Innovations in Clinical Breast Imaging: Novel Mammography Applications –Contrast Imaging

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AAPM Austin, TX
24 July, 2014

DISCLOSURE

Martin Yaffe's laboratory has a collaborative research agreement in the areas of tomosynthesis and contrast-enhanced digital mammography with GE Healthcare

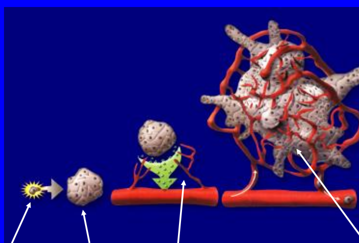
Some of the techniques discussed here have not been approved by FDA.

Outline

Principles and motivation for contrast imaging
Physics
- temporal method
- dual energy technique

Image quality
Quality control considerations

Folkman: 1971
The Angiogenic Switch



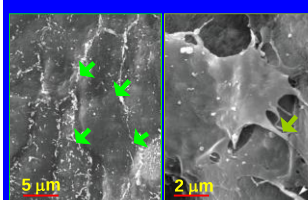
Somatic Mutation

Small Avascular Tumour

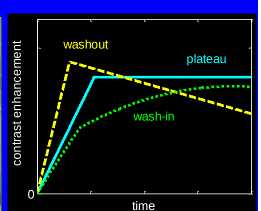
Tumour Secretion of Proangiogenic Factors Stimulates Angiogenesis

Rapid Tumour Growth and Metastasis

Imaging angiogenesis

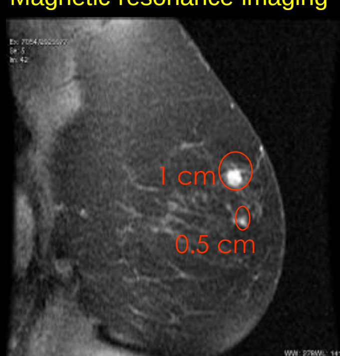


McDonald and Choyke, 2003.



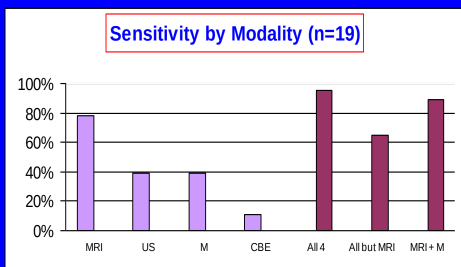
Kuhl et al., 1999.

Magnetic resonance imaging



Courtesy of Dr. E. Ramsay

Breast Cancer Screening
High-risk Women (25% lifetime risk)



Warner et al.JAMA. 2004 292(11):1317.

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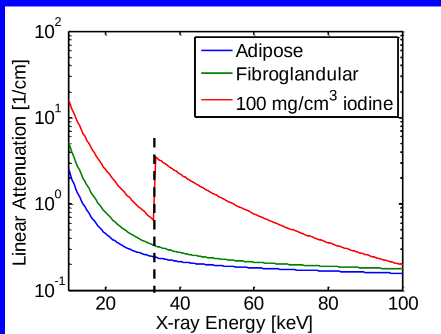
Use of X Rays for Imaging Angiogenic Effects

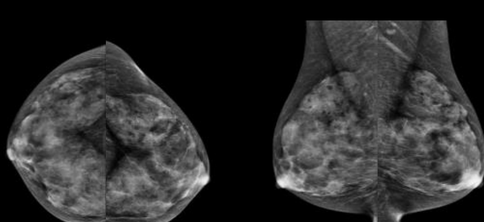


Clinical Motivation for CE Breast Imaging

- Detect cancers where native attenuation contrast is weak or absent
  - Angiogenesis is a new signal!
- Alternative to MRI where access, patient size, claustrophobia or other factors are an impediment
- Possibly lower false positive rate than MRI
- Demonstrate extent of disease

Example: Mammographically equivocal (occult?) lesion

79 yo w palpable mass on left breast, original mammography

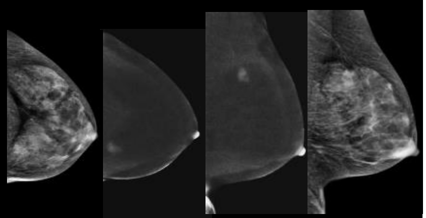


Images courtesy of Mikawa Breast Center, Mikawa, Japan and GE Healthcare

CESM
Clarification of mammographically equivocal lesion

79 yo w palpable mass on left breast

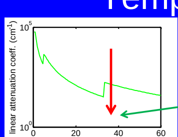
contrast-enhanced images clearly localize the lesion



