Breast MR guided Focused Ultrasound Hardware Design and Treatment Strategies

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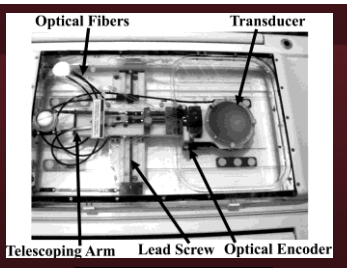
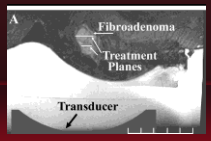
Background

- Breast is an excellent target for MRgFUS
  - Easily accessible
  - Outside body
  - No complicating structures
- Minimally invasive treatments
  - Improved targeting
  - No general anesthesia, reduced recovery time, no scarring, economic benefits

Background

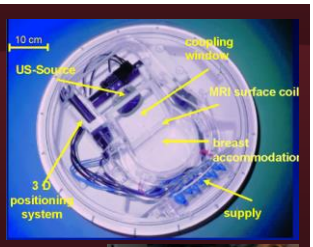
- Breast fibroadenoma study
  - First clinical study with MRgFUS
  - Demonstration of utility of MR monitoring
  - Good clinical outcomes





Hynynen et al., Radiology 219(1), 2001.

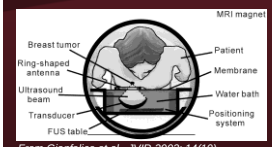
Background



- Invasive ductal carcinoma (N = 1)
- Lateral transducer
- MR compatible

J. W. Jenne et al. German Cancer Research Center
Huber et al. Cancer Research 2001;61.

Background



From Gianfelice et al., JVIR 2003; 14(10).

Challenges identified

- Targeting accuracy
- Patient motion
- Vertically propagating beam
- Treatment time

Histopathological Response

Author	Lesions Treated	Complete Necrosis
Hynynen (2001)	11	55%
Huber (2001)	1	100%
Gianfelice (2003)	17	24%
Zippel (2005)	10	20%
Furusawa (2006)	28	54%
Khiat (2006)	25	31%

Gianfelice et al., Breast Cancer Res Treat 2003; 82. Zippel et al., Breast Cancer 2005; 12. Furusawa et al. J Am Coll Surg 2006; 203. Khiat et al., Br J Radiol 2006; 192.

Breast-dedicated MRgFUS

Philips Sonalleve Breast MR-HIFU Platform

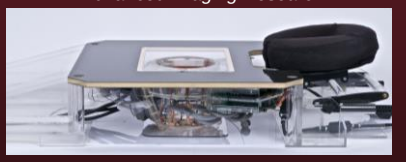
- Large aperture transducer
  - 1.45 MHz, phased array, 13 cm focal length
- Laterally propagating
- Distribution of near-field energy
- Volumetric ablation

Merckel et al., Cardiovasc Interv Radiol 2013; 36.

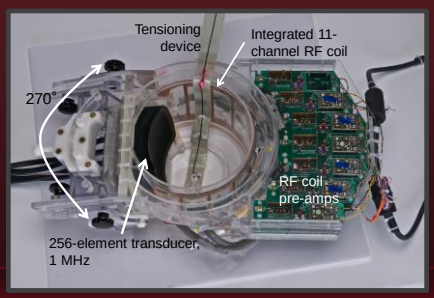
Breast-specific MRgFUS device

University of Utah, Utah Center for Advanced Imaging Research

- Laterally shooting small aperture transducer
- Integrated phased array RF coil
- Potentially compatible with different vendors

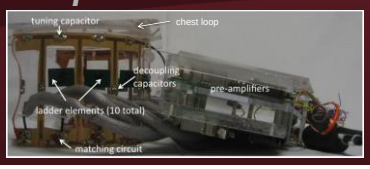


Breast-specific MRgFUS device

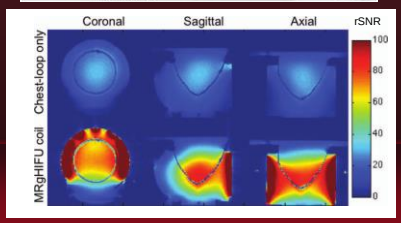


Payne, A. et al., Med Phys 2012; 39(3).
Minalga, E. et al., MRM, 2013; 69(1).

