Dose Measurement in Mammography; What are we measuring?

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Average Glandular Dose

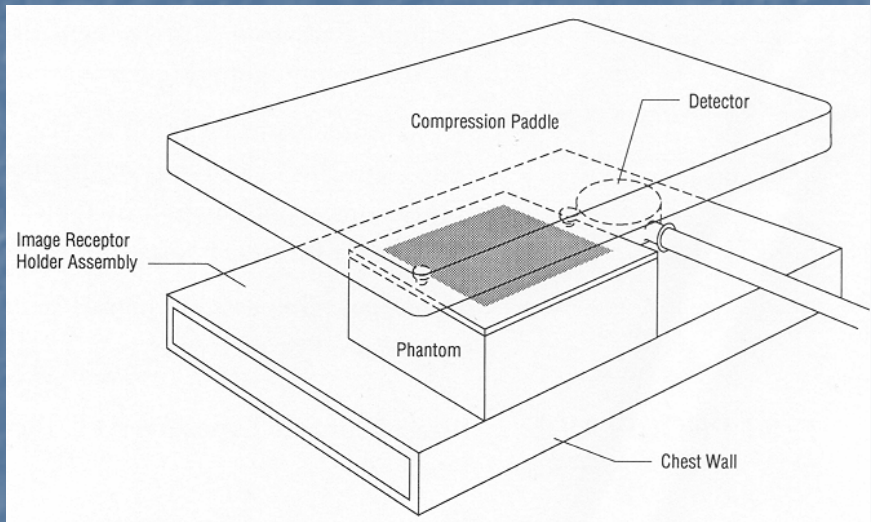
- Required measurement performed by medical physicist as part of Mammography quality Control Tests
- Objective: To measure the typical entrance exposure for an average patient (approximately 4.3 cm compressed breast thickness – 50% adipose, 50% glandular composition, to calculate the associated average glandular dose,……

Prescribed Dose Measurement Procedure

- Phantom:
  - Mammography phantom (equivalent to approximately 4.2 cm compressed breast tissue – 50-50 composition) or
  - A phantom made of either acrylic or BR-12 and consisting of at least four 2 cm thick slabs to provide thicknesses of 2, 4, 6 and 8 cm of linear dimensions representative of typical breast sizes may be used to determine doses for other breast thicknesses (optional)

Review of measurement procedure

- Set-up for typical clinical exam
  - 4-6 cm breast thickness (average patient)
  - Load cassette
- Position Phantom
  - Centered
  - AEC sensor centered under phantom
    - Below wax insert
- Position Ion Chamber
  - Center 4 cm in from chest-wall edge
  - Top of chamber even with top of phantom



Review of measurement procedure cont'd

- Compression Paddle
  - in beam
  - just above phantom and chamber
- Select Techniques
  - kVp
  - Target and Filter
  - As used clinically
- Measurements
  - Record four exposures & mAs

Calculation of Dose

$$AGD\,(mGy) = f\,(mGy\ /\ R) \times X\,(R)$$

AGD = Average Glandular Dose mGy (or mrad)

f = Conversion factor (mGy/R or mrad/R)

X = Averaged Exposure Measurement (R)

Includes chamber corrections and inverse square scaling if necessary

f - Conversion Factor

- Depends on x-ray spectrum, breast composition and compressed breast thickness.
- Spectrum affected by:
  - kVp
  - Target/Filter Combination
  - Half-Value Layer

Glandular Dose Conversion Factors (mrad/R) extracted from Table 1*

HVL	25	26	27	28	29	30
0.25	131					
0.26	135	138				
0.27	140	142	143			
0.28	144	146	147	149		
0.29	148	150	151	153	154	
0.3	153	155	156	157	158	159
0.31	157	159	160	161	162	163
0.32	162	163	164	166	167	168
0.33	166	168	169	170	171	173
0.34	171	172	173	174	175	176
0.35	175	176	177	178	179	180
0.36	179	181	182	183	184	185
0.37		185	186	187	188	189
0.38			190	191	192	193
0.39				196	197	198
0.4					201	202
0.41						206

Sample Cal

- Technique for 4 cm compressed bre
  - 26 kVp, 100 mAs
- Measured Exposure using Mo/Mo ta combination = 1.018 R
- Measured HVL = 0.33 mm Al

Look up conversion factor:

168 mrad/R

$$AGD = 1.018\,R \times 168\,mrad\ /\ R = 171\,mrad$$

1.71 mGy < 3 mGy per viev

HVL	25	26	27	28	29	30
0.25	131					
0.26	135	138				
0.27	140	142	143			
0.28	144	146	147	149		
0.29	148	150	151	153	154	
0.3	153	155	156	157	158	159
0.31	157	159	160	161	162	163
0.32	162	163	164	166	167	168
0.33	166	**168**	169	170	171	173
0.34	171	172	173	174	175	176
0.35	175	176	177	178	179	180
0.36	179	181	182	183	184	185
0.37		185	186	187	188	189
0.38			190	191	192	193
0.39				196	197	198
0.4					201	202
0.41						206

- "The product obtained represents the mean dose received by the glandular tissue for that specific energy, breast composition, and compressed thickness and is an *approximation of the actual patient dose."*

Options at this point:

- Proceed with the rest of the survey
- Perform additional dose measurements at 2, 4, 6, and 8 cm thicknesses with BR12

- Do these represent actual patient doses at those compressed breast thicknesses?