Images courtesy of Mikawa Breast Center, Mikawa, Japan

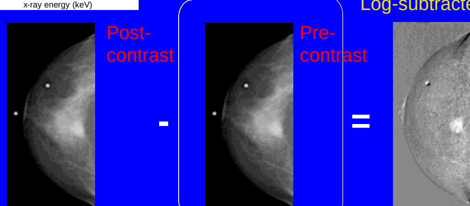
TEMPORAL METHOD

Temporal subtraction



Iodinated contrast agent

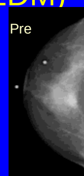
High energy – low dose

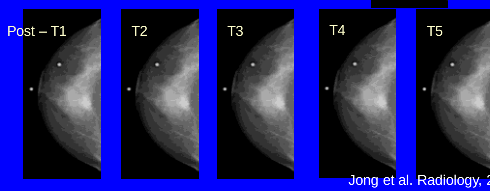


Courtesy Dr. R. Jong

Contrast-enhanced digital mammography (CEDM)

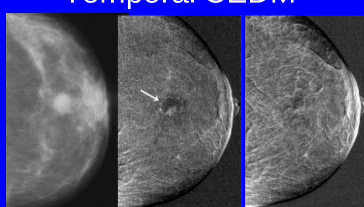
1. Pre-contrast image
2. Intravenous injection of iodinated contrast agent
3. Post-contrast image(s)



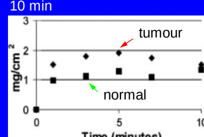


Jong et al. Radiology, 2003.

Temporal CEDM

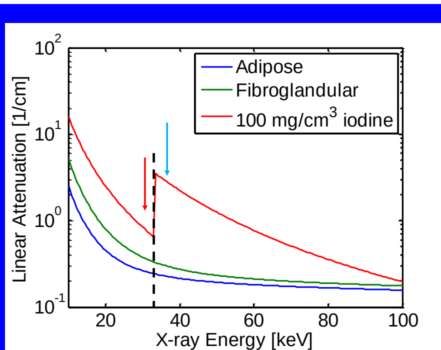


- Potential for functional information – provides info on kinetics



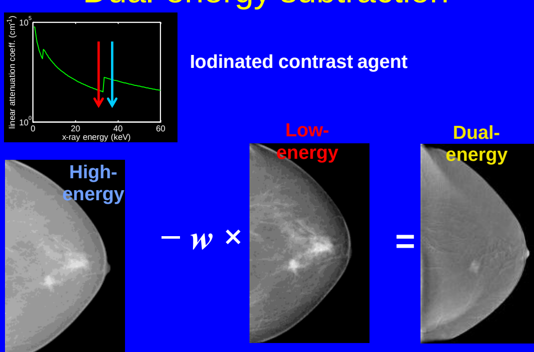
Jong et al. Radiology, 2003.

DUAL-ENERGY METHOD



Maximum contrast at energies just below and above K edge

Dual-energy subtraction



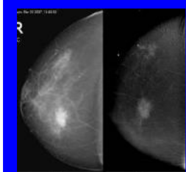
Courtesy Dr. C. Dromain

$$I_{\mathrm{DE}}(x,y,t)=\log[I_{\mathrm{HE}}(x,y,t)]-w_{\mathrm{B}}\log[I_{\mathrm{LE}}(x,y,t)]$$

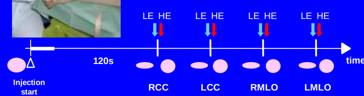
Principles of CESM

Image acquisition
- One image with low kV (→ Low Energy, LE)
- One image with high kV (→ High Energy, HE)
- Low and high-energy images acquired successively within short time

Image processing
- Low and high-energy image combination

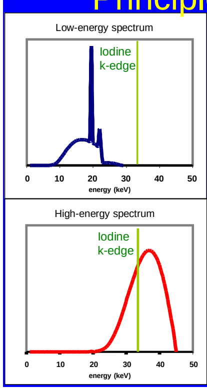


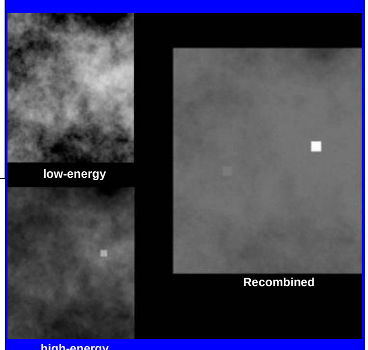
Conventional Mammog. CESM image



Courtesy: GE Healthcare

Principles of CESM





Simulated images

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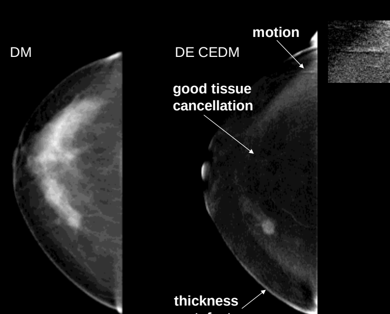
Image Quality Considerations in CEDM

