Magnetic Resonance Electrical Impedance Mammography (MREIM): Computer Simulations of Clinical application and Theoretical Analysis

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- MREIM is being developed to improve SPECIFICITY in MR breast imaging to reduce false positive findings that lead to negative biopsies. It may also enhance diagnostic sensitivity

- Operates as an additional acquisition during any MR breast examination: imperceptible to the patient, does not require special image reconstruction, and is not affected by and does not require gadolinium contrast injection

- MREIM is an emerging technology in the earliest stage of development
- Combines magnetic resonance (MR) breast imaging with Electrical Impedance Scanning (EIS) to exploit electrical conductivity differences between normal and malignant breast tissue
- Electrical conductivity is a clinically validated and FDA approved (EIS Siemens TranScan 2000) biomarker for malignancy

The MREIM Effect

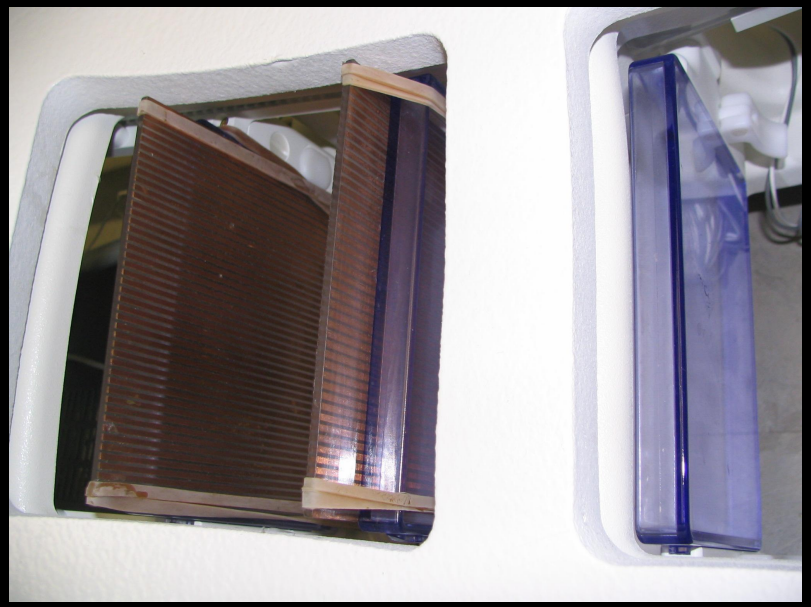
- MREIM induces two observable effects because malignant cells produces localized electrical conductivity differences in the adjacent stroma:

- A frequency encode effect that manifests as a differential signal across the malignancy area

- A phase encode effect that manifests as a differential signal about the malignancy border

- These can be explained with Fourier Shift Theory of a Complex Feature Space

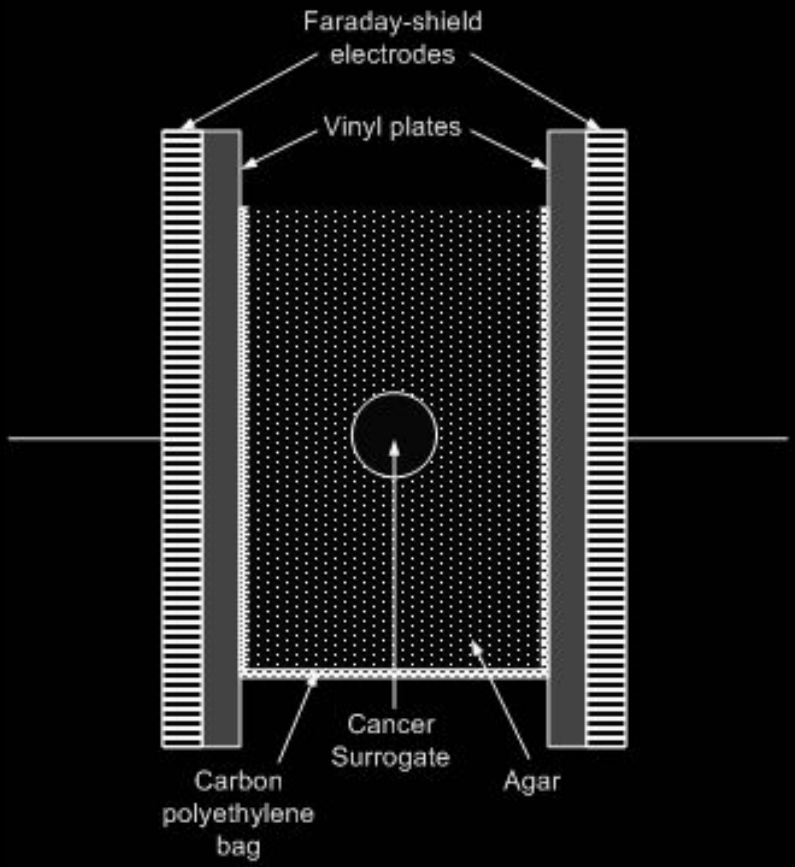
Experimental Grade MREIM Device



Faraday shields attached to the stabilization paddles of a breast coil with the resistive coupling removed.

