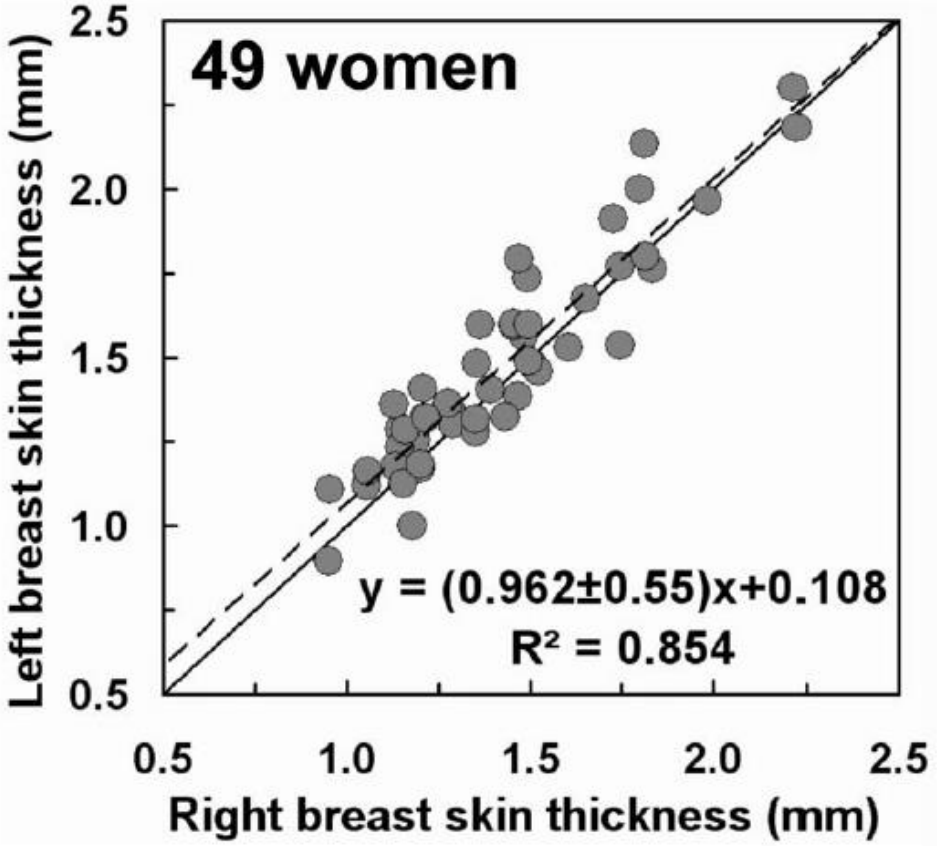
Skin Thickness measurements ranged from 0.9 mm to 2.3 mm (m = 1.45 mm)

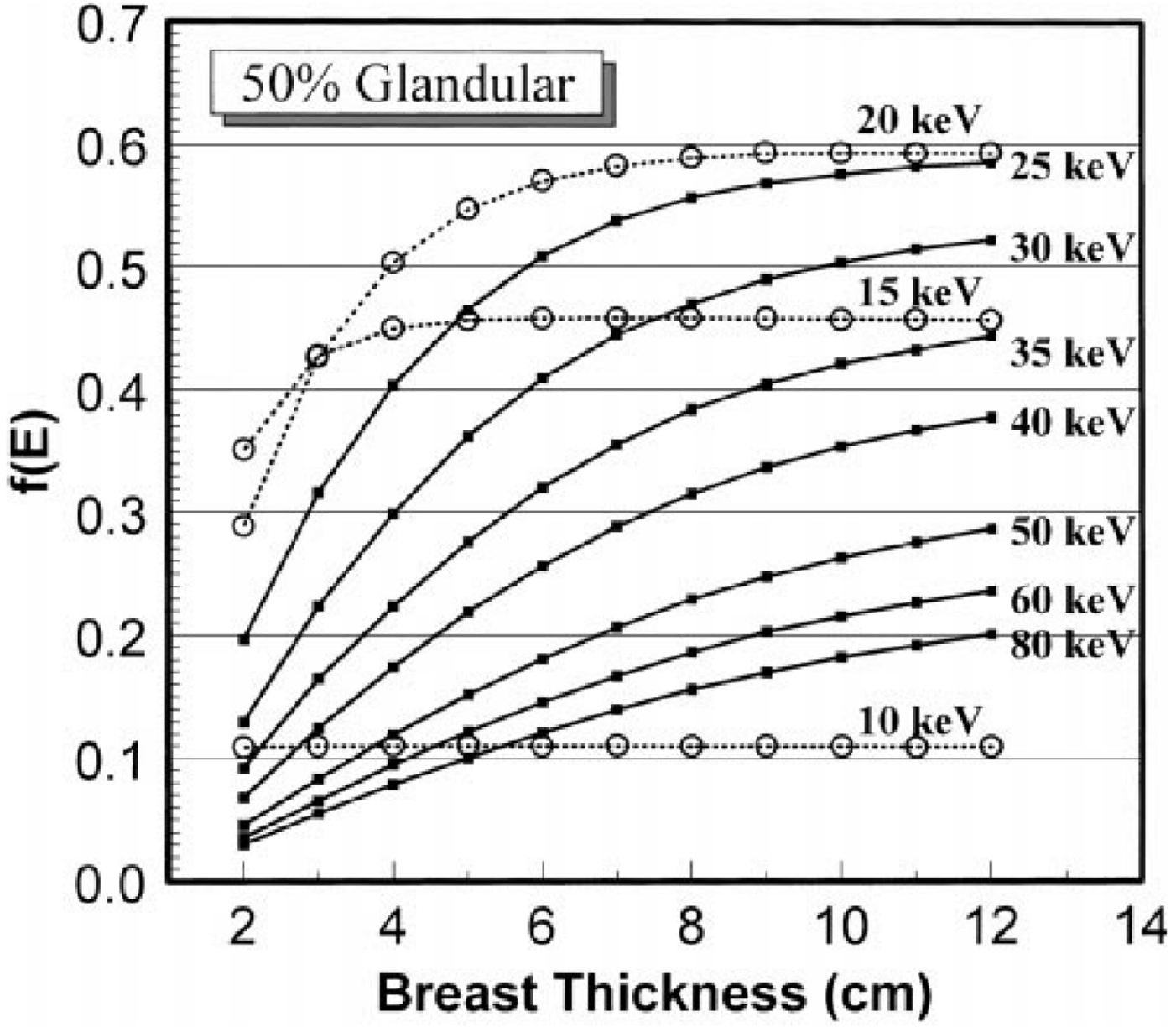


Measurements from 51 different women

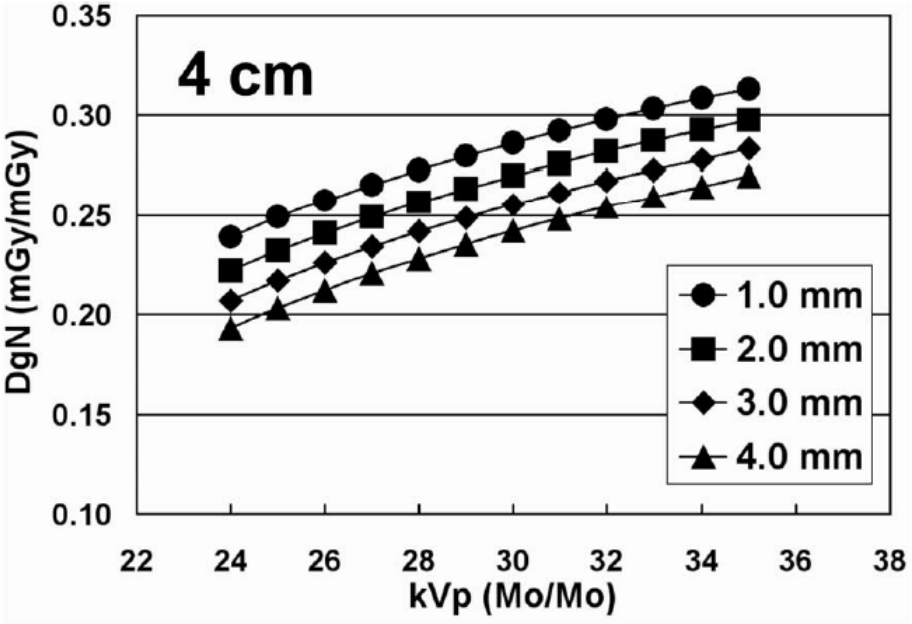
FIG. 6. A histogram showing the distribution of breast skin thickness using the three-dimensional, patch-by-patch approach on the breast surface sampled from the clinical bCT volumes. Among 100 breasts (51 women), the average breast skin thickness (±inter-breast standard deviation) was 1.45 ± 0.30 mm, ranged from 0.9 to 2.3 mm.

