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

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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

Magnetic resonance imaging

Courtesy of Dr. E. Ramsay
Breast Cancer Screening
High-risk Women (25% lifetime risk)

Sensitivity by Modality (n=19)


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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
CESM
Clarification of mammographically equivocal lesion
79 yo w palpable mass on left breast
contrast-enhanced images clearly localize the lesion

TEMPORAL METHOD

Temporal subtraction
Iodinated contrast agent

Log-subtracted
Contrast-enhanced digital mammography (CEDM)

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

Temporal CEDM

• Potential for functional information – provides info on kinetics

DUAL-ENERGY METHOD
Maximum contrast at energies just below and above K edge.

**Dual-energy subtraction**

Iodinated contrast agent

Dual-energy subtraction

\[ I_{DE}(x, y, t) = \log[I_{HE}(x, y, t)] - w_B \log[I_{LE}(x, y, t)] \]
**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

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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
**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
Image Quality Considerations in CEDM

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

- Quantitative signal
  - Potential advantage over breast MRI

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Calibration

![Calibration Diagram]

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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: $\text{SD}_{\text{iod}} / \text{SD}_{\text{soft tissue}}$
- 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 = \( \frac{S_1 - S_2}{\sqrt{\sigma_1^2 + \sigma_2^2}} \)
- 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 cancel in subtraction, but some uncorrected spatial artifacts can affect subtraction images.
Ghosting

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/cm² 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’)

\[ d'^2 = \frac{\iint MTF^2(f)W^2_{task}(f) \, df \, \, df}{\iint NPS^2(f_x, f_y)MTF^2(f)W^2_{task}(f) \, df \, \, df} \]

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

In effect, \( d' \) is the SNR of the detection task.
For monoenergetic x-ray beams the optimal energies for contrast dual E imaging are:

1. Lowest and highest energies available
2. 24 and 34 keV
3. Depend mainly on breast thickness
4. Immediately above and below k-edge of target
5. Immediately above and below k-edge of iodine

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

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

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

Answer: 4. Adipose tissue

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

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

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

Answer:

3. Better imaging of contrast kinetics


An ideal breast imaging system for screening would

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

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:...

- 7% 1. lead-time bias
- 10% 2. lack of detection sensitivity
- 13% 3. lack of specificity
- 15% 4. misinformation re benefits/harms
- 11% 5. overdiagnosis

Answer: 4. misinformation re benefits/harms

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