SNR improvements

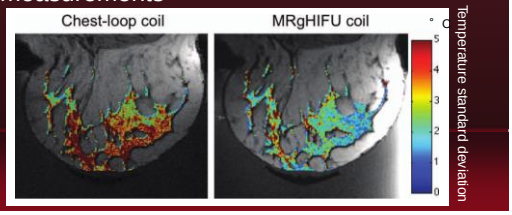


Designed by
E. Minalga
R. Hadley



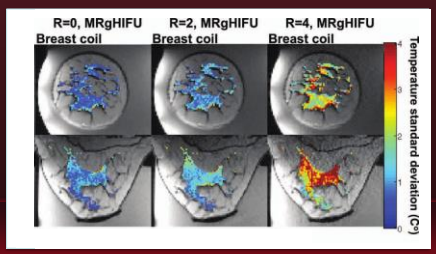
SNR improvements

- Overall image quality
  - Improve spatial and/or temporal resolution
  - Finer structure
- Increases accuracy of MR thermometry measurements



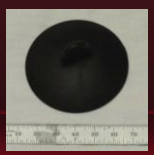
SNR improvements

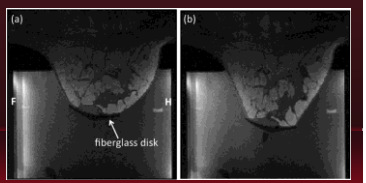
- Multiple channels allows for accelerated imaging protocols



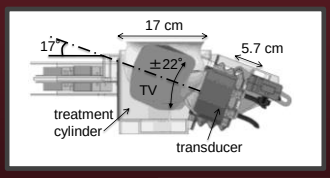
Tensioning device

- Molded disk attached over the nipple with double sided tape
- Partially immobilizes and elongates the breast



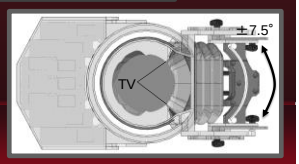


Treatment volume



Treatment cylinder:
17 cm diameter, 3.25 L

Treatment Volume (TV): 1.1 L



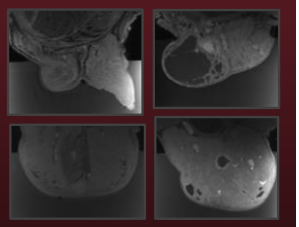
Pre-clinical evaluation

Validate ablation capabilities in vivo

- Treat anatomies of varying sizes
- Evaluate SNR for 3D MR thermometry techniques in vivo
- Assess both focal region and near-field heating

Pre-clinical evaluation

- Female goats
  - Both lactating and non-lactating
  - Weight: 22-52 kg
  - N=8
- Eligibility based on udder size, abdomen size

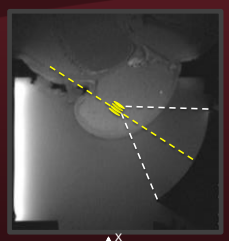


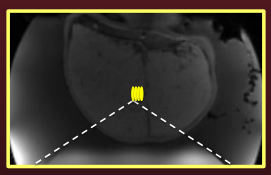
Udder Size Range	Mean (cm)	Range (cm)
Width	10.61	7.6-13.25
Length	6.77	3.05-12.4

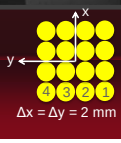
All experiments were approved by the Institutional Animal Care and Use Committee.

Payne et al. 2013. Med Phys, 40(7).