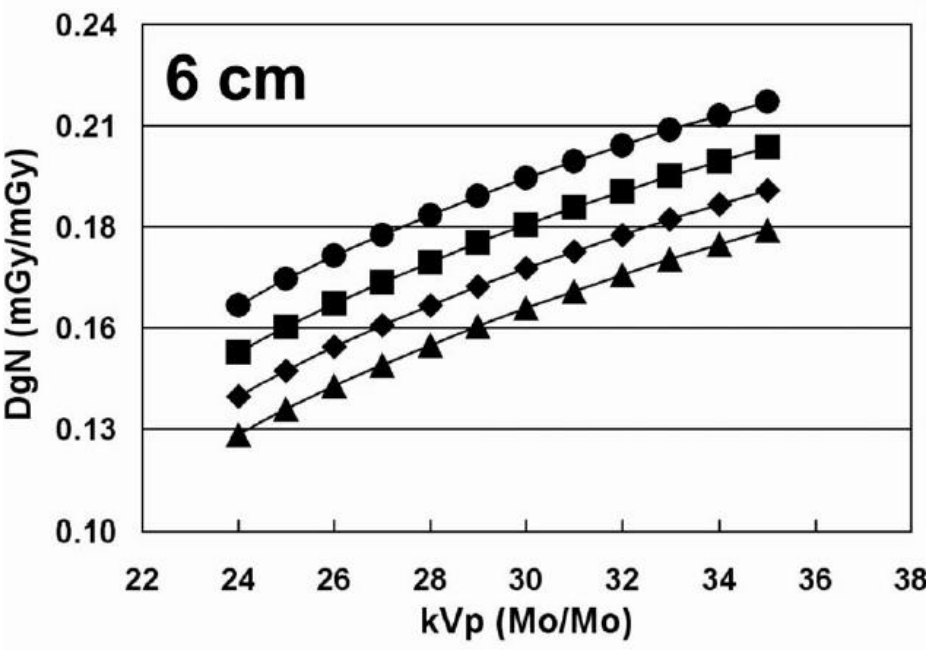
Left / Right Comparison provided a consistency check, with good results



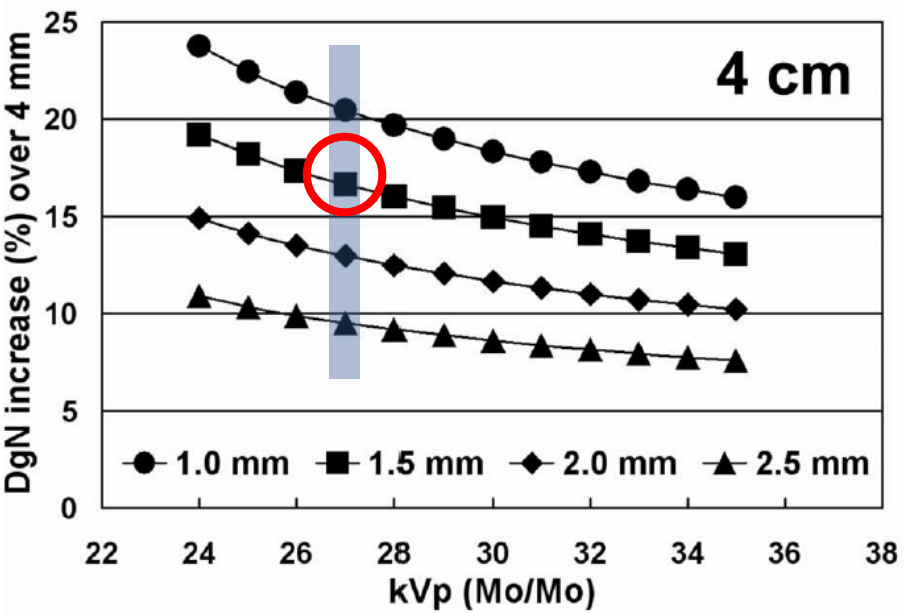

50% Glandular
20 keV
25 keV
30 keV
15 keV
35 keV
40 keV
50 keV
60 keV
80 keV
10 keV
f(E)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2
4
6
8
10
12
14
Breast Thickness (cm)

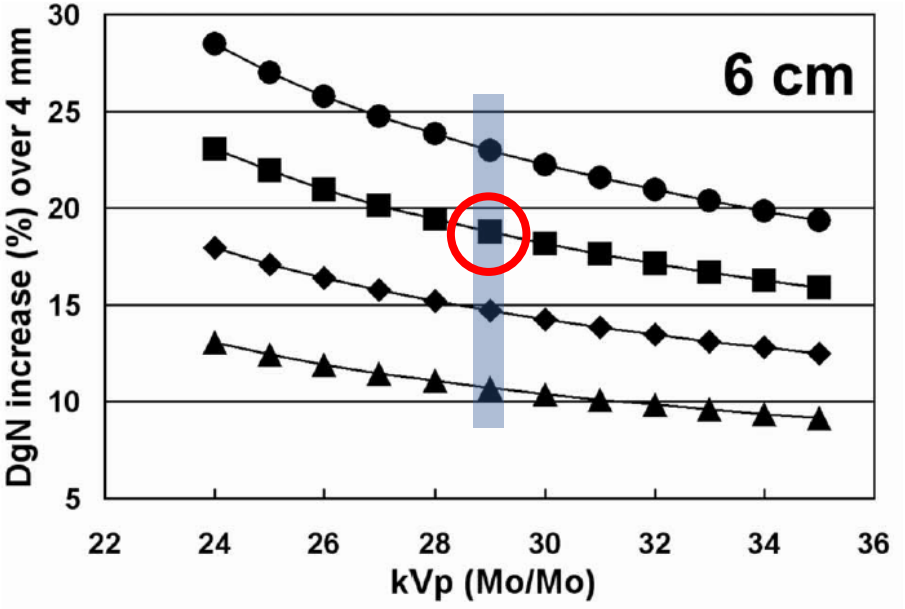
DgN values versus skin thickness





Change (in %) in DgN values versus skin thickness, Relative to the assumption of t = 4 mm





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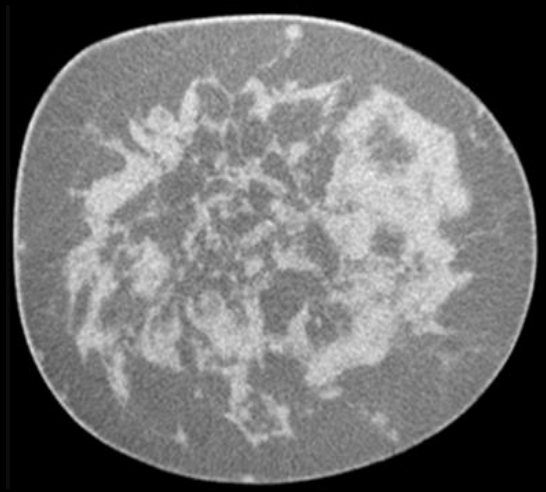
Summary