Illustration of the MREIM phantom and hardware. The entire assembly fits within the breast stabilization paddles of a standard breast coil

- Bo field orthogonal to diagram
- Spherical tumor embedded within uniform normal tissue background contained in skin surrogate bag
- Alpha-dispersion low frequency phase modulation voltage applied to the Faraday shields produces a local periodic Bo magnetic field aberration in tumor induced regions of higher electrical conductivity
- High resistance vinyl plates insulate skin surrogate from Faraday shield conductors

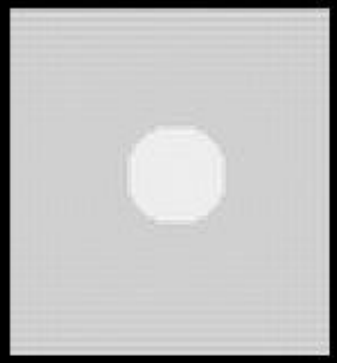


MREIM Simulations

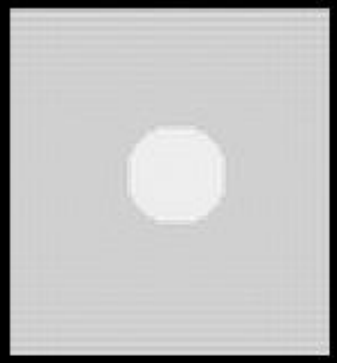
- Simulate the MR image of the physical phantom placed within the MREIM device
- Show control images with ample native MR contrast but with no MREIM effects
- Show both MREIM effects together with ample native MR image contrast
- Show the MREIM effects separately with ample native MR image contrast
- Show the MREIM effects together when there is no native MR image contrast

No Effects

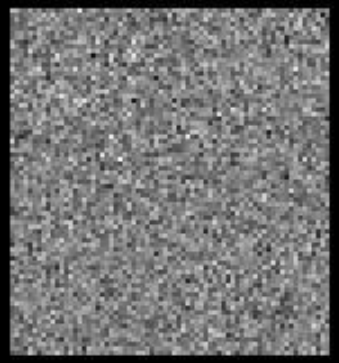
- Phase modulation voltage disconnected during the entire imaging sequence



Control Image (C_1)



Control Image (C_2)

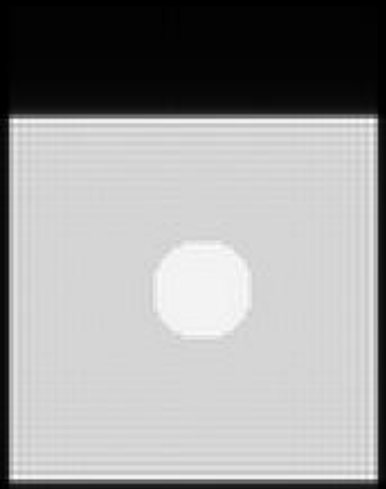


Difference Image
$C_1 - C_2$

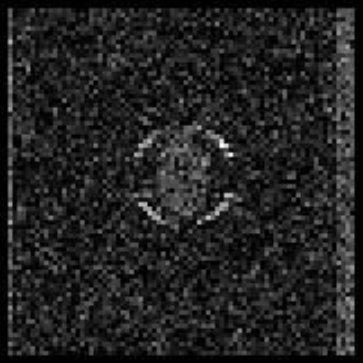
Simulated sequence without MREIM: This shows two statistically similar simulated raw (i.e. control) magnitude images (left and middle) with ample native MR image contrast. The image on the right shows the difference between the two control images. The two raw images are **control images** used in the following analyses. FOV 12.8 cm. Matrix 128x128. 60 Hz./pixel. 22mT/m

