Physics of a Novel Magnetic Resonance and Electrical Impedance Combination for Breast Cancer Diagnosis

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Summary

The theoretical framework of a new breast imaging technique is established and validated with simulation and phantom measurements.

What do we propose? Combination of **magnetic resonance with electrical impedance imaging (MREIM).** Specifically, a time varying electric field is added during a supplementary sequence to a standard magnetic resonance mammography examination with a patented apparatus embedded in the breast coil that is "invisible" to the patient.

Why add the electric field? Because the electrical conductivity of cancerous breast tissue is approximately 3-40 times higher than that of normal breast tissue and is a known clinical disease biomarker **related to hypoxia induced vascular permeability**.

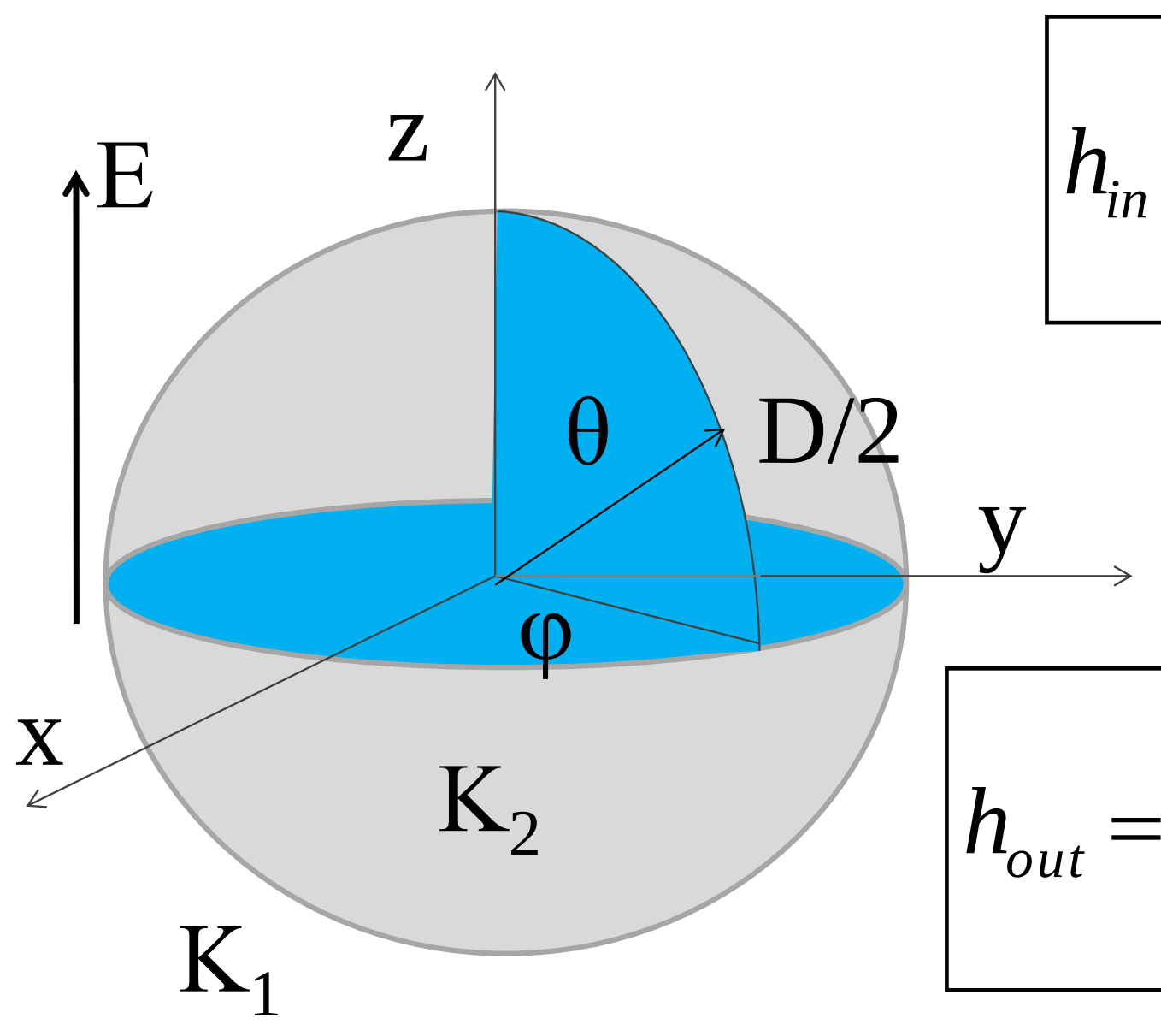
What happens in MREIM? The applied electric field produces a current that creates an additional magnetic field with a component aligned with the bore magnetic field that can alter the native signal in areas of higher electrical conductivity via two effects: **a frequency shift and a phase incrementation**. The changes are confirmed in simulations and observed in phantom studies.