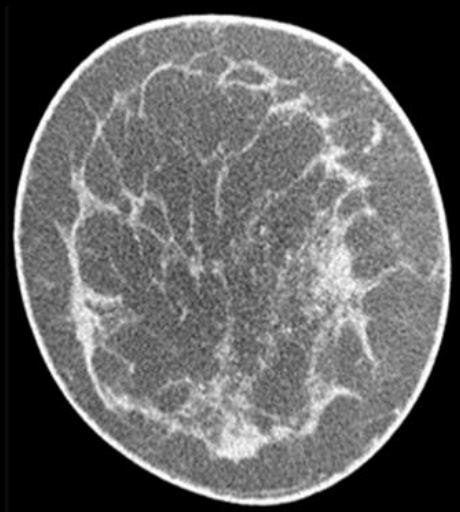
Mean Glandular Fraction

high



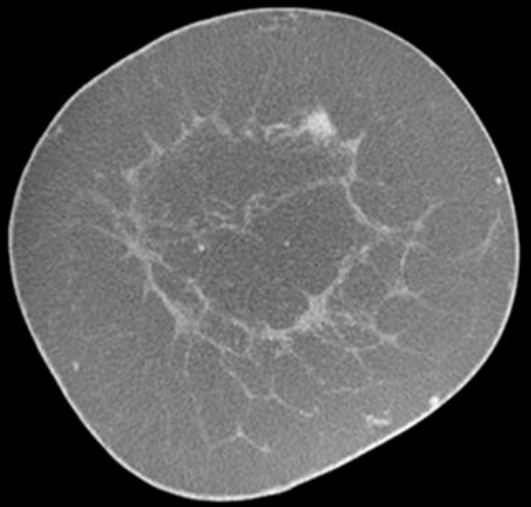
100%

medium



50%

low



0%

The myth of the 50-50 breast

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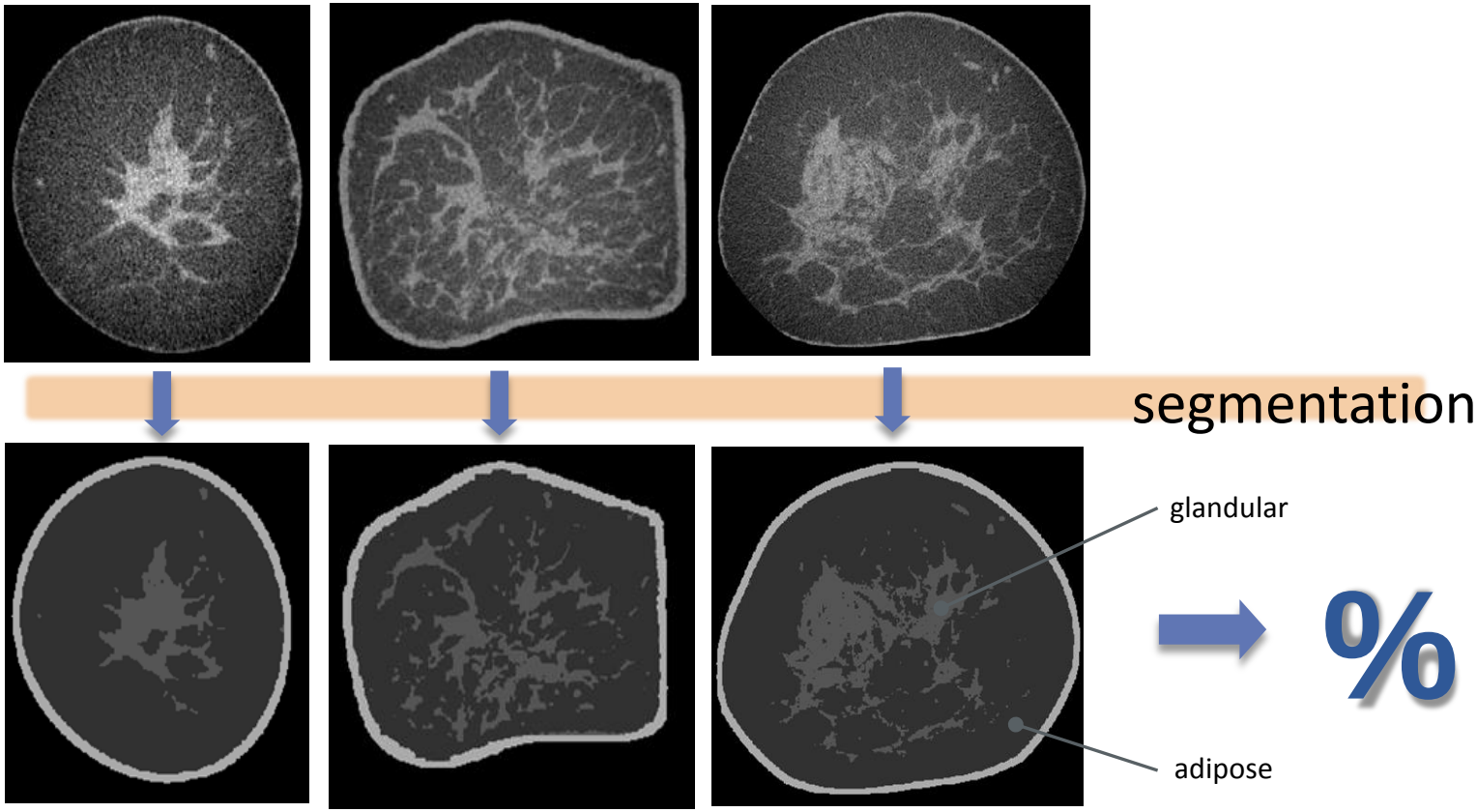
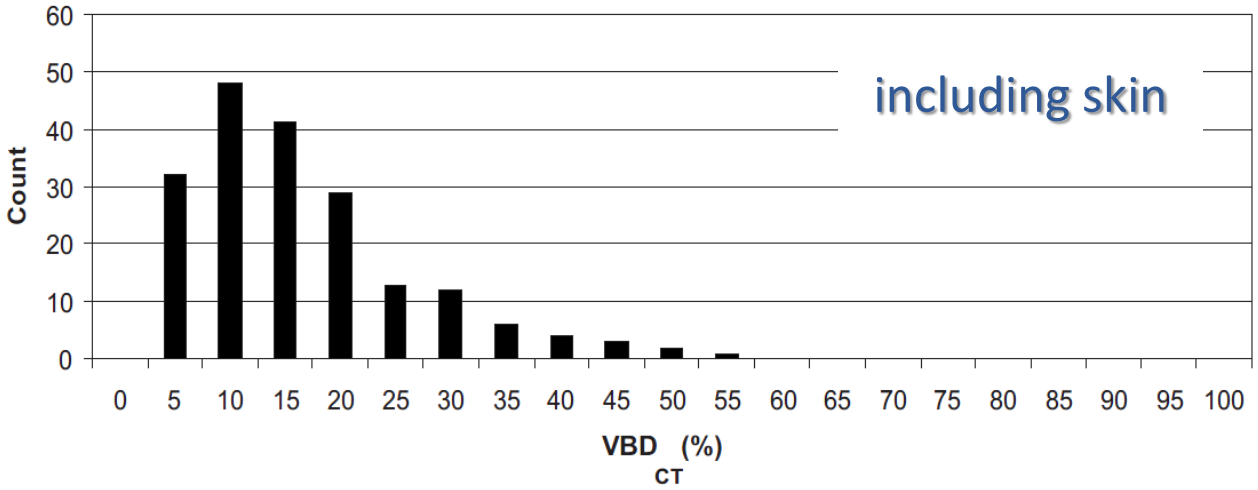
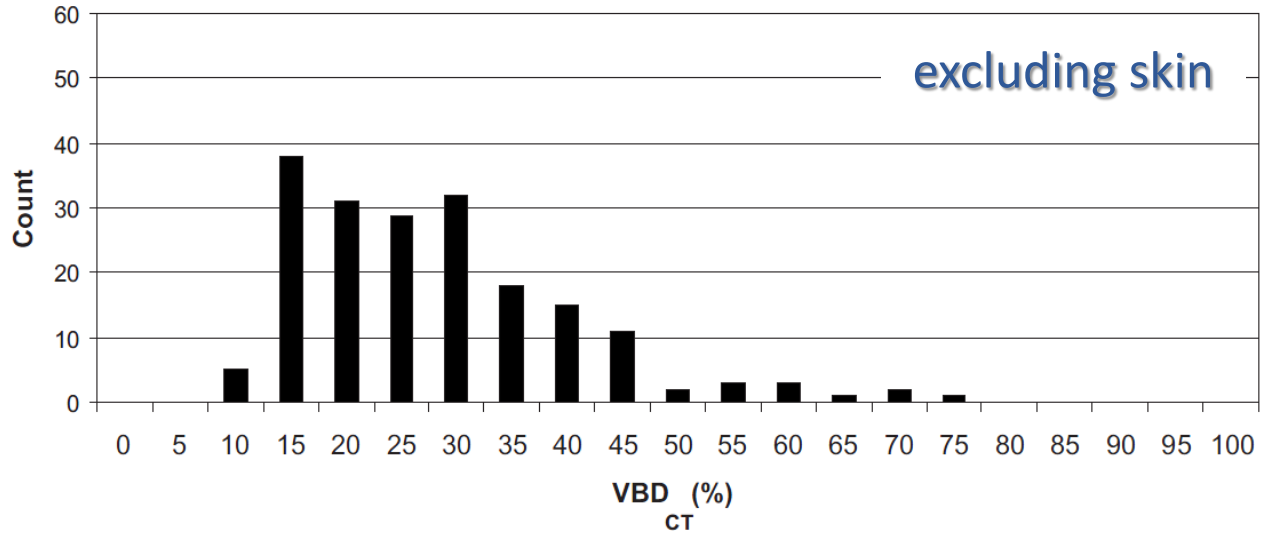
Breast Density Analysis



risk assessment & dosimetry

validation of 2D approaches (M. Yaffe)