Expectations:
Changing thickness likely

- changes beam energy
- results in different breast composition
- requires additional tables for dose conversion factors

- Options:

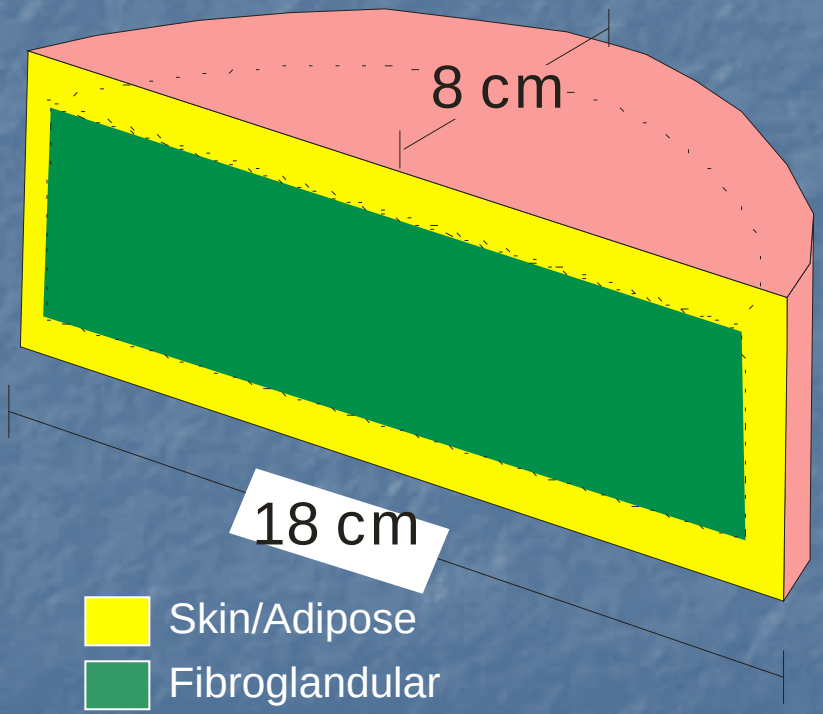
"Conversion factors for other breast or phantom thicknesses may be found in the articles by Dance, by Wu et al., and by Sobol et al, ….

Where do these conversion factors come from anyway?

- A series of Monte Carlo simulations in the early 1990's

Current Dosimetry Model (U.S.)

Wu *et al.* 1991,1994; Sobol and Wu, 1997



- Physical dimensions
  - FDA medium breast (8 cm x 18 cm)
- Adipose thickness, 0.4 cm,
- Fibroglandular Region:
  - Variable thickness
  - Variable composition glandular/adipose tissue

Table 2

Glandular Tissue Dose (millirad) for 1-R Entrance Skin Exposure and 100% Glandular Breast

X-ray Tube Voltage (kVp)/HVL (mm Al)	Compressed Breast Thickness (cm)					
	3	4	5	6	7	8
23						
0.24	136	100	78	63	53	46
0.26	146	107	84	68	58	50
0.28	157	115	90	73	62	53
0.30	167	123	96	79	66	57
0.32	177	131	102	84	70	61
0.34	188	139	109	89	75	64
25						
0.26	151	112	87	71	60	52
0.28	161	119	93	76	64	55
0.30	171	127	99	81	68	59
0.32	181	134	105	86	73	63
0.34	191	142	111	91	77	66
0.36	201	149	117	96	81	70
27						
0.28	165	122	96	78	66	57
0.30	174	130	102	83	70	61
0.32	184	137	108	88	74	64
0.34	194	144	114	93	78	68
0.36	203	152	119	98	83	71
0.38	213	159	125	103	87	75
29						
0.30	177	132	104	85	72	62
0.32	187	139	110	90	76	66
0.34	196	147	116	95	80	69
0.36	205	154	121	100	84	73
0.38	215	161	127	104	88	76
0.40	224	169	133	109	92	80
31						
0.31	184	138	109	89	75	65
0.33	193	145	115	94	80	69
0.35	203	152	120	99	84	72
0.37	212	160	126	104	88	76
0.39	221	167	132	109	92	80
0.41	231	174	138	113	96	83
33						
0.32	190	143	113	93	79	68
0.34	200	150	119	98	83	72
0.36	209	158	125	103	87	75
0.38	218	165	131	108	91	79
0.40	228	172	137	113	96	83
0.42	237	179	143	118	100	86
35						
0.33	197	148	118	97	82	71
0.35	206	156	124	102	86	75
0.37	215	163	130	107	91	79
0.39	225	170	136	112	95	82
0.41	234	178	142	117	99	86
0.43	243	185	148	122	104	90

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

100 % Glandular

Table 4

Glandular Tissue Dose (millirad) for 1-R Entrance Skin Exposure and 100% Adipose Breast

X-ray Tube Voltage (kVp)/HVL (mm Al)	Compressed Breast Thickness (cm)					
	3	4	5	6	7	8
23						
0.24	207	163	132	110	94	82
0.26	221	175	142	119	102	89
0.28	236	187	152	128	109	95
0.30	251	199	163	136	117	101
0.32	265	211	173	145	124	108
0.34	280	223	183	153	131	114
25						
0.26	227	180	147	123	106	92
0.28	241	192	157	132	113	98
0.30	255	203	166	140	120	104
0.32	268	214	176	148	127	111
0.34	282	226	186	156	134	117
0.36	296	237	195	164	141	123
27						
0.28	245	195	160	135	115	101
0.30	258	206	170	143	122	107
0.32	271	217	179	151	129	113
0.34	285	229	188	159	136	119
0.36	298	240	198	167	143	125
0.38	311	251	207	175	150	131
29						
0.30	261	209	172	145	125	109
0.32	274	220	181	153	132	115
0.34	287	231	191	161	138	121
0.36	299	240	200	169	145	127
0.38	312	253	209	177	152	133
0.40	325	263	218	185	159	139
31						
0.31	268	217	179	151	130	114
0.33	282	227	188	159	137	120
0.35	295	238	197	167	144	126
0.37	307	249	206	175	150	132
0.39	320	259	215	182	157	138
0.41	332	270	224	190	164	144
33						
0.32	277	224	185	157	135	118
0.34	290	234	194	164	142	124
0.36	302	245	203	172	149	130
0.38	315	256	212	180	155	136
0.40	327	266	221	188	162	142
0.42	339	277	230	196	169	148
35						
0.33	285	231	191	162	140	122
0.35	297	241	200	170	147	129
0.37	310	252	209	178	154	135
0.39	322	262	219	186	161	141
0.41	334	273	228	194	167	147
0.43	347	284	237	201	174	153

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

100 % Adipose

Wu X, Barnes GT, Tucker DM. Radiology. 1991; 179: 143-148.