What are the advantages of MREIM?

- No need of contrast agent injection but compatible with dynamic contrast enhanced magnetic resonance mammography (DCEMRM)
- No extraneous reconstruction techniques
- No cumbersome positioning of electrodes on skin

Theoretical Analysis

- Spherical tumor with diameter D and conductivity K_2 embedded in a medium of conductivity K_1, where K_2 is 20-30 times greater than K_1 (see figure below)
- Application of a uniform electric field E in the z-direction perpendicular to the main magnetic field H_0
- Analytical solutions to potential, field, and current equations inside and outside the sphere lead to two different induced magnetic field components due to differences in conductivity that cause aberrations to the standard magnetic resonance mammography (MRM) image

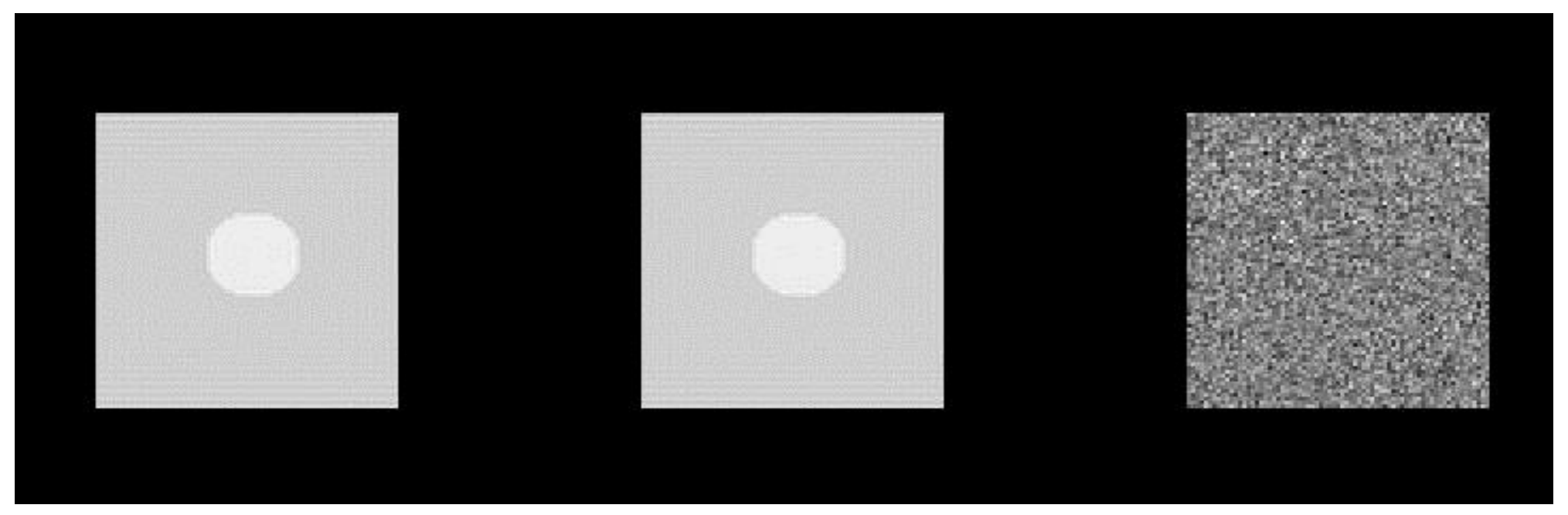


$$h_{in} = -\frac{3i}{2}\left(\frac{(K_2/K_1)}{(K_2/K_1)+2}\right) r\sin\theta\sin\phi$$

$$h_{out} = -i\left[\frac{r}{2} - \left(\frac{(K_2/K_1)-1}{(K_2/K_1)+2}\right)\frac{D^3}{8r^2}\right]\sin\theta\sin\phi$$