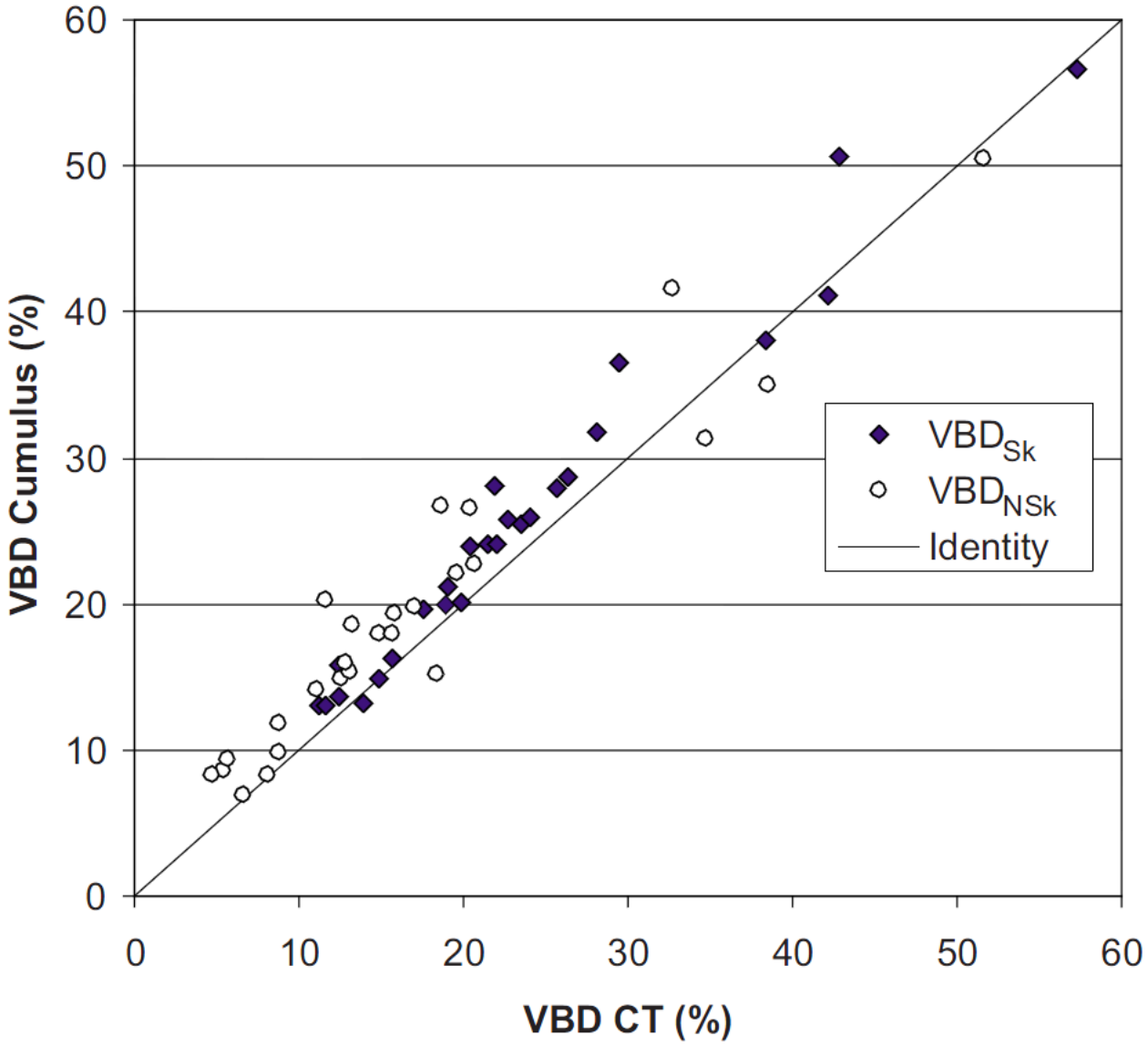




UC Davis breast CT

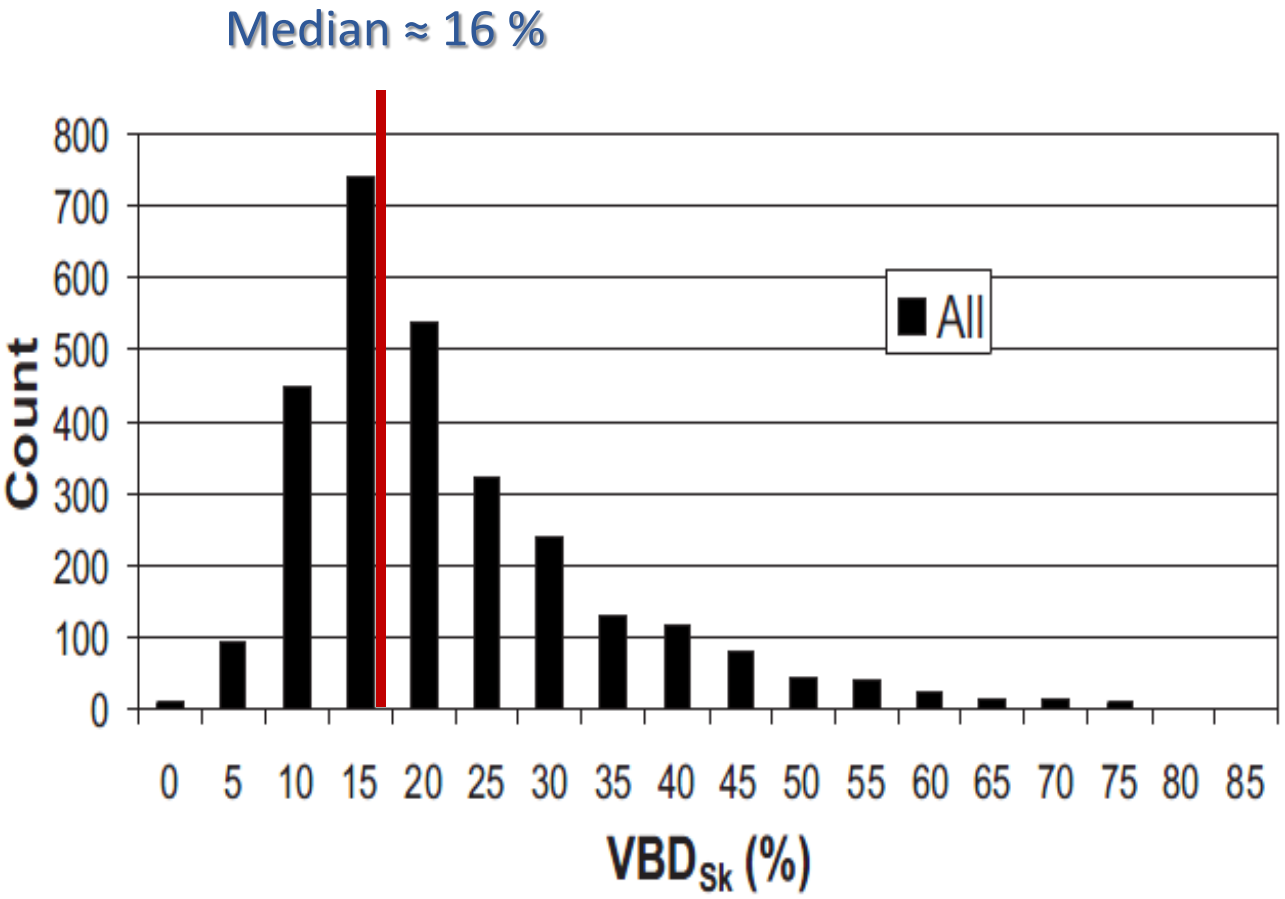
N = 191

Density analysis done on mammograms at University of Toronto

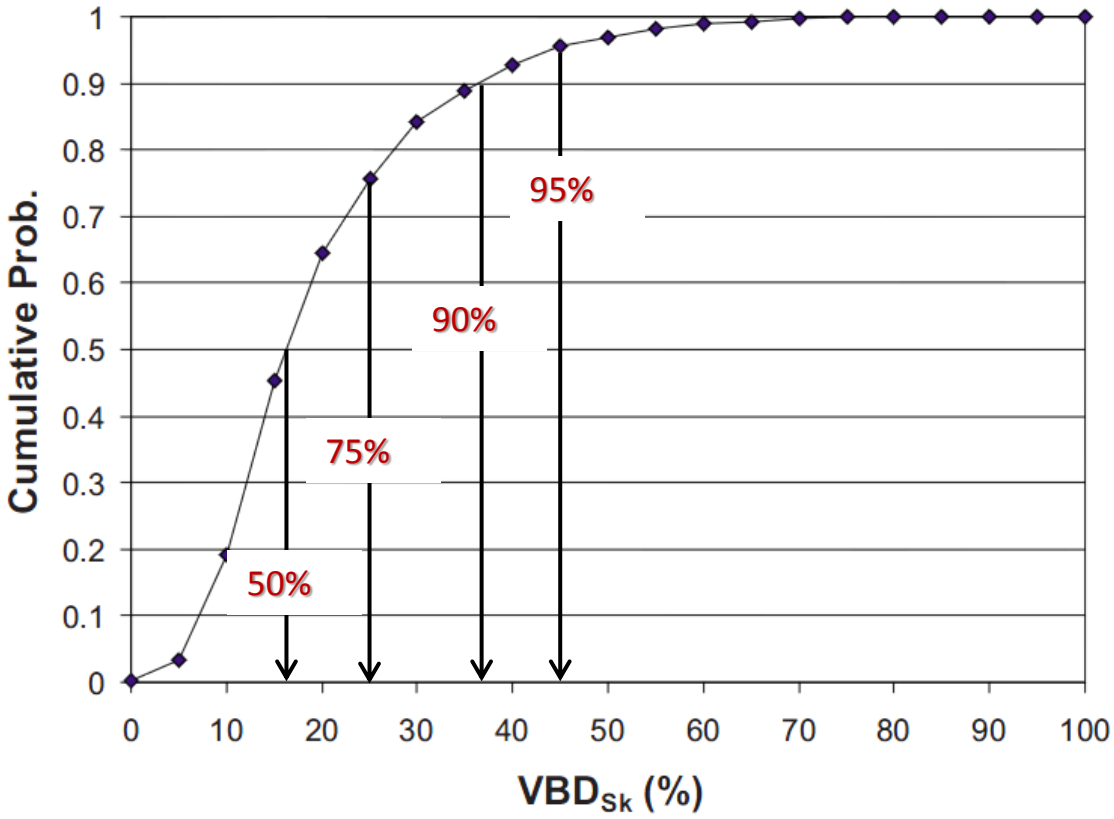


Data from UC Davis Breast CT

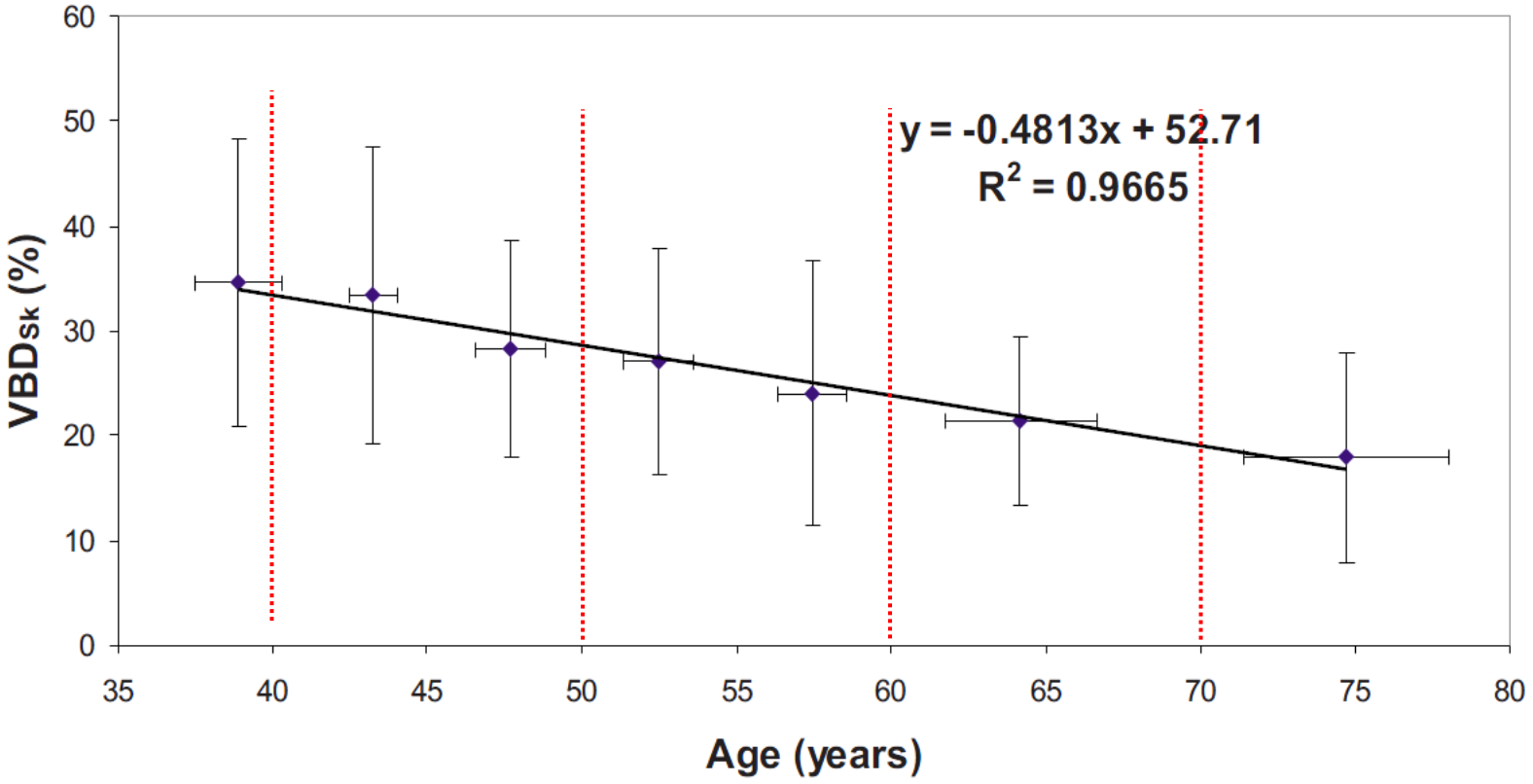
UCD & UT data combined (N = 2831)



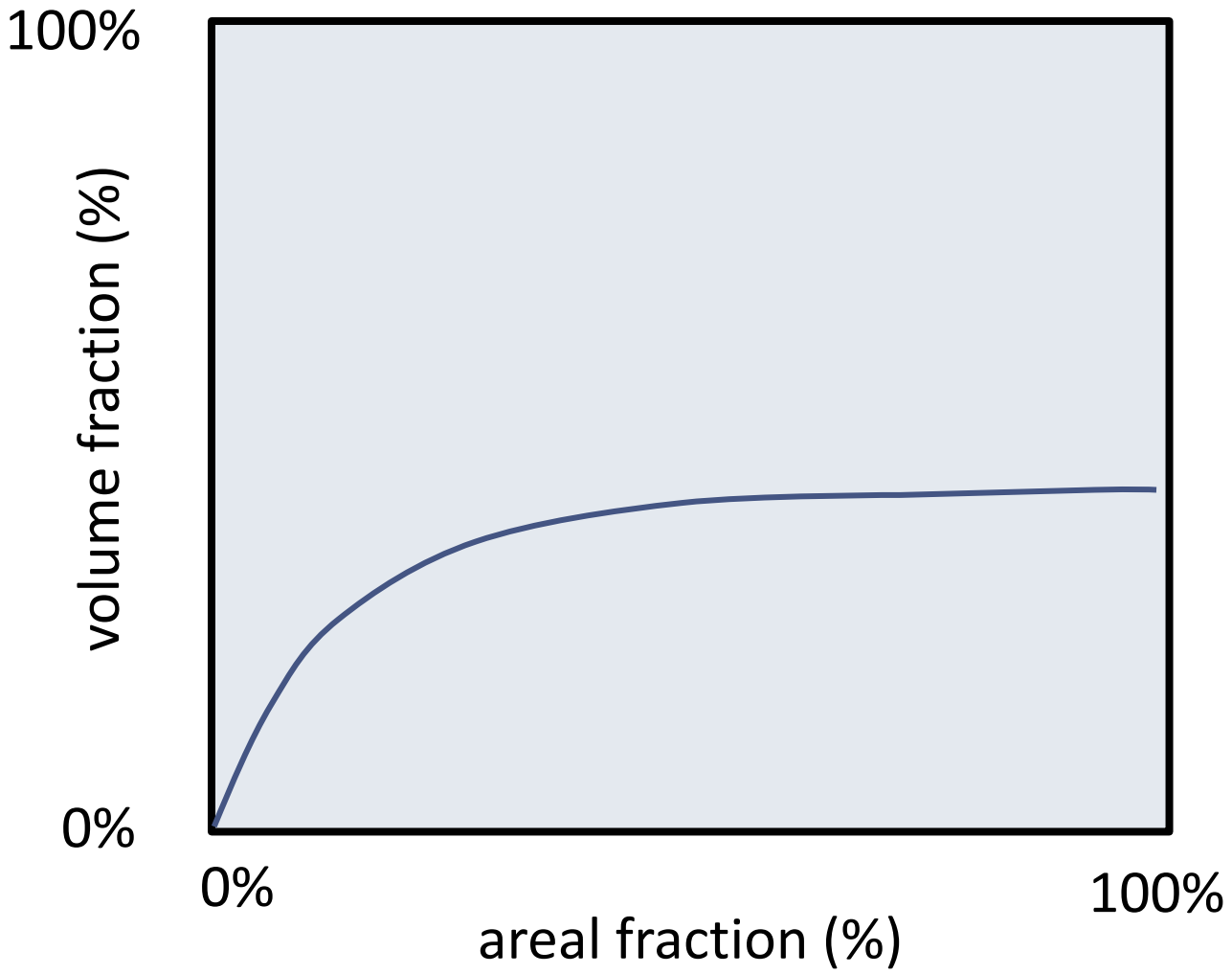
UCD & UT data combined (N = 2831)
Cumulative Distribution



Breast density decreases about 5 % per decade



Areal Fraction versus Volume Fraction



DgN for 0% Glandular Breast

TABLE 7
D_{gN} Values for W-Rh (50-μm-thick) Anode-Filter Combination and a 0% Glandular Breast

Energy (kV)	HVL	Breast Thickness (cm)										
		2	3	4	5	6	7	8	9	10	11	12
20	0.338	342	258	202	164	136	116	101	89	79	71	65
21	0.365	368	282	224	183	153	131	114	100	90	81	74
22	0.392	392	306	245	202	170	146	127	112	101	91	83
23	0.420	415	328	266	221	187	161	140	124	111	101	92
24	0.444	434	347	284	237	201	174	152	135	121	109	100