Ablation strategy



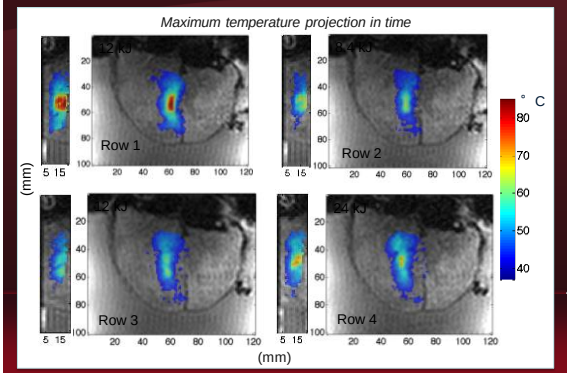




Δx = Δy = 2 mm

FUS trajectory	
Grid pattern	1-2 planes (8-10 mm spacing)
9-25 points/plane	Δx=Δy=2 mm
24-70 acoustic W	t_{heat}= 30-60 seconds/point

Temperature response



Treatment outcome

TD (> 240 CEM)	DCE-MRI (20 min.)	DCE-MRI (14 days)
1.23 cm³	1.10 cm³	0.91 cm³
2.04 cm³	6.27 cm³	4.31 cm³
3.60 cm³	8.20 cm³	4.63 cm³

Pre-clinical outcome

- Successfully treated a wide range of udder sizes
- Excellent SNR, 3D MR thermometry performed well
  - Thermal dose measurements agree with 14-day DCE-MRI data
- No skin burns/irritations

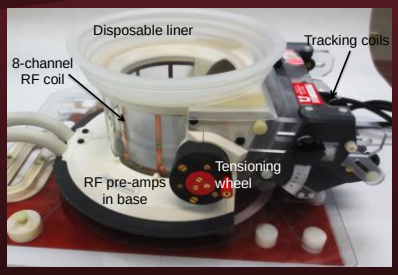
System limitations

- Treatment volume at chest wall limited
- Not clinically robust
  - Difficult to clean
  - Transducer positioning suboptimal
- Designed for one field strength
- Small bore size (60 cm)
- Uncomfortable for long periods

Updated breast MRgFUS

- Larger bore size (70 cm)
- 1.5 and 3T
- Contoured, modular table design
  - Left/right breast specific tables

Treatment cylinder

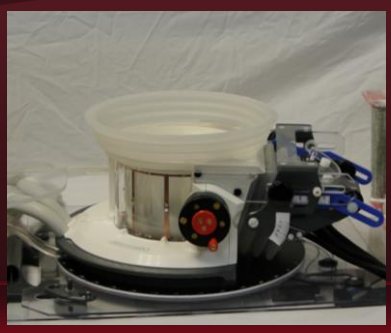


Robb Merrill, designer

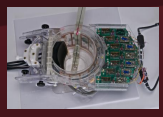
Tensioning device

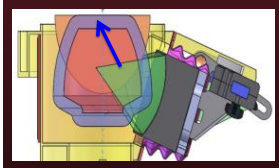
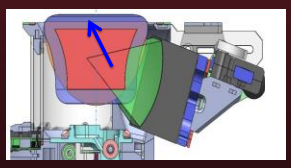
- Improvement to nipple cover