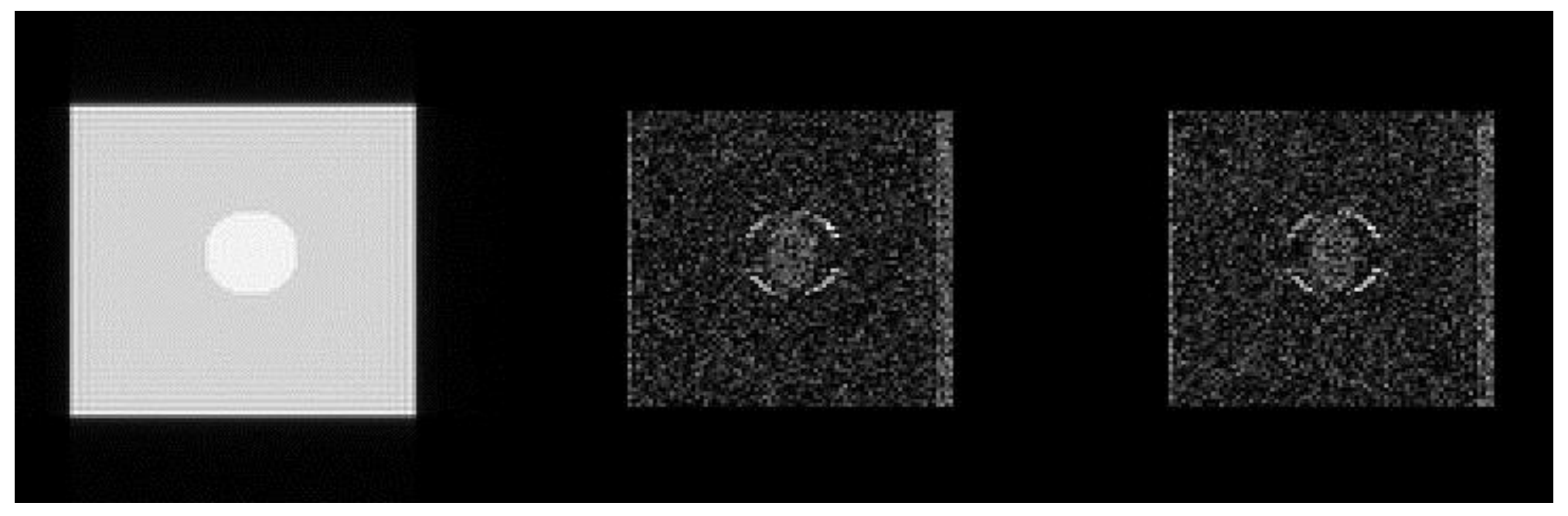
Simulation Experiments

- Tumor is considered as a uniformly conducting 2-dimensional disk embedded in a uniformly conducting medium of lower conductivity
- Response to a spin-echo sequence was determined first with the disk unperturbed (no external current) and then perturbed (with current)
- Two effects observed based on spatial encoding