25	0.462	447	360	296	248	211	183	160	142	128	116	106
26	0.477	457	370	305	257	219	190	167	148	133	120	110
27	0.489	465	378	313	264	226	195	172	153	137	124	113
28	0.500	472	385	320	270	231	200	176	157	141	128	116
29	0.509	478	391	326	275	236	205	180	160	144	131	119
30	0.518	484	397	331	280	241	209	184	164	147	134	122
31	0.527	489	403	336	285	245	213	188	168	151	137	125
32	0.535	494	408	342	290	250	218	192	171	154	140	128
33	0.544	499	413	347	295	254	222	196	175	158	143	131
34	0.552	504	418	352	300	259	226	200	179	161	146	134
35	0.560	509	424	357	306	264	231	205	183	165	150	137
36	0.569	514	429	363	311	269	236	209	187	169	154	141
37	0.577	519	434	368	316	275	241	214	192	173	158	144
38	0.585	524	440	373	321	280	246	218	196	177	161	148
39	0.593	528	444	379	327	285	251	223	200	181	165	152
40	0.601	532	449	383	331	289	255	227	204	185	169	155

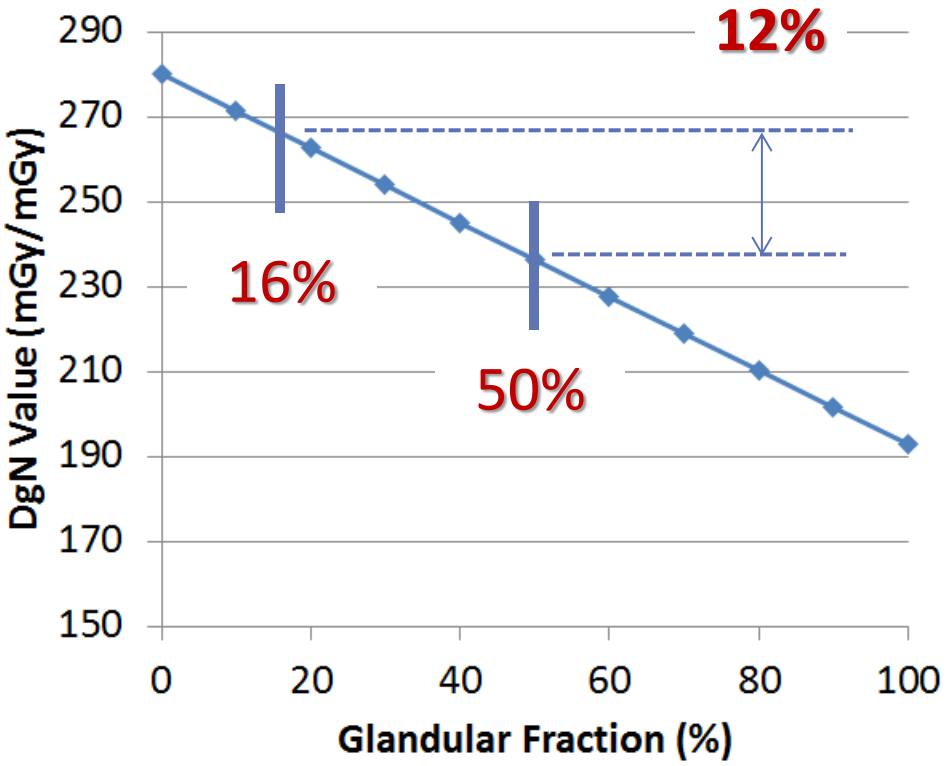
Note.—D_{gN} values are expressed in millirad per roentgen. To convert to SI units (mGy · mGy^{-1}), multiply by 873^{-1}.

