Contrast-Enhanced Mammography: Physics and QC Testing

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Disclosures

- OSU has research agreements with Siemens Healthineers and Qaelum NV (unrelated to talk).
- Most of the QC I will discuss is for Hologic units because that is what we have at OSU.

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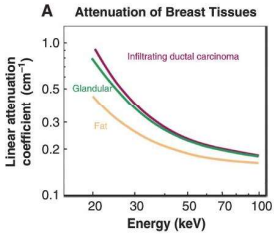
X-ray Energy

- Contrast is important
- Attenuation coefficients (μ) of breast cancer are very close to that of normal tissue
- Low kVp (23-32 kVp) gives increased contrast



Bushberg et al, 3rd ed.

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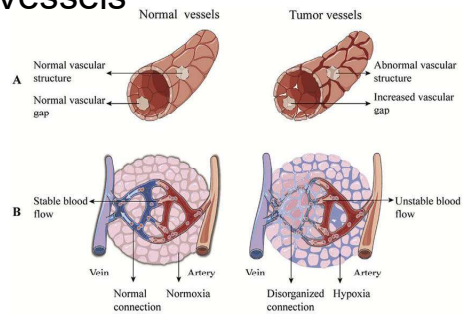
Leaky Vessels



Y Sun, D Zhao, G Wang, Y Wang, L Cao, J Sun, Q Jiang, and Z He, "Recent progress of hypoxia-modulated multifunctional nanomedicines to enhance photodynamic therapy: Opportunities, challenges, and future development," Acta Pharm. Sin. B **10**(8), 1382-1396, 2020.

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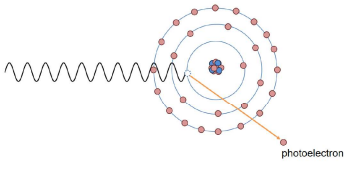
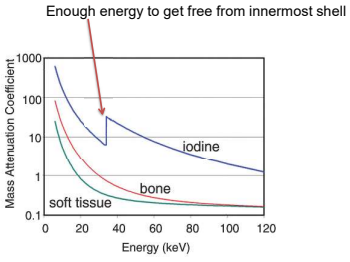
Iodine *k*-edge

Photoelectric effect





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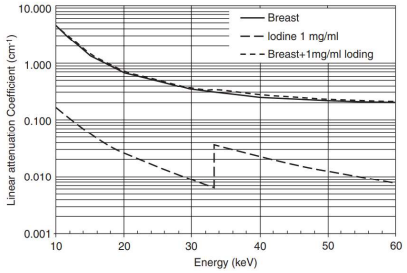
Iodine *k*-edge



C. R. L. P. N. Jeukens, "Physics of Contrast-Enhanced Mammography," in *Contrast-Enhanced Mammography*, edited by M. Lobbes and M. S. Jochelson (Springer, Cham, 2019), p. 26.

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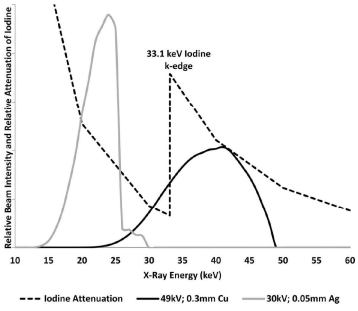
X-ray Spectra

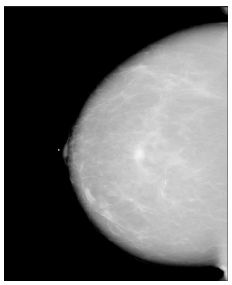
To maximize iodine contrast:

- Higher kVp: 45-49 kVp
- Filtration: ~0.3 mm copper (GE, Hologic) or 1 mm titanium (Siemens)

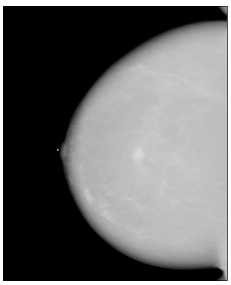


Sensakovic, Carnahan, Czaplicki, Fahrenholtz, Panda, Zhou, Pavlicek, Patel, "Contrast-enhanced Mammography: How Does It Work?" *Radiographics* **41**(3), 829-839, 2021.