Table 3

Glandular Tissue Dose (millirad) for 1-R Entrance Skin Exposure and 50% Adipose, 50% Glandular Breast

X-ray Tube Voltage (kVp)/HVL (mm Al)	Compressed Breast Thickness (cm)					
	3	4	5	6	7	8
23						
0.24	166	126	100	82	69	60
0.26	179	135	107	88	75	65
0.28	191	145	115	95	80	69
0.30	203	155	123	101	86	74
0.32	216	164	131	108	91	79
0.34	228	174	139	114	97	84
25						
0.26	184	140	112	92	78	67
0.28	196	149	119	98	83	72
0.30	207	159	127	104	89	77
0.32	219	168	134	111	94	81
0.34	231	177	142	117	99	86
0.36	242	186	149	123	104	90
27						
0.28	199	153	122	101	85	74
0.30	211	162	129	107	91	79
0.32	222	171	137	113	96	83
0.34	234	180	144	119	101	88
0.36	245	189	152	125	107	92
0.38	256	198	159	132	112	97
29						
0.30	214	164	132	109	93	80
0.32	225	173	139	115	98	85
0.34	236	182	146	121	103	89
0.36	247	190	154	127	108	94
0.38	258	200	161	134	114	99
0.40	269	209	168	140	119	103
31						
0.31	231	171	137	114	97	84
0.33	232	180	145	120	102	89
0.35	243	189	152	126	107	93
0.37	254	197	159	132	113	98
0.39	265	206	166	138	118	102
0.41	276	215	174	144	123	107
33						
0.32	229	177	143	119	101	88
0.34	239	186	150	125	106	92
0.36	250	195	157	131	112	97
0.38	261	203	164	137	117	102
0.40	272	212	172	143	122	106
0.42	282	221	179	149	127	111
35						
0.33	236	183	148	123	105	91
0.35	246	192	155	129	110	96
0.37	257	201	163	136	116	101
0.39	268	210	170	142	121	105
0.41	279	218	177	148	126	110
0.43	289	227	185	154	132	115

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

Wu X, Barnes GT, Tucker DM. Radiology. 1991; 179: 143-148.

Similar tables are provided for:

- Mo/Mo Target filter combinations
- Mo/Rh Target filter combinations
- Rh/Rh Target filter combinations
- W/Al Target filter combinations

ACR dosimetry measurements are intended to

60%

20%

0%

10%

10%

1. measure the typical entrance exposure for an average patient and to calculate the associated average glandular dose.
2. provide the basis for determining patient specific average glandular dose. .
3. ensure an adequate radiation output rate of mammography x-ray systems.
4. measure the typical entrance exposure and average dose delivered to an acrylic phantom.
5. Provide dosimetry data for the FDA NEXT program.

Entrance exposure to glandular dose conversion factors listed in the ACR Manual

8%

25%

33%

0%

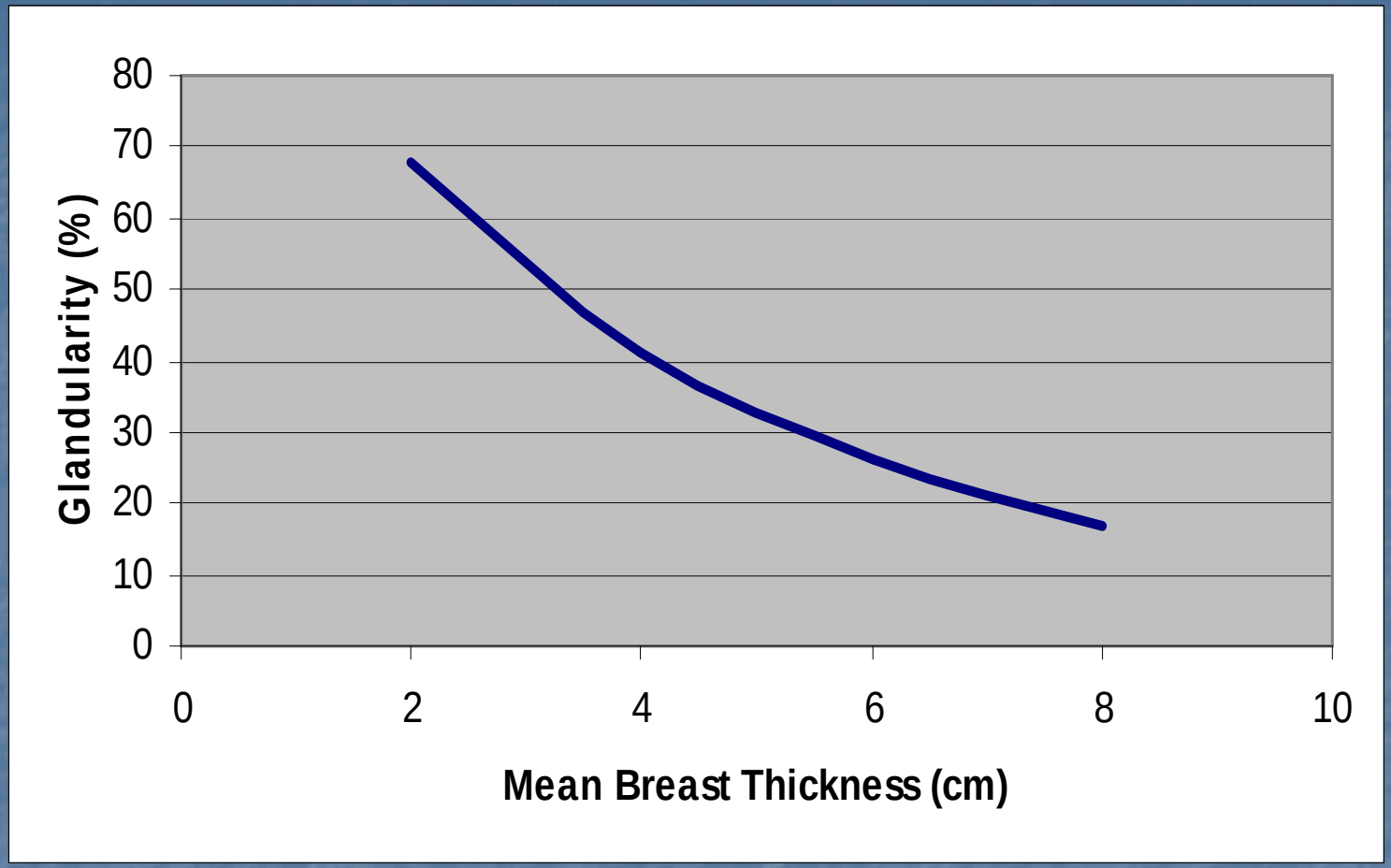
1. can be applied to BR-12 phantoms providing 2, 4, 6 and 8 cm simulated breast thickness.
2. are applicable to only the ACR mammography phantom.
3. can be used to determine dose using Mo/Mo, Mo/Rh, or Rh/Rh target filter combinations.
4. are developed from measured patient data
5. are based upon Monte Carlo simulations of an idealized breast anatomy.