DgN for 100% Glandular Breast

TABLE 8
D_{gN} Values for W-Rh (50-μm-thick) Anode-Filter Combination and a 100% Glandular Breast

Energy (kV)	HVL	Breast Thickness (cm)										
		2	3	4	5	6	7	8	9	10	11	12
20	0.338	271	182	133	104	84	71	61	54	48	43	39
21	0.365	296	203	150	118	96	81	70	61	55	49	45
22	0.392	320	223	167	132	108	91	79	69	61	55	50
23	0.420	342	243	184	146	120	101	88	77	69	62	56
24	0.444	361	260	199	158	131	111	96	84	75	68	62
25	0.462	374	272	209	167	138	117	101	89	80	72	65
26	0.477	384	281	217	174	144	122	106	93	83	75	68
27	0.489	392	289	223	179	149	126	109	96	86	77	70
28	0.500	399	295	229	184	153	130	112	99	88	80	73
29	0.509	405	301	234	188	156	133	115	102	91	82	75
30	0.518	411	306	239	193	160	136	118	104	93	84	76
31	0.527	417	311	244	197	164	140	121	107	95	86	78
32	0.535	422	317	248	201	168	143	124	110	98	88	80
33	0.544	427	322	253	206	172	147	127	112	100	91	83
34	0.552	433	327	258	210	176	150	131	115	103	93	85
35	0.560	438	333	263	215	180	154	134	119	106	96	88
36	0.569	443	338	269	220	185	158	138	122	109	99	90
37	0.577	449	344	274	225	190	163	142	126	113	102	93
38	0.585	454	350	280	230	194	167	146	130	117	105	96
39	0.593	459	355	285	235	199	172	151	134	120	109	99
40	0.601	464	360	290	240	204	176	155	137	124	112	102

Note.—D_{gN} values are expressed in millirad per roentgen. To convert to SI units (mGy · mGy^{-1}), multiply by 873^{-1}.



increase in "average" DgN coefficient of:

(265-237)/237 = **12%**

5 cm

		2 cm		4 cm		6 cm		8 cm				
30	0.518	411	306	239	193	160	136	118	104	93	84	76
30	0.518	484	397	331	280	241	209	184	164	147	134	122

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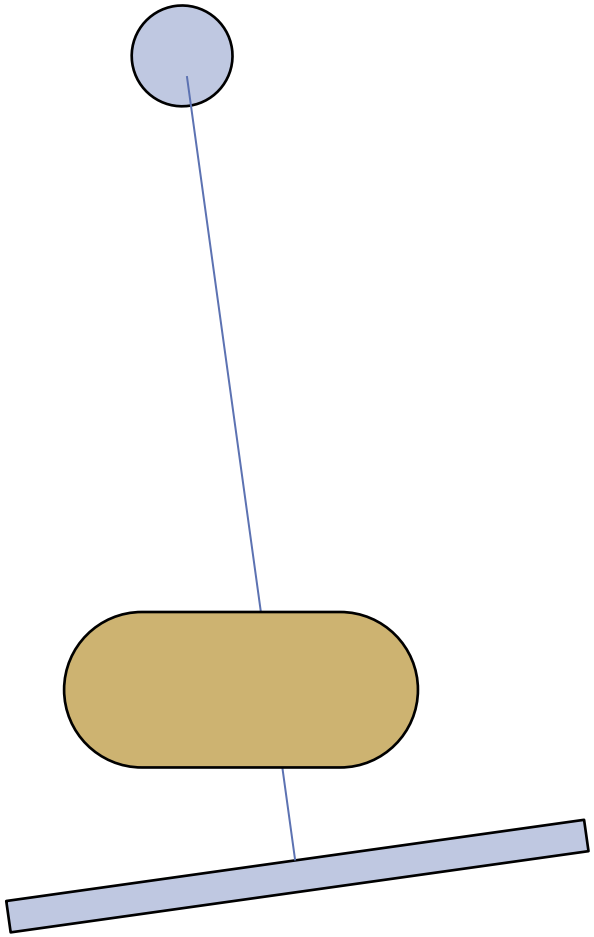
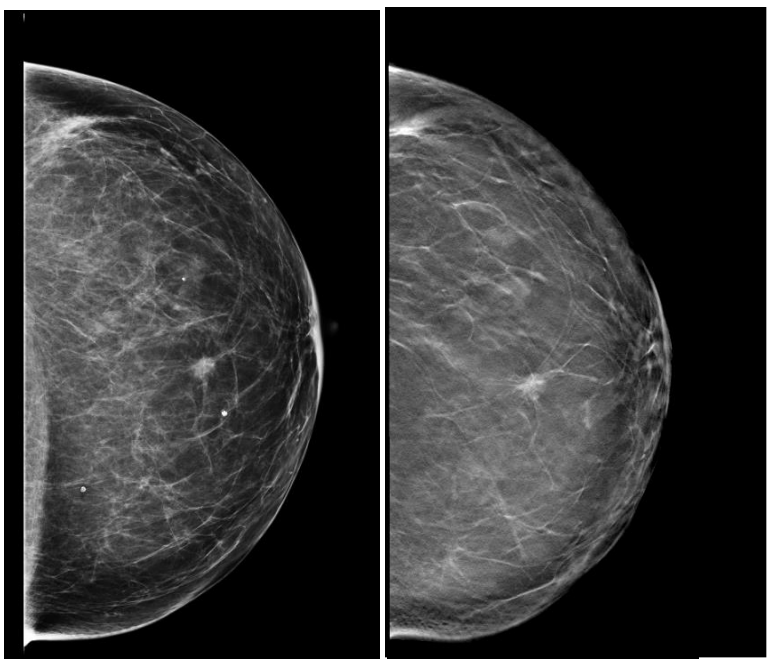
Summary

Tomosynthesis (limited angle tomography)