Image Acquisition



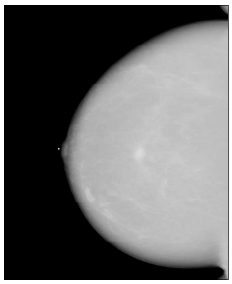
Low E – 30 kVp with Ag filter



High E – 49 kVp with Cu filter

Image Acquisition

Low E – 30 kVp with Ag filter



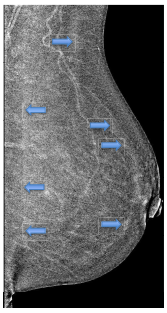
High E – 49 kVp with Cu filter

Dual-energy subtraction

$$\ln\left[\text{High E – 49 kVp with Cu filter}\right] - k*\ln\left[\text{Low E – 30 kVp with Ag filter}\right] = \text{Subtraction}$$

"Breast-in-Breast" or Rim Artifact

- On subtraction images, band at the periphery
- From scatter distribution differences between high- and low-energy images
- Also occurs at the chest wall
  - You will most likely see this on artifact evaluation images



CEM QC

Hologic: 

GE: SenoBright™ HD CESM HD Quality Control Manual

Additional tests required:

- Artifact Evaluation/Flat-field Uniformity with Cu filter
- Half-value layer (HVL) for copper filter and high kV
- Entrance exposure, AEC reproducibility, and average glandular dose (AGD) for high- and low-energy subtraction acquisition

- GE-specific automated tests:
  - Flat field test with copper filter
  - AOP & SNR tests with copper filter

CEM QC

2018 ACR QC Manual FAQ: Use **manufacturer's QC** manual for CEM

Q. Our facility has a digital mammography unit that performs 2D and/or DBT imaging and contrast enhancement (imaging of an iodinated contrast agent using mammography equipment). Will we be allowed to use the ACR Digital Mammography QC Manual instead of our manufacturer's manual for QC of the 2D and DBT applications of our digital mammography unit and then follow our manufacturer's QC manual for contrast enhancement?

A. Yes. The FDA has determined that facilities may use the manual for QC of the 2D and DBT applications of these units, and recommends that facilities follow manufacturer QC procedures for contrast enhancement applications.

https://www.acraccreditation.org/-/media/ACRAccreditation/Documents/Resources/DMQC/DMQCFAQs.pdf?la=en

Artifact Evaluation

- Hologic QC manual revision 010: must use **Manual** mode for CEM, unlike other target/filter combos, which use Auto-Time mode

Table 13: Artifact Evaluation Cu Filter Exposure Techniques (CE2D Option)

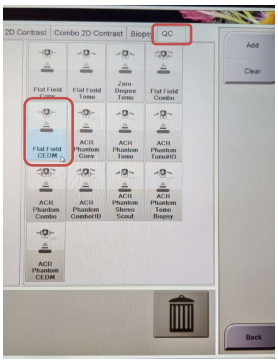
Mode	kVp	mAs	Filter	Focal Spot
Manual	28	100	Rh	Large

Note
The CE2D modality is only compatible with Manual and Auto-Filter AEC modes.

- Hologic QC manual revision <010: Auto-Time mode instructed

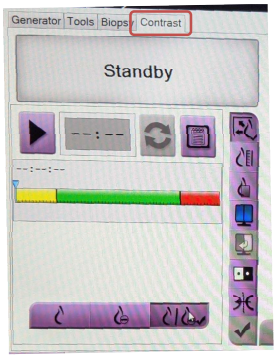
Artifact Evaluation

Hologic:
- Add View
- QC tab
- Flat Field CEDM
- Add



CEM QC

Hologic: Viewing CEM images
- Contrast tab
- Low-energy image
- Subtraction image
- Split screen