Extension to other cases:

- Appropriate dose conversion factors may be obtained for:
  - BR12 of different thicknesses using the previous table.
  - Other compositions of glandular and adipose tissues by interpolation between the values provided on the previous tables.

Glandular:Adipose compostion

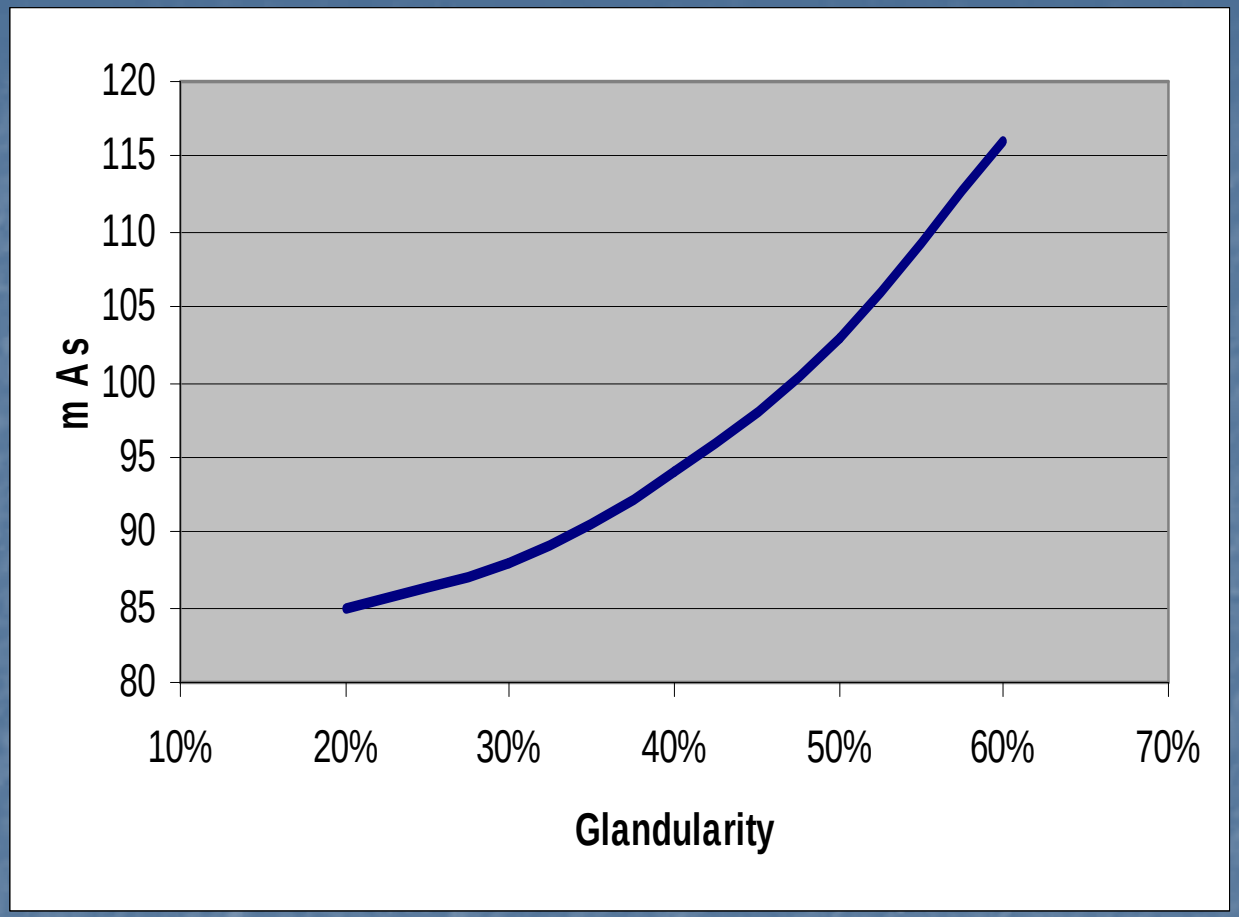
- Population exhibits a broad distribution of tissue compositions
- The glandular:adipose percentage is a function of multiple variables:
  - Compressed breast thickness
  - Age
  - Individual variation



Adapted from Geise and Palchevsky,Composition of mammographic phantom materials,Radiology 1996, 198:347-350.