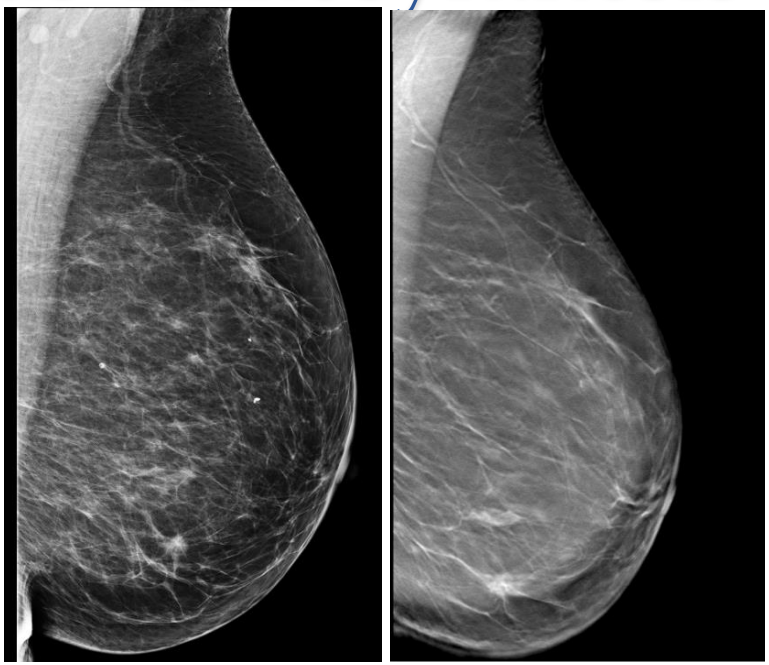



HOLOGIC

Conventional versus Tomosynthesis



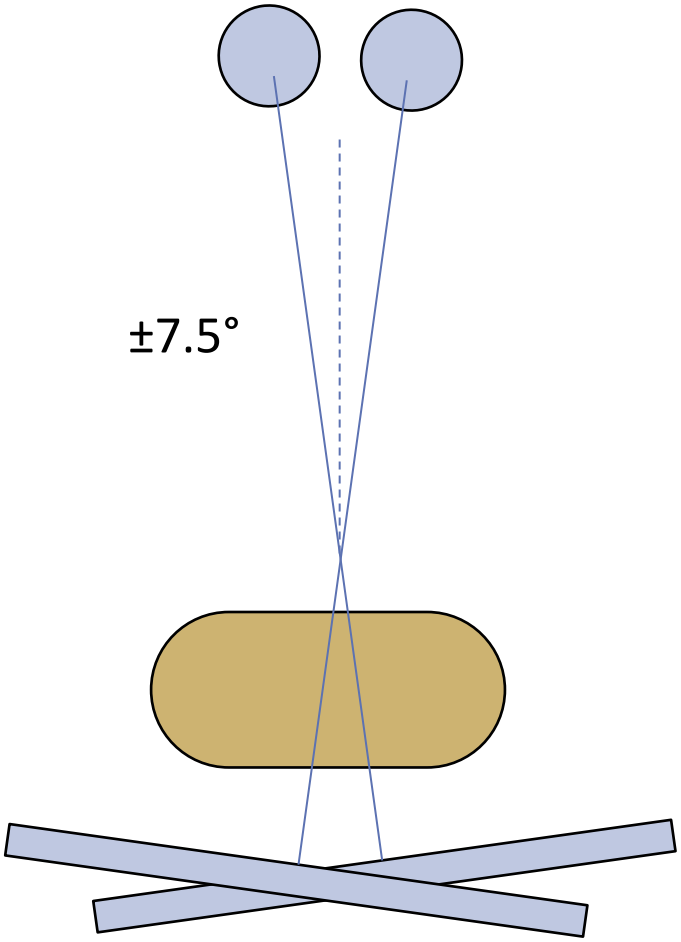
Conventional Tomosynthesis



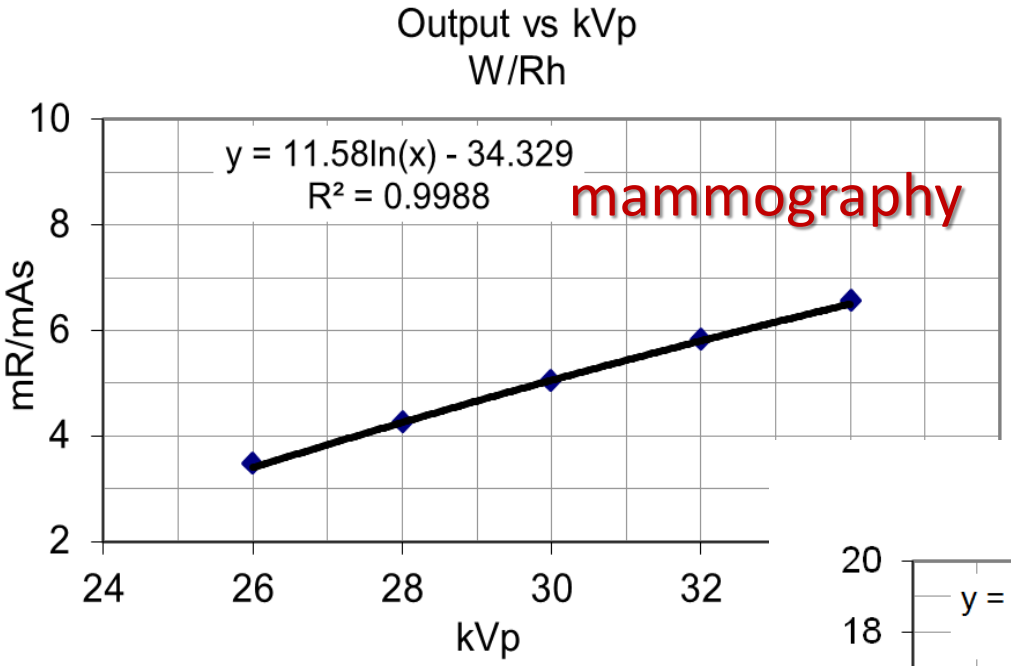
Conventional Tomosynthesis

Similar display characteristics

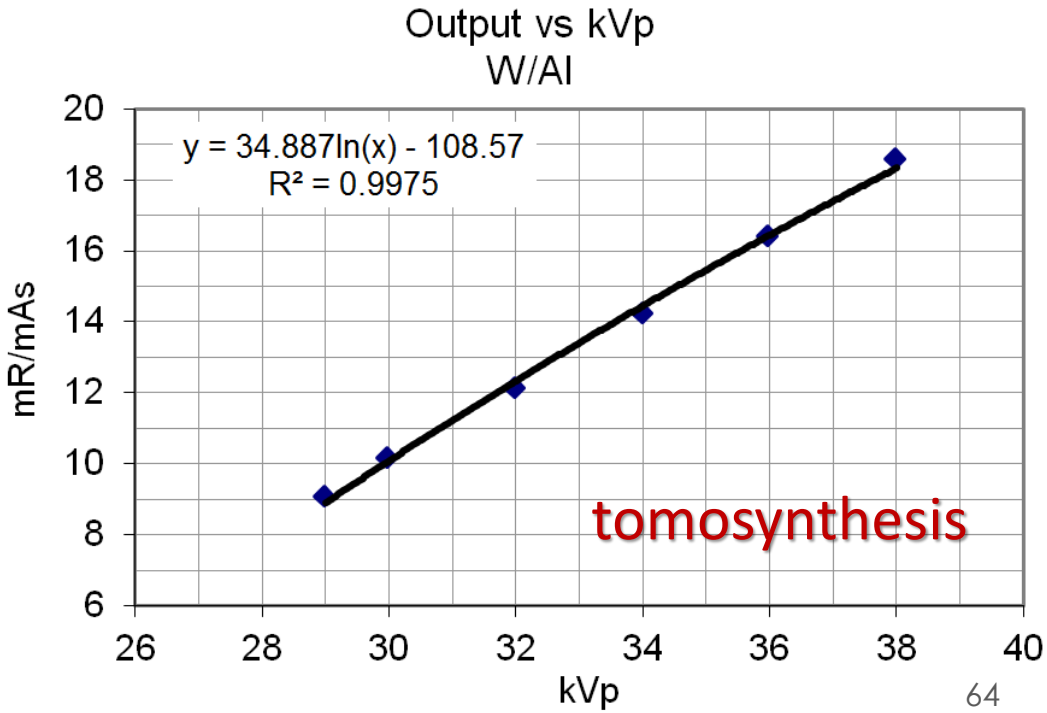
Tomosynthesis (limited angle tomography)