NO ELECTRIC FIELD

Left: MRM1 image - control
Center: MRM2 image - control
Right: Difference image

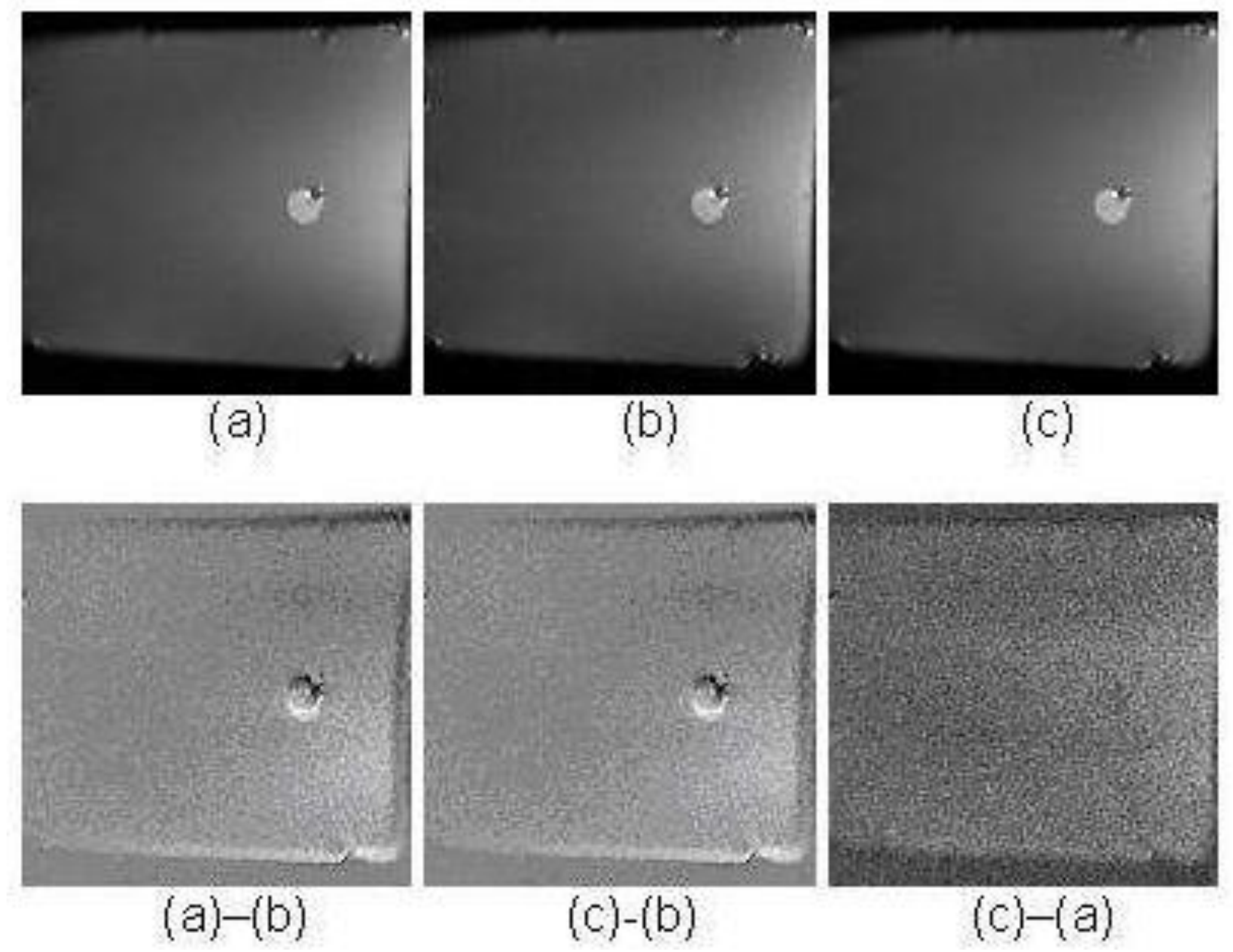


WITH ELECTRIC FIELD

Left: MREIM image
Center: Difference MREIM-MRM1
Right: Difference MREIM-MRM2
(Frequency encode effect horizontal - Phase encode effect vertical)

Phantom Data

- Custom made phantom with conducting plastic, agar gel, and fat-free hotdog pieces as skin, normal tissue, and cancer surrogates respectively
- Siemens Magnetom Symphony 1.5 T MRI system with a patented breast coil modification to allow safe application of external electric field without disturbing image acquisition



Sagittal views of phantom acquired with a spin-density spin-echo sequence with TE=50 ms, TR=2 s, NEX=1, slice thickness=4 mm, FOV=128 mm, d*x*=1 mm and d*f* =60 Hz/pix .

Top raw: (a) Current off, (b) Current on (i=10 A/m^2 at f = 300 Hz), (c) Current off.

Bottom raw: Difference images.

Potential Applications

- Possibly stand-alone screening of average risk population for both cancer detection and risk stratification
- Improve specificity of DCEMRM
- Risk stratification of lesions detected by non-contrast MRM or DCEMRM
- Convenient and low-cost surveillance of low probability (BIRADS 3) patients