- Background tissue cancellation
  - Potentially perfect in temporal mode
  - Approximate in DE due to spectrum, scatter etc.
  - Parenchymal background uptake fairly common
- Motion artifact

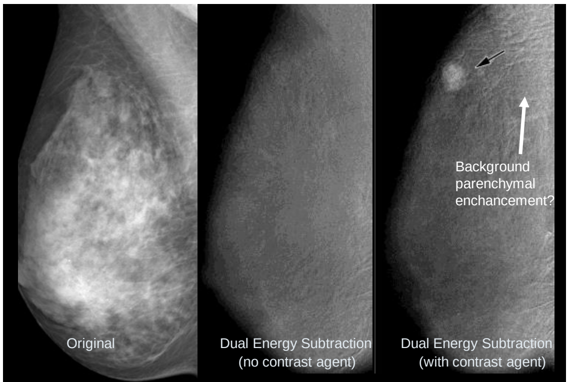
Image Quality Considerations in CEDM

- Background tissue cancellation
- Iodine signal enhancement / quantification
- Motion artifact

CEDM Normal tissue cancellation



Courtesy Dr. C. Dromain



Fat is avascular – little or no uptake in adipose tissue

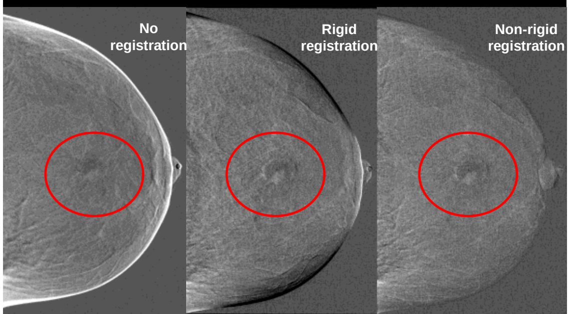
Image Quality Considerations in CEDM

- Background tissue cancellation
- Motion artifact and correction
- Iodine signal enhancement / quantification

Motion artifact in CEDM

- Potential disadvantages:
  - Reduced lesion conspicuity
  - Inaccurate iodine quantification
- Strategies for minimized artifacts
  - Breast compression (?)
  - Short exam time
  - Image registration

Motion artifact in CEDM



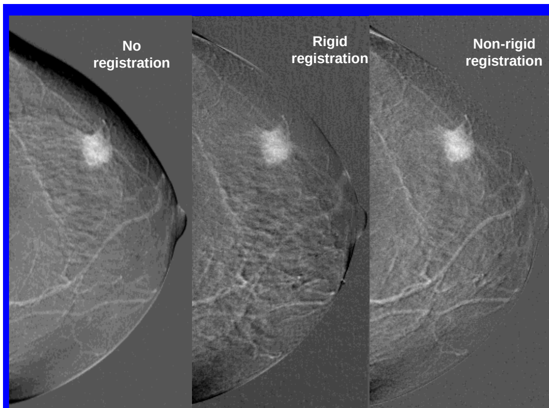


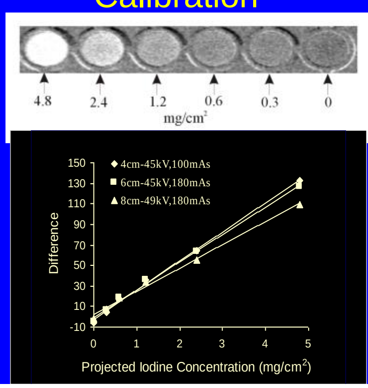
Image Quality Considerations in CEDM

- Background tissue cancellation
- Motion artifact
- Iodine signal enhancement / quantification

Iodine signal enhancement

- Quantitative signal
  - Potential advantage over breast MRI

Calibration



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Important to Test for Digital Mammography

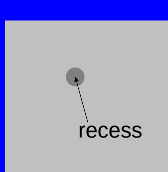
- Signal vs entrance exposure (dose)
- Signal Difference to Noise Ratio (SDNR)
- Artifacts
- Ghosting (acceptance testing)
- System MTF
- Image display system

