Walk-Through MRI: Affordable Technology for Well-Patient Cancer Screening

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Background

A new approach to magnetic design algorithms has been used to project a domain of magnetic field *outside* the structure of a magnet, with 1.5 T field strength and <ppm homogeneity in the volume of interest of a target organ. The patient can then walk into the target location and before/after contrast images can be acquired in a few minutes time. This provision uniquely makes it possible to reduce the cost/image to be comparable to radiology procedures. A design specific for breast imaging has been developed. It can implement an abridged prototol that could provide >90% sensitivity and 70% specificity with 10 minute/patient throughput.

Mammography is the 'gold standard' for early detection of breast cancer, but it misses half!

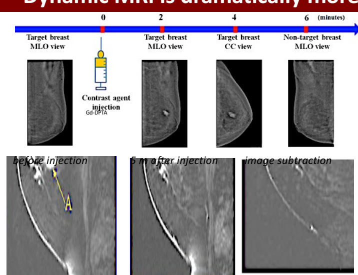
- 40,000 US women die of breast cancer each year.
- 12% of all women will be diagnosed with breast cancer during their lifetime.
- 98.6% of patients survive >5 years if cancer is detected while it Is localized.
- ***The key to long-term survival is early detection.***

Mammography has several limitations:

➢It has a high rate of false negatives – it misses tumors that are invasive.
➢It has a high rate of false positives – it flags lesions that are not invasive.
➢It has a high interval cancer rate: women have a negative mammogram, then palpate a tumor within a year!

Variable	Digital Mammography	Film Mammography	Dynamic MRI
Sensitivity	0.41±0.03	0.41±0.03	0.91
Specificity	0.98±0.001	0.98±0.001	0.97
Positive predictive value	0.12±0.01	0.13±0.01	0.33
Women with heterogeneously dense or extremely dense breasts			
Sensitivity	0.38±0.04	0.36±0.04	0.91
Specificity	0.97±0.001	0.97±0.001	0.97
Positive predictive value	0.10±0.01	0.10±0.01	0.33

Dynamic MRI is dramatically more effective in early detection, but it is not affordable!



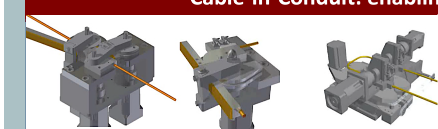
Invasive lobular carcinoma - Mammography missed it!

Dynamic MRI today is done only in whole-body MR imagers.
It takes one hour to image one patient.
Time is money – Breast MR costs >$1,000.
It is not affordable for well-patient screening.

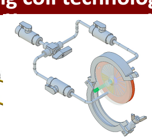
We undertook to develop a way to project a domain of 1.5 T field with homogeneous ~0.1 ppm outside the magnet/cryostat - ***Open MR.***
Open MR has been in manufacture and use for many years, but never with 1.5 T and never with 0.1 ppm homogeneity.

	OpenMR	WholeBody MR	
Consumables	85	85	/image
operating staff salary/fringe	250,000	250,000	/year
maintenance contract	150,000	150,000	/year
MRI unit capital cost	800,000	800,000	
facility cost	500	500	/sqft
floor area	744	1,311	Sqft
facility cost	472,222	755,556	
capital cost	**1,472,222**	**1,755,556**	
APR	5%	5%	
amortization period	5	5	Years
total interest expense	**194,716**	**232,190**	**/5 years**
images/year	8,000	1,800	/year
pro-rated capital cost	**54**	**276**	**/image**
pro-rated operating cost	**135**	**307**	**/image**
professional cost	**84**	**84**	**/image**
IDC @ 60%TDC	**113**	**350**	**/image**
total cost	**$377**	**$977**	**/image**

Cable-in-Conduit: enabling coil technology for IR magnets



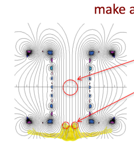
Motorized bend tools form windings in precise contours.
Form racetrack or flared-end windings.
Demonstrated that finished windings have same I_c as wires.