Expectations (variable glandularity):

- Glandular tissue has greater density than adipose tissue
- For breast of same thickness, increased glandularity (percentage of glandular tissue) will require
  - a greater phototimed mAs
  - a greater delivered dose

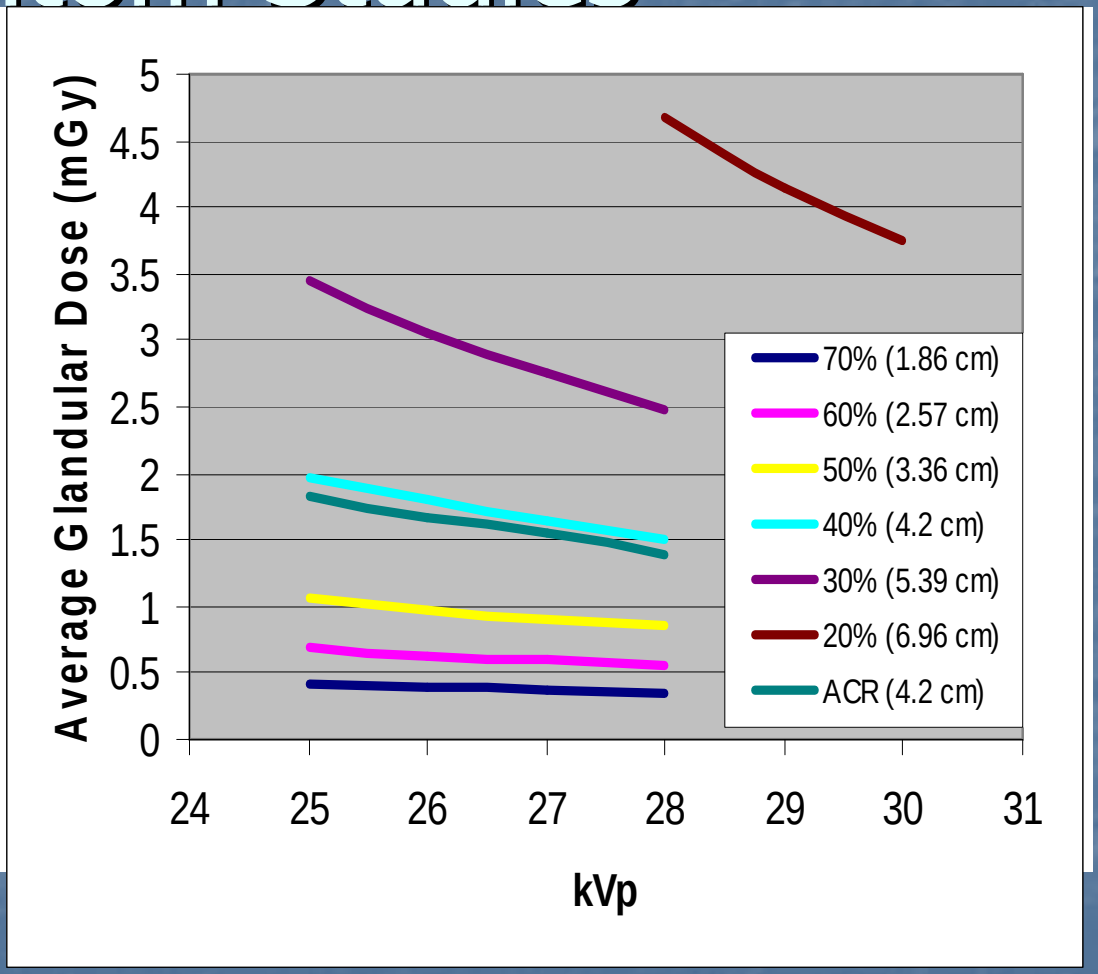


Argo et al., Tissue equivalent phantom series for mammography dosimetry, JACMP, 5,4,112-119 2004.

Expectations (variable thickness):

- For increased thickness (constant glandularity) phototimed mAs will increased entrance exposure and mid-line dose.
- But generally: increased compressed thickness correlates with decreased glandularity
- Effects on dose?

Phantom Studies



Argo et al., Tissue equivalent phantom series for mammography dosimetry, JACMP, 5,4,112-119 2004.

- Substantial differences in dose occur as a function of varying breast thickness and composition.
  - Quite possibly a factor of two larger or smaller than that predicted by the 4.2 cm accreditation phantom.
  - The 4.2 cm accreditation responds more like a 4 cm and 40% glandular tissue.

For a given compressed breast thickness the average glandular dose

100%	1.	increases with increasing % glandularity.
0%	2.	decreases with increasing % glandularity.
0%	3.	is independent of % glandularity.
0%	4.	reaches a minimum at 50% glandularity.
0%	5.	reaches a maximum at 50% glandularity .

The average glandular dose from photo-timed exposures is generally observed to

0%	1.	be independent of half-value-layer.
0%	2.	be independent of compressed breast thickness.
83%	3.	increase with increasing compressed breast thickness.
17%	4.	decrease with increased compressed breast thickness.
0%	5.	decrease with increased glandular/adipose tissue ratios.