For CEDM - Extended to High Energy imaging (45 kV-49 kV)

Additional Tests for CE Digital Mammography

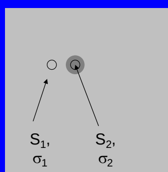
- Beam quality (L and H beams for dual E)
  - Consistency of beam quality
- Subtraction algorithm
  - Weighting
  - Registration
  - Tissue suppression: $SD_{Iodine} / SD_{soft\ tissue}$
- Iodine calibration
  - Linearity
  - Change in slope

Signal-Difference-to-Noise Ratio (SDNR)



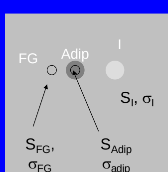
- Uniform phantom 4 cm thick with circular recess 16 mm in diameter and 1.0 mm deep

Signal-Difference-to-Noise Ratio (SDNR)



- $SDNR = (S_1 - S_2) / (\sigma_1^2 + \sigma_2^2)^{1/2}$ where S = mean pixel value
- Normalize for fluence by dividing by $\sqrt{mAs}$

Soft Tissue Suppression Test



- $SD_I = (S_I - S_{FG})$
- $SD_{soft} = (S_{FG} - S_{Adip})$
- $SDR = SD_I / Sd_{soft}$

Artifacts

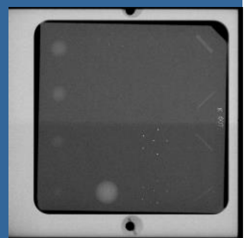
Effects may cance rin subtraction, but some uncorrected spatial artifacts can affect subtraction images.

Stitching

Filter mottle

Flat-fielding

Ghosting



-1.30 %

Schematic of CEDM Phantom

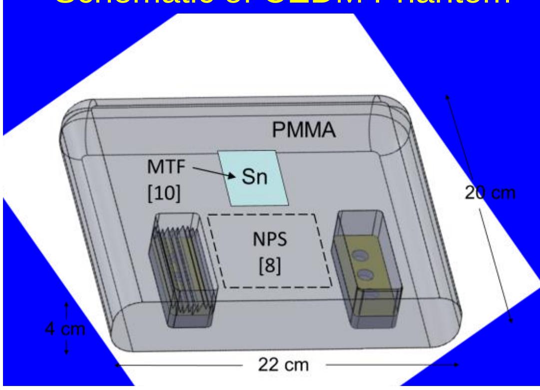


Photo of CEDM Phantom

Automated QC – eg MTF Tracking

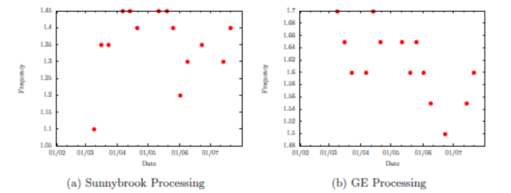
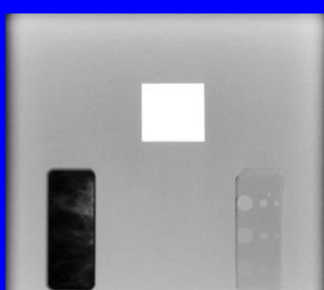
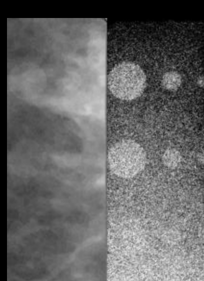


Figure 4: Frequency where MTF X goes below 0.5 results for unit MG1SUNB

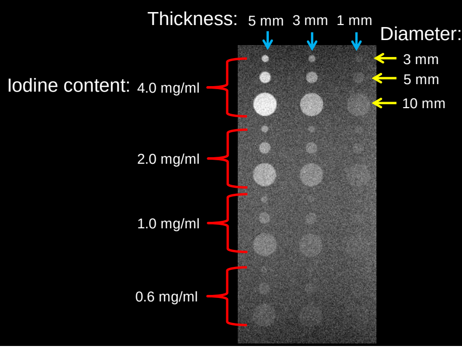
HE image (Mo/Cu, 45 kV)



DE image revealing discs with 0.2, 0.6 and 1.0 mg/cm^2 iodine areal densities from left to right, at diameters of 10, 5, and 3 mm.



CEDM contrast-detail phantom



Detectability Index

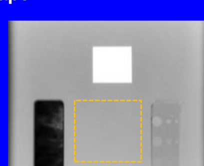
- Define a detectability index that takes all relevant features of the imaging task and performance factors for the imaging system (resolution, contrast, noise)
- How well can a structure be detected?