Tensioning device



Treatment volume



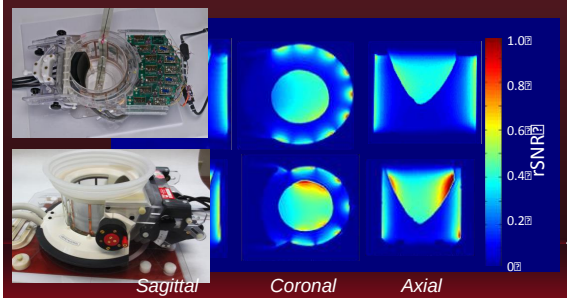



- 1.1 L volume
- Lack of chest wall coverage

- 0.9 L volume
- Conforms to the breast shape

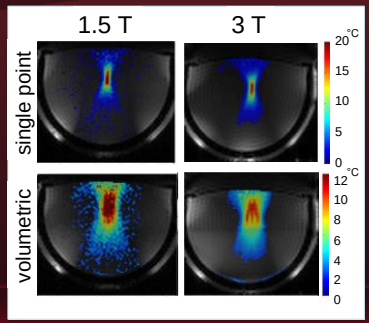
SNR performance

System comparison



Designed by E. Minalga and R. Hadley

Temperature accuracy

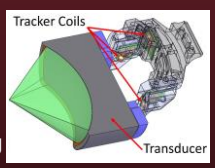


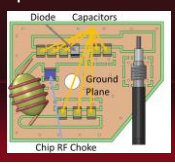
σ_{temp} = 0.31 ° C σ_{temp} = 0.09 ° C

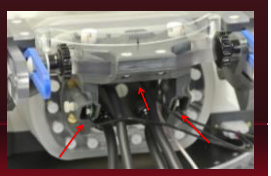
Transducer movement

Tracking coils

- Three coils mounted on transducer assembly
  - Wire wrapped around ~7 mm benzonatate capsule.
- Coil position determined using simple MRI 1D readout sequence



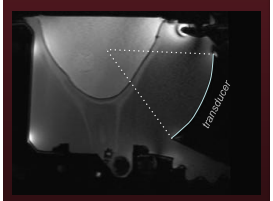


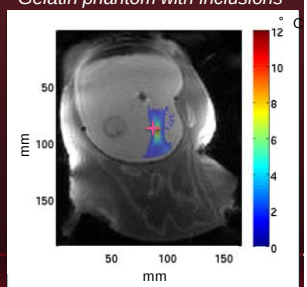


Designed by R. Hadley, M. Beck, B. Svedin

Tracking coils

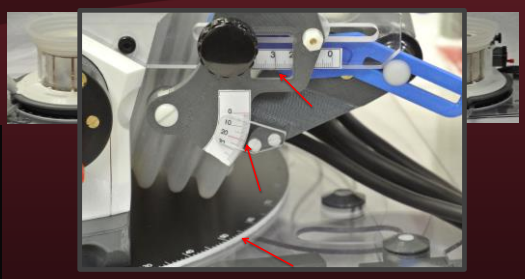
Gelatin phantom with inclusions





= *tracking coil prediction*

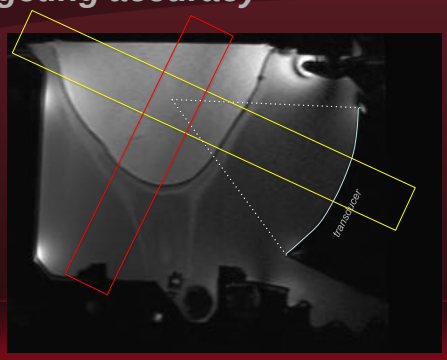
Targeting accuracy



- Prediction of focal point location
  - MR slice assignment

Designed and constructed by R. Merrill

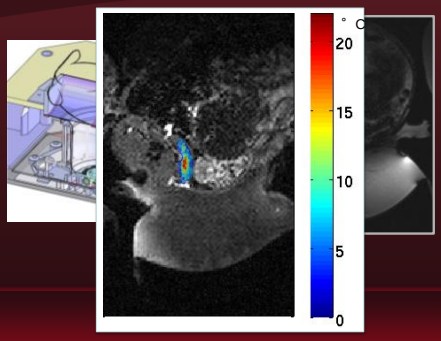
Targeting accuracy



Summary

- Engineering solutions for breast-specific MRgFUS
  - Integrated RF coil for improved SNR, treatment time reductions
  - Tracking coils for focus location, MR scan setup
- Pre-clinical evaluation is ongoing

Pre-clinical evaluation



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  - Integrated RF coil for improved SNR, treatment time reductions
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- Pre-clinical evaluation is ongoing
- Clinical trial in final approval stages

Acknowledgments

Robb Merrill
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