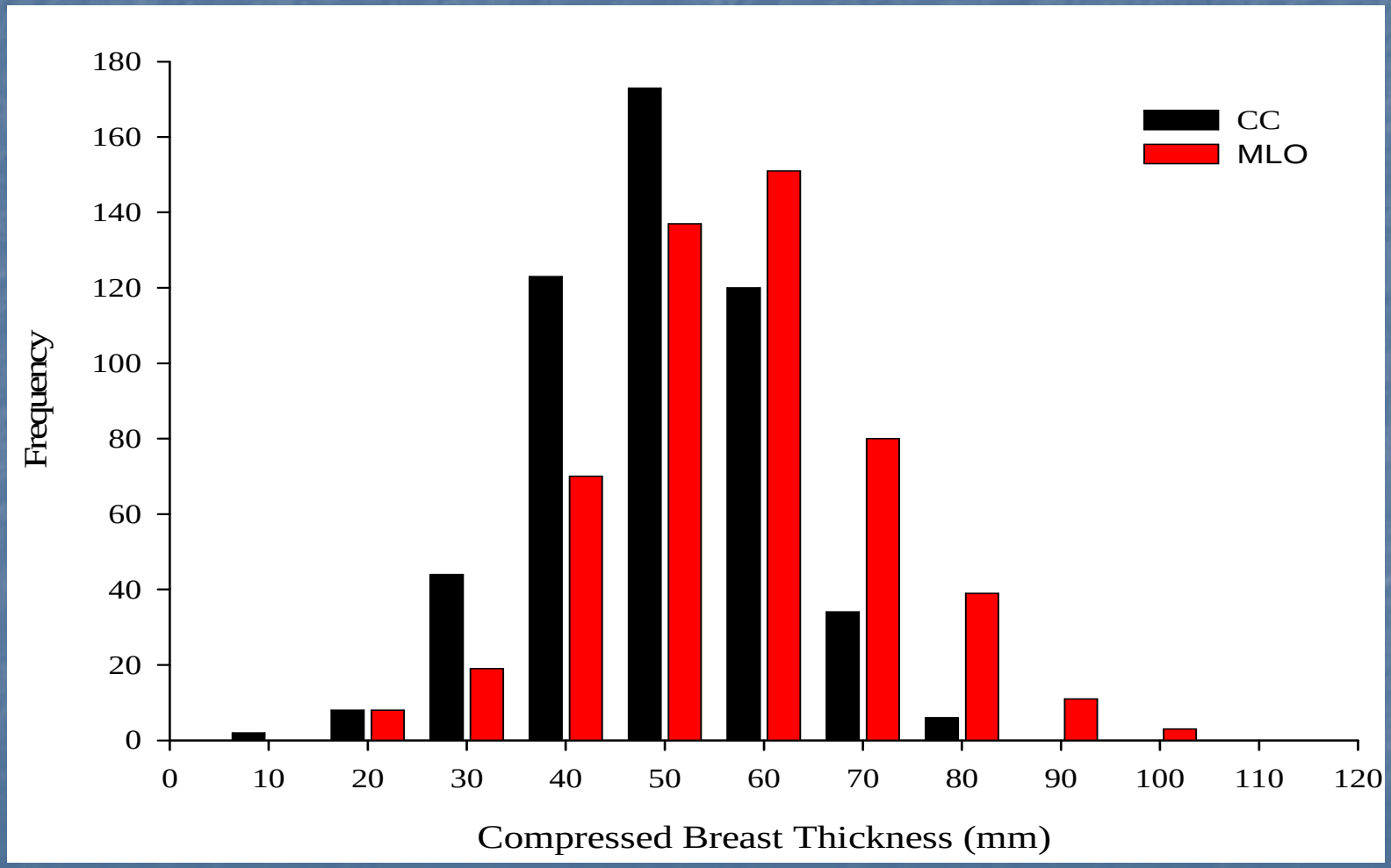
The 4.2 mm ACR phantom has a radiological response closest to

0%	1.	a 2 cm breast of approximately 20% glandularity.
8%	2.	a 2 cm breast of approximately 50% glandularity.
83%	3.	4 cm breast of approximately 40% glandularity.
8%	4.	a 4 cm breast of approximately 70% glandularity.
0%	5.	an 8 cm breast of approximately 20% glandularity.

Real Patient Distributions

- Distributions of thickness and glandularity will result in dose distributions.
- Study performed by Benevides examined ~ 3000 patients