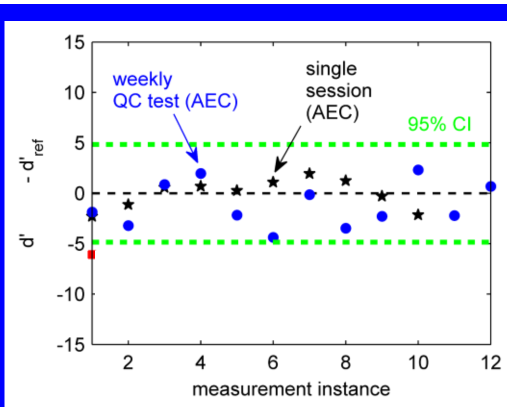
CEDM detectability index (d')

$$d'^2 = \frac{\left[\iint MTF^2(f) W_{\text{task}}^2(f)\right]^2}{\iint NPS^2(f_x, f_y) MTF^2(f) W_{\text{task}}^2(f)\, df},$$

- **MTF is the system modulation transfer function**
- **NPS is the noise power spectrum,**
- **$W_{\text{task}}(f_x, f_y)$ =Iodine contrast × Shape**

In effect, d' is the SNR of the detection task.





For monoenergetic x-ray beams the optimal energies for contrast dual E imaging are:

- 9% 1. Lowest and highest energies available
- 41% 2. 24 and 34 keV
- 18% 3. Depend mainly on breast thickess
- 18% 4. Immediately above and below k-edge of target
- 14% 5. Immediately above and below k-edge of iodine

For monoenergetic x-ray beams the optimal energies for contrast dual E imaging are:

Answer:
5. Immediately above and below k-edge of iodine

1. Skarpathiotakis M, Yaffe MJ, et al. Development of contrast digital mammography. Med Phys. 2002 **29**:2419-26.
2. Jong RA, Yaffe MJ, et al. Contrast-enhanced digital mammography: initial clinical experience. Radiology. 2003 **228**:842-50.
3. Lewin JM, Isaacs PK, et al. Dual-energy contrast-enhanced digital subtraction mammography: feasibility. Radiology. 2003 **229**:261-8.
4. C. Dromain, F. Thibault, et al. Dual-energy contrast-enhanced digital mammography: initial clinical results. Eur Radiol. 2011. **21**: 565–574.

Which of the following is NOT true? Bright areas in dual E contrast imaging occur due to…

- 15% 1. Neovascularity due to tumour angiogenesis
- 15% 2. Benign lesions
- 15% 3. Poor flat fielding correction
- 4% 4. Adipose tissue
- 7% 5. Blood vessels

Which of the following is NOT true? Bright areas in dual E contrast imaging occur due to…

Answer:

4. Adipose tissue

1. Skarpathiotakis M, Yaffe MJ, et al. Development of contrast digital mammography. Med Phys. 2002 **29**:2419-26.
2. Jong RA, Yaffe MJ, et al. Contrast-enhanced digital mammography: initial clinical experience. Radiology. 2003 **228**:842-50.
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Which factor below is NOT an advantage of dual E vs temporal contrast imaging?

- 11% 1. Ability to image both breasts with one injection
- 11% 2. Fewer motion artifacts
- 7% 3. Better imaging of contrast kinetics
- 11% 4. Reduced breast compression time
- 25% 5. Ability to produce CC and MLO views with single injection

Which factor below is NOT an advantage of dual E vs temporal contrast imaging?

Answer:

3. Better imaging of contrast kinetics

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2. Jong RA, Yaffe MJ, et al. Contrast-enhanced digital mammography: initial clinical experience. Radiology. 2003 **228**:842-50.
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An ideal breast imaging system for screening would

- 14% 1. find 90% of cancers
- 14% 2. only find invasive cancers
- 10% 3. only find cancers destined to be lethal
- 17% 4. only find lethal cancers that can be treated
- 14% 5. find all cancers

An ideal breast imaging system for screening would

Answer:

4. only find lethal cancers that can be treated

Of the following factors, the one most responsible for mammography screening NOT achieving maximal mortality reduction is:...

17%	1. lead-time bias
7%	2. lack of detection sensitivity
10%	3. lack of specificity
17%	4. misinformation re benefits/harms
14%	5. overdiagnosis

Of the following factors, the one most responsible for mammography screening NOT achieving maximal mortality reduction is:...

Answer:

4. misinformation re benefits/harms

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24 July, 2014