Combo Tomo / Mammo mode output



mR/mAs or
mGy per 100 mAs

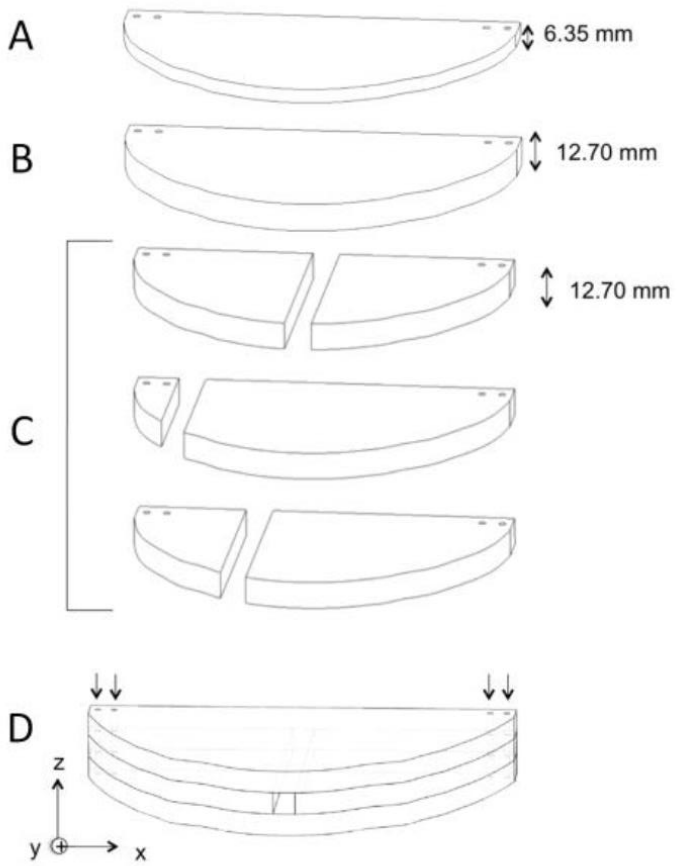


3D Dose measurements in tomosynthesis using a high bandwidth dosimeter

Anita Nosratieh, George W. Burkett, John M. Boone

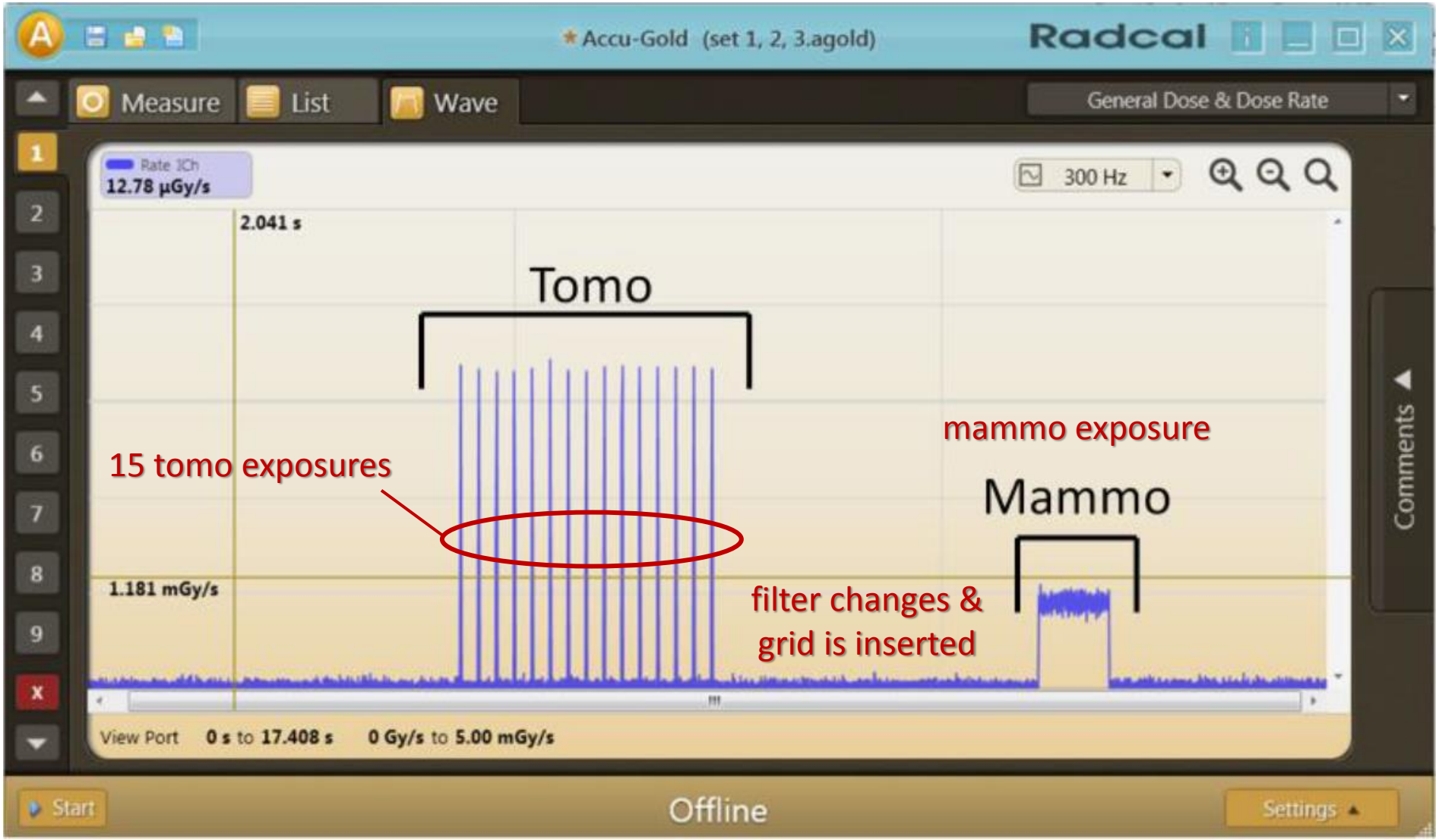
UC Davis Medical Center

Physical measurements of dose in Tomo/Mammo

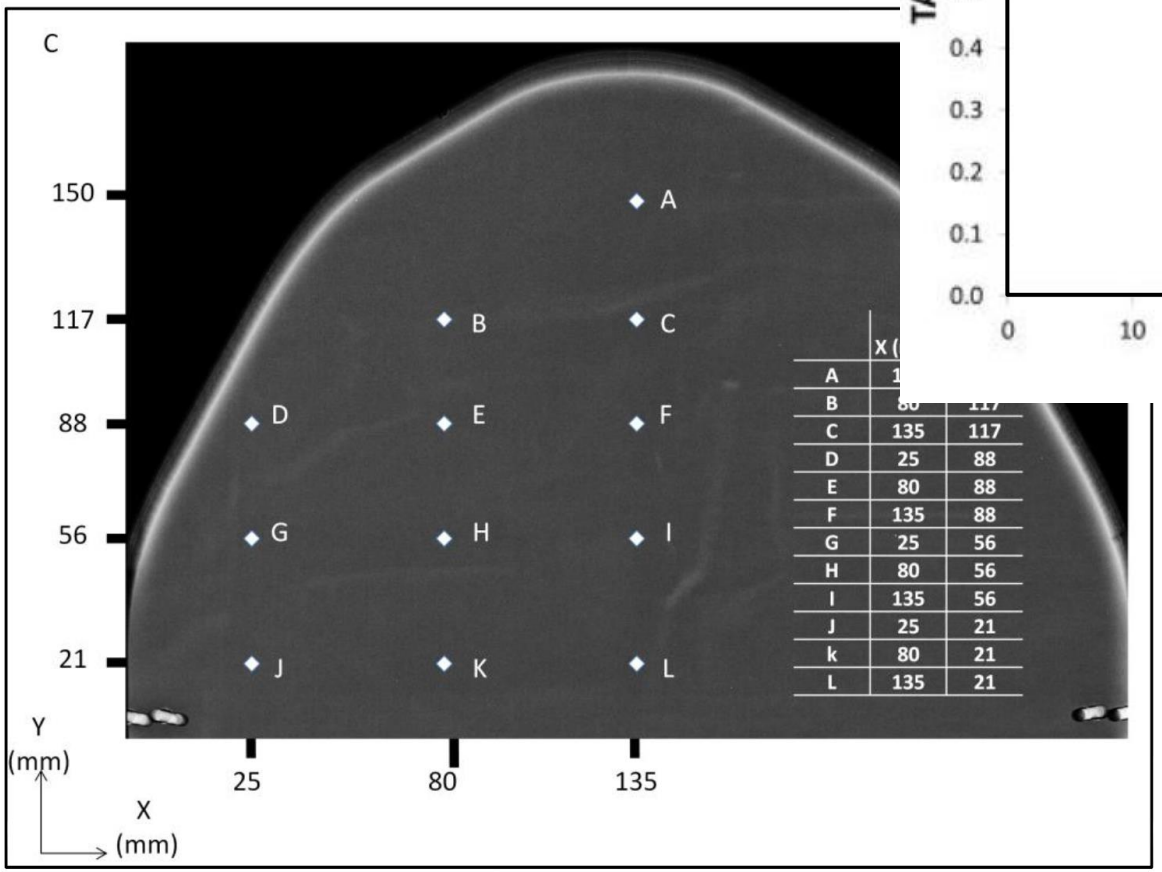


Polyethylene is an excellent surrogate for adipose

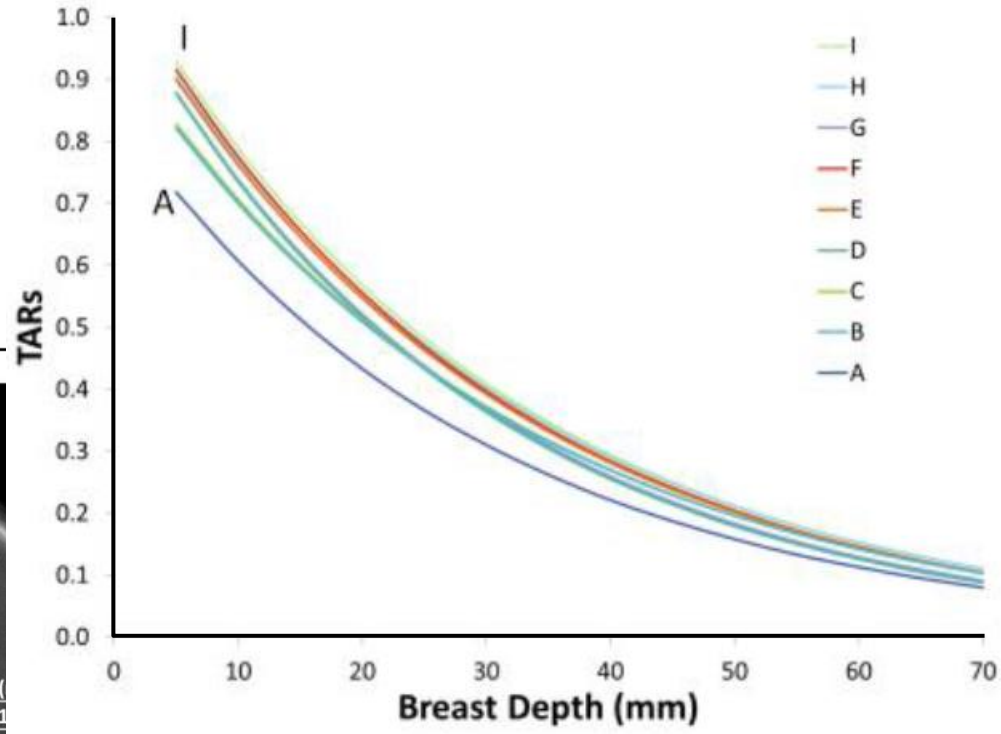
Output of real time exposure meter



Point dose measures: Tissue Air Ratios



	X	
A	1	
B	80	117
C	135	117
D	25	88
E	80	88
F	135	88
G	25	56
H	80	56
I	135	56
J	25	21
k	80	21
L	135	21



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- Complete characterization of the x-ray system is necessary
  (kV accuracy, HVL, and air kerma / 100 mAs @ anode/filter)
- Ionization chambers must be mammo beam compatible
  thin windowed and calibrated
- Practical Assessment requires table of DgN values
  specific to the conditions of the actual exam
- Current DgN tables may slightly under-estimate dose
  due to % glandular fraction and skin thickness issues
- Tomosynthesis is similar enough to the geometry of mammo
  anode/filter combo may differ; different DgN tables needed