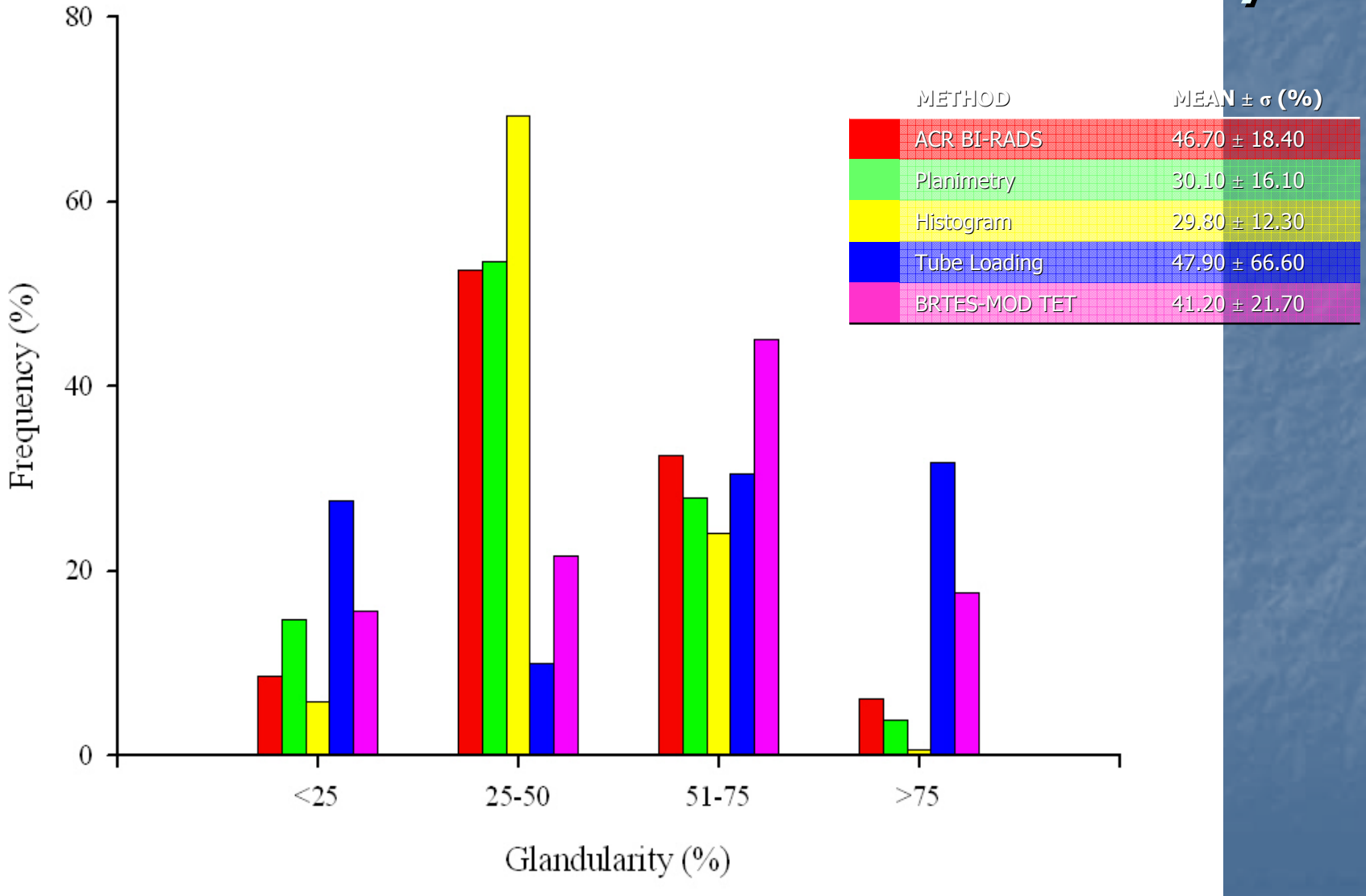
Distribution of Compressed Breast Thickness



The distribution shows that:

- There is a broad distribution in compressed breast thickness about 4.2 cm.
- The compressed thickness differs between CC and MLO views.
- Mean CC breast thickness may be closer to 5 cm

Distribution of Glandularity



The distribution shows that:

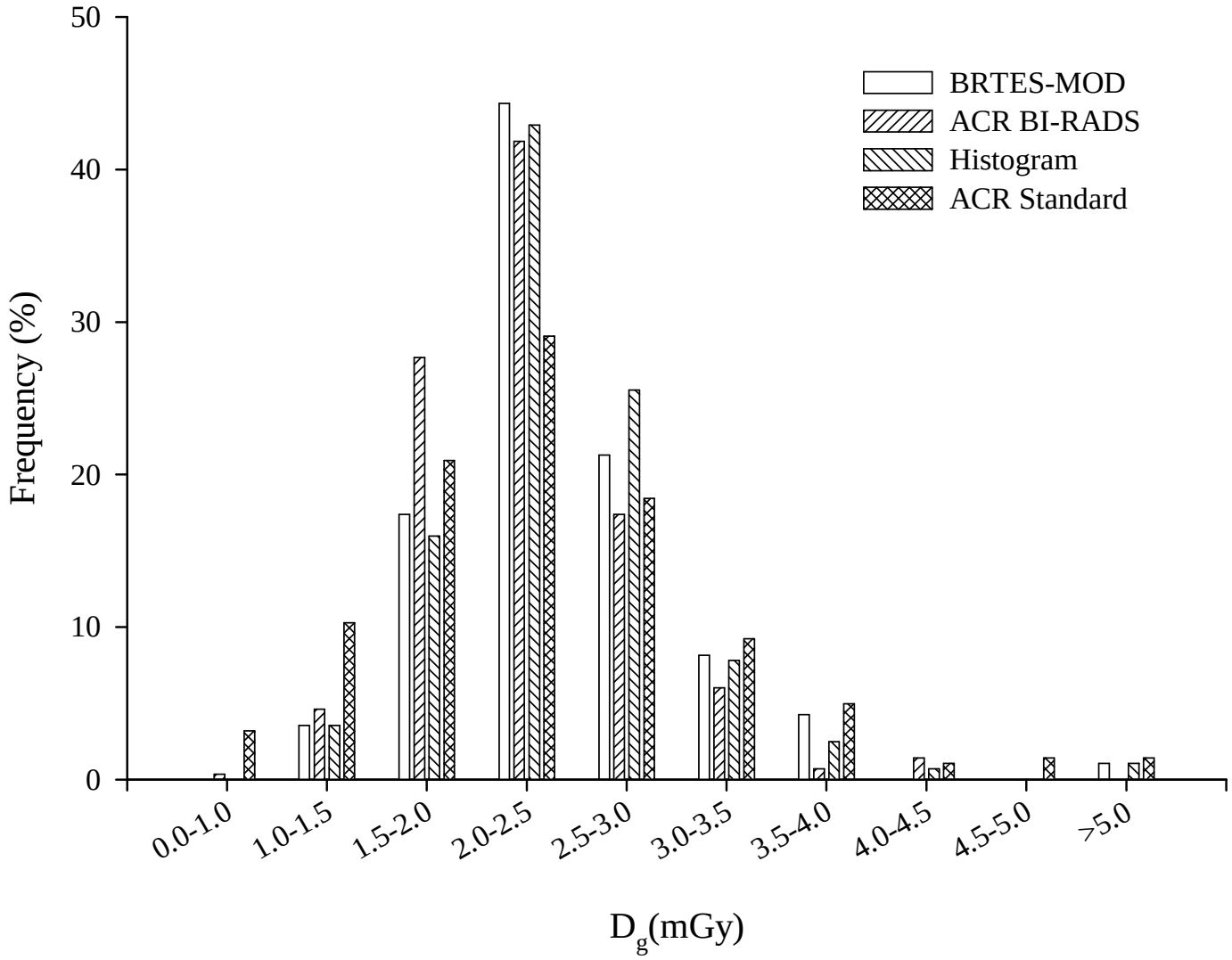
- There is a broad distribution of glandularity
- The mean glandularity is closer to 40% (than the 50% suggested by the accreditation phantom)

- Based on this study a 5 cm, 40% glandular – 60% adipose phantom would be more representative of this population.