Both Effects

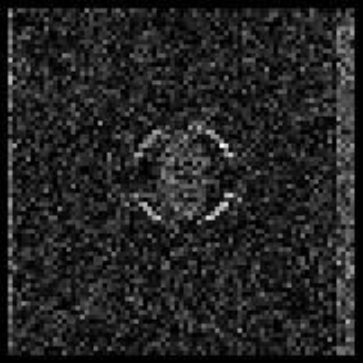
- Two Effects: apply the phase modulation voltage during the entire MR imaging sequence



Effects Image (E)



Control and Effects Difference Image $E - C_1$

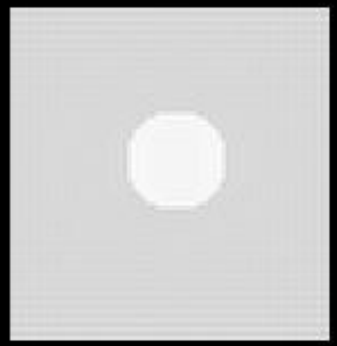


Control and Effects Difference Image $E - C_2$

Simulated MREIM Effects Image: The magnitude image on the left was simulated with the MREIM phase modulation voltage connected during the entire image acquisition. The effects-on images (middle and right) show the difference between the left image and the control images. Frequency encoding is in the horizontal direction, phase encoding and Bo field is in the vertical direction. i=10a/m2

Isolate the Effects

- Frequency Encode Effect: apply the phase modulation voltage during frequency encoding only



Frequency Encode Effect Image (E_{FE})

Control and Effect Difference Image $E_{FE} - C_1$

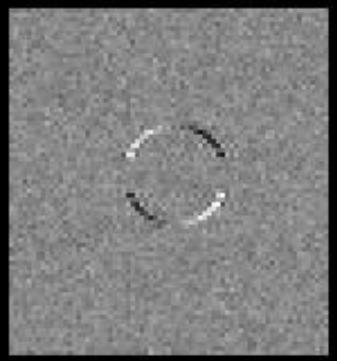
Control and Effect Difference Image $E_{FE} – C_2$

Simulated sequence with Isolated MREIM frequency encode effect: The magnitude image on the left was simulated with the MREIM phase modulation voltage applied during frequency encoding only. The effects-on images (middle and right) show the difference between the left image and the control images. This effect captures the tumor bed.

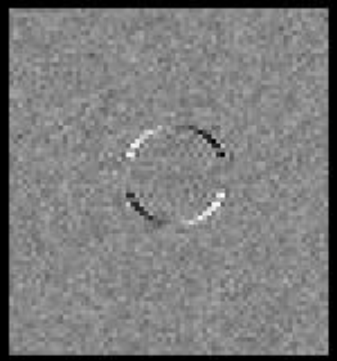
Isolate the Effects

- Phase Encode Effect: disconnect the phase modulation voltage during frequency encoding

Phase Encode Effect Image (E_{PE})



Control and Effect Difference Image $E_{PE} - C_1$



Control and Effect Difference Image $E_{PE} – C_2$

Simulated sequence with Isolated MREIM phase encode effect: The magnitude image on the left was simulated with the MREIM phase modulation voltage disconnected during frequency encoding. The effects-on images (middle and right) show the difference between the left image and the control images. This shows a differential signal in the regions where the electrical conductivity changes. Note: window and level were adjusted to emphasize the effects.

Simulation with no native MR image contrast

- Show electrical conductivity MREIM effects only

No native Contrast control Image (C_{NC})

Effects Image (E_{NC})

Control and Effects Difference Image $E_{NC} - C_{NC}$

Simulated sequence with MREIM effects with no native image contrast. The magnitude image on the left is a simulated magnitude image with no native MR contrast. The middle image is the MREIM image acquired with the phase modulation voltage applied during the entire acquisition. The right image shows the difference between the left and middle images. This shows that the differential MREIM image is due to electrical conductivity changes only.

Achievements

- Experimental proof of concept previously presented
- Theory and simulation agree with experiment (see poster presentation for experimental imaging results)
- The Faraday shield resistive coupling provides the design for a patient grade MREIM device by modifying the sagittal stabilization paddles of any breast coil
- Doctoral dissertation: “Advances in Magnetic Resonance Impedance Mammography”, Nataliya Kovalchuk. http:www.lib.usf.edu

Future Objectives

- Industry support to provide clinical grade equipment
- Develop durable compliant phantom with stable electrical and mechanical properties
- Perform phantom experiments to optimize MR sequence parameters
- Secure investigational device exemption
- Image BiRads 4 and 5 patients with FDA approved apparatus at the H. Lee Moffitt Cancer Center and Research Institute