CEM QC

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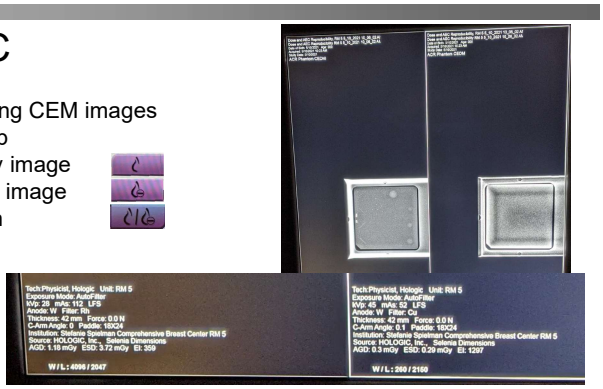


Half-value layer (HVL)

Note

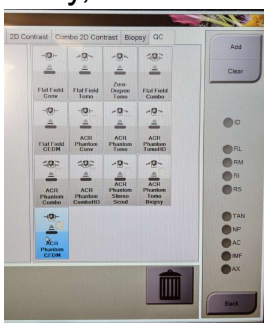
Use the Conventional modality and select the Cu filter to measure the HVL for the CE2D high energy exposure. Adjust the kVp accordingly (i.e. 45 kVp) when using the Cu filter (CE2D Option). Use two to four aluminum 1145 or 1100 alloy sheets of 1 mm thickness for HVL measurements.

HVL

Nominal kVp setting	45
Target Material	W
Filter	Cu
mAs	100
Exposure measurements (mR):	73.045
No aluminum filtration, $E(0_a)$	73.11
0.2 mm of added Al, E(2)	
0.3 mm of added Al, E(3)	
0.4 mm of added Al, E(4)	
0.5 mm of added Al, E(5)	
0.6 mm of added Al, E(6)	
No aluminum filtration, $E(0_b)$	72.98
Upper exposure value (E_a)	46.77
Corresponding Al thickness (t_a)	2
Lower exposure value (E_b)	30.87
Corresponding Al thickness (t_b)	4
$E_{1/2}$ = E(0)/2	36.52
Calculated HVL (mm Al)	**3.19**

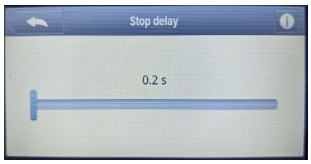
Entrance exposure, reproducibility, and AGD

- Hologic:
  - Add View
  - QC tab
  - ACR Phantom CEDM
  - Add



Entrance exposure, reproducibility, and AGD

- Each acquisition will have a low- and high-energy exposure
- Set your meter's calculation/stop delay to the minimum, putting the dose from the three separate exposures (AEC pre-pulse, low energy, high energy) into the correct category.



Entrance exposure, reproducibility, and AGD

Breast thickness (cm)	4.2	4.2
Phantom	ACR	ACR
Acquisition Mode	CE2D	
	Low E	High E
Image Receptor	24x29	24x29
Nominal kVp setting	28	45
Target Material	W	W
Filter	Rh	Cu
AEC mode	Auto-Filter	Auto-Filter
Density control setting	0	0
Measured HVL (mm Al)	0.514	3.191

Breast Entrance Exposure and AEC Reproducibility				
	R	mAs	R	mAs
Exposure #1	0.4777	112	0.0371	52
Exposure #2	0.4811	112	0.0373	52
Exposure #3	0.4754	112	0.0370	52
Exposure #4	0.4755	112	0.0369	52
Mean value	**0.477**	**112.0**	**0.04**	**52.0**
Standard deviation	**0.003**	**0.0**	**0.000**	**0.0**
Coefficient of variation	**0.006**	**0.000**	**0.005**	**0.000**

Entrance exposure, reproducibility, and AGD

Average Glandular Dose		
Displayed average glandular dose (mrad)	118	30
Inv sq corrected skin exposure	0.48	0.04
Dose conversion factor, Tables 1-3 (mrad/R)	265.6	824.2
Computed average glandular dose (mrad)	**126.8**	**30.6**
% diff. disp. from meas.	-6.9%	-1.8%
Total average glandular dose (mrad)	**157.4**	

Entrance exposure, reproducibility, and AGD

Alternatively, if your meter is not that fast or can't record multiple measurements, you can use the average R/mAs from your conventional exposure measurements and the mAs of each low-energy exposure to distribute the total exposure.