Splice/lead joint is easily mounted/demounted, manifolds SCHe flow

Challenge for Magnetics

make a homogeneous imaging field outside the magnet!

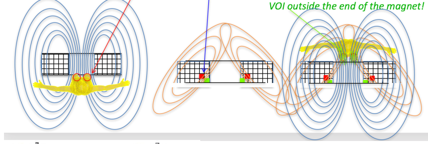


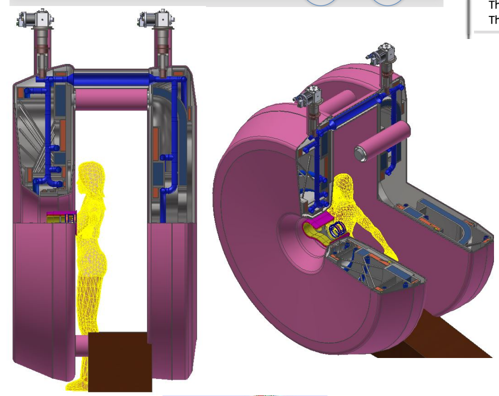
A whole-body MRI scanner produces a ~homogeneous field in its center by extending the body long enough
- expensive, claustrophobic, and the patient is inaccessible.

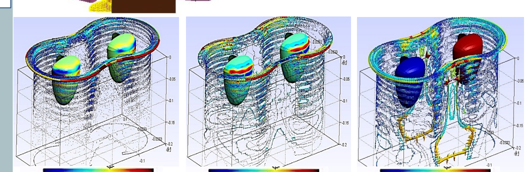
The field distribution in the end region strongly diverges,
so you cannot do MRI there.

Now make a *structured coil*, in which the current in each element is an independent variable. You can adjust the currents however, but *you can't get homogeneous field in the end region*.

Now put *opposing currents* in diagonal pairs of elements. It produces *converging field* in an end region. *Superpose the two distributions* and you can make *local homogeneous field in a VOI outside the end of the magnet!*

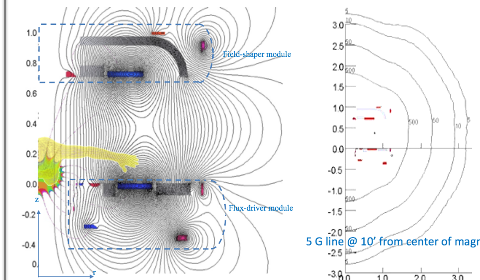




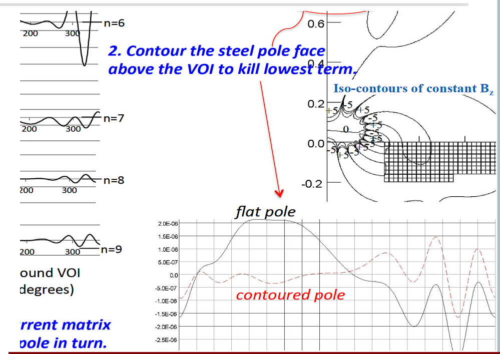


Field design for the three gradient coils: a) z gradient; b) x gradient; c) y gradient. In each coil the pattern of currents on the coil surface, and the variation of the gradient over the VOI is shown.

Magnetic fields you can walk into for imaging



This is a slice through the horizontal midplane of the OpenMR Breast Imager.
There are 15 windings: 9 have clockwise current (red), 6 have counterclockwise current (blue).
The green region is the toroidal imaging field: 1.5 Tesla with <ppm variation over the breast.



Conclusions

- ❖ We have developed an optimization algorithm in which the region of currents is meshed, and an orthonormal basis of multipoles is generated on the desired homogeneous region.
- ❖ We have developed a method of killing vectors in which each succeeding multipole is removed by re-optimization, including the nonlinear response of the steel flux return elements.
- ❖ We have a toroidal region with <0.1 ppm homogeneity that is suitable for dynamic breast imaging in a walkthrough geometry.
- ❖ The projected cost per image is comparable to that of mammography.

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