Effects on the Glandular Dose

- The distributions of compressed thickness and glandularity combine to result in a distribution in mean glandular doses to the population

Average Glandular Dose



"Average" patient dose

- The systems used in these studies predicted an average glandular dose to the 4.2 cm accreditation phantom of 1.75 mGy.
- The mean of the predicted distribution is higher, 2.4 mGy
- The distribution of doses is broad
- A portion of the population receives average glandular doses exceeding 3 mGy.

Conclusions

- Standard dose measurement provides a means of comparing standard output.
- Individual patient doses can vary significantly from the standard dose measurement.
- Even “average” patient dose may differ and is a function of specific examination populations.

References

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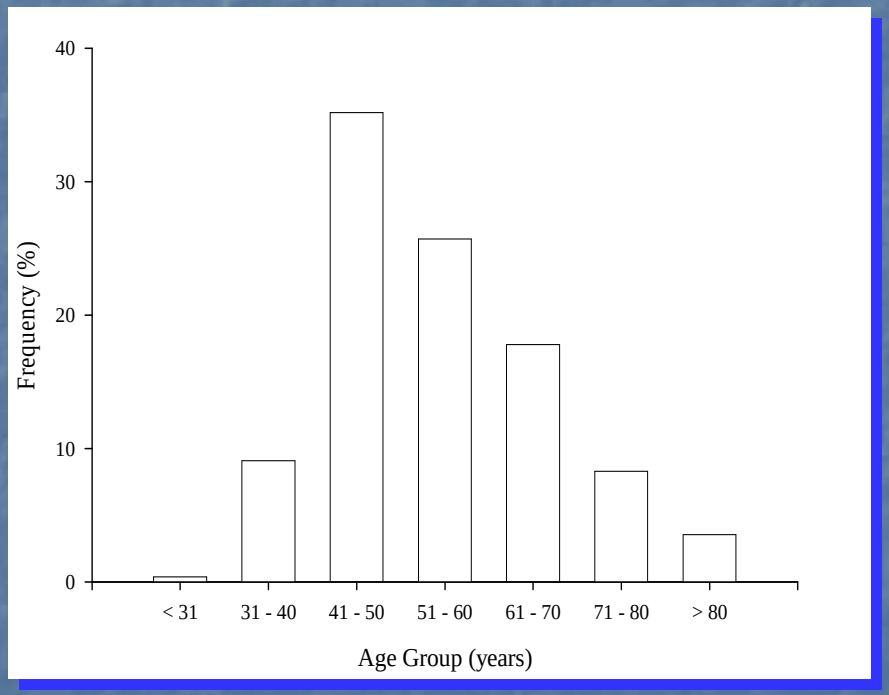
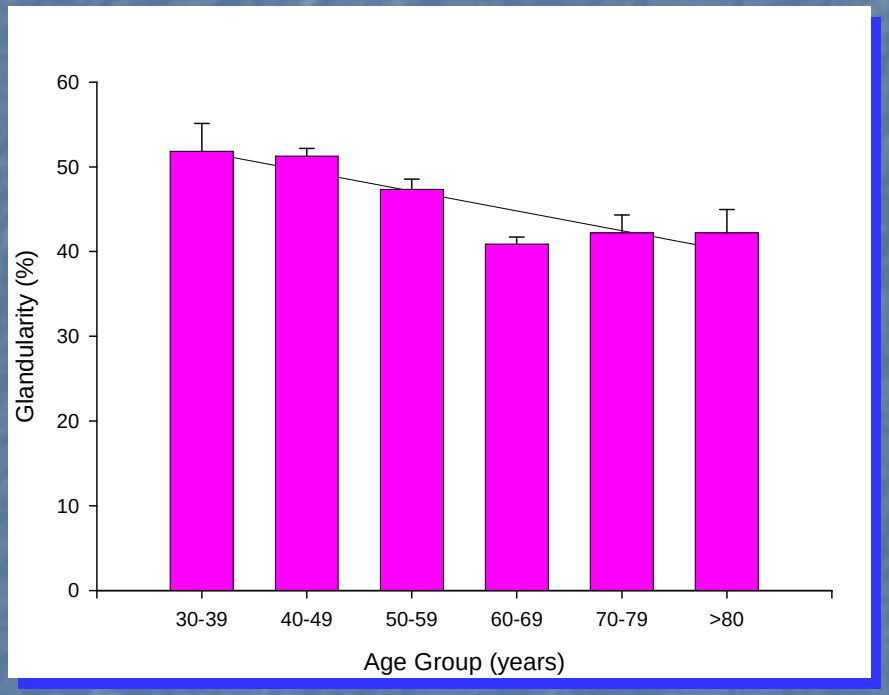
- Argo WP, Hintenlang, KM, Hintenlang DE. Tissue equivalent phantom series for mammography dosimetry, JACMP. 2004: 5,4,112-119.
- Benevides LA, Breast dosimetry in clinical mammography, Ph.D. Dissertation, University of Florida. 2005.

Mammography Population

- Mean Age
  - 54 ± 12 years
- BI-RADS Assessment categories
  - 57% (1), 43% (2)



Glandularity



Error bars are standard error