Note

An ACR Phantom CEDM view includes both a low and a high energy exposure. If the measuring equipment does not allow for separating the low from the high exposure, then you can use the average R/mAs computed from form 8a and the mAs of the low energy exposure to distribute the accumulated exposure between the low and the high energy exposures.

Entrance exposure, reproducibility, and AGD

Average R/mAs from the conventional exposure measurements:

	R	mAs	
Mean value	**0.480**	**112.8**	→ 0.004258 R/mAs

Total R	mAs	R	mAs	R
0.5148	112	0.4769	52	0.0379
0.5185	112	0.4769	52	0.0415
0.5124	112	0.4769	52	0.0355
0.5125	112	0.4769	52	0.0356

Entrance exposure, reproducibility, and AGD

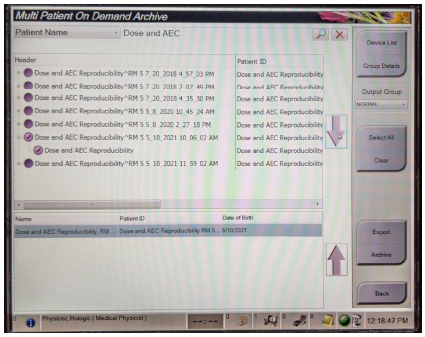
Average R/mAs from the conventional exposure measurements:

Example comparison:

	Individual Exposures		Average R/mAs	
	Low E	High E	Low E	High E
Computed average glandular dose (mrad)	**126.8**	**30.6**	**126.7**	**31.0**
Total average glandular dose (mrad)	**157.4**		**157.7**	

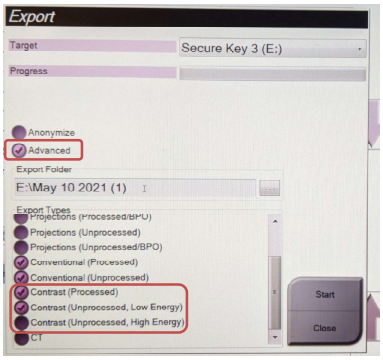
Exporting data

- Go to Admin > Archive
- Search for study you wish to export
- Select acquisitions you wish to export
- Click the down arrow to move them into the export queue

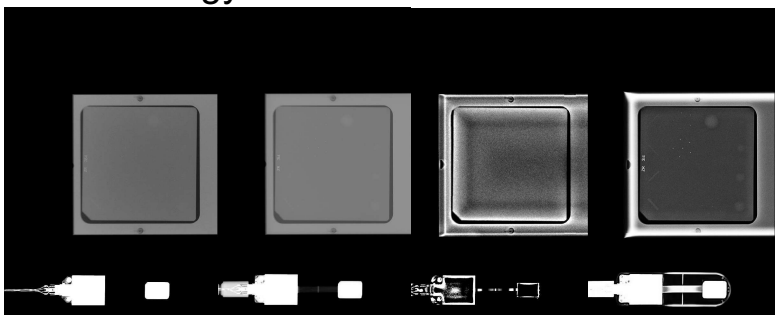


Exporting data

- In the export window, make sure to check “Advanced”
- Make sure high and low unprocessed energy images are checked to see pre-subtraction images
- For patient images, be aware that “Anonymize” does not produced completely de-identified data



Dual-energy subtraction



Resources

- W. F. Sensakovic, M. B. Carnahan, C. D. Czaplicki, S. Fahrenholtz, A. Panda, Y. Zhou, W. Pavlicek, B. Patel, “Contrast-enhanced Mammography: How Does It Work?” *Radiographics* **41**(3), 829-839, 2021.
- M. Lobbes and M. S. Jochelson, ed. *Contrast-Enhanced Mammography* (Springer, Cham, Switzerland, 2019).