HEALTH UNIVERSITY OF UTAH
DEPARTMENT OF RADIOLOGY AND IMAGING SCIENCES

Volumetric real-time magnetic resonance imaging in breast focused ultrasound treatments

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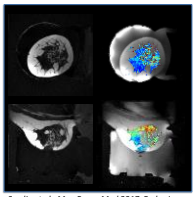
MAGNETIC RESONANCE IMAGING

- Generally qualitative images weighted by tissue properties
- Quantitative information rapidly increasing
- Rapid advancement of MRI sequences and reconstructive techniques



Svedin et al., Mag Reson Med 2017, Early view

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OUTLINE

- Benefits of volumetric imaging
  - Breast MRgFUS
- Hardware and treatment protocol advancements
  - Integrated RF receive and positioning coils
  - Planning: MR-acoustic radiation force imaging
  - Monitoring: MR temperature imaging
  - Assessment: MR shear wave elastography
- Looking forward – voxel-based correlation to histology

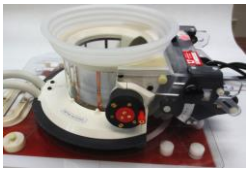
TRADEOFFS OF VOLUMETRIC IMAGING

+ Allows for multi-plane reformatting
+ Interpolation in all directions
+ Complete and accurate planning, monitoring and assessment
- Increased scan time
+ Higher SNR
- Increased artifacts

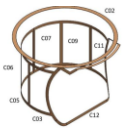
HARDWARE: BREAST MRgFUS SYSTEM

Payne et al. Med Phys 39(3), 2012

HARDWARE: RADIOFREQUENCY COILS



Minalga et al., MRM 2013, 69:295-302
Svedin et al., MRM 2017, 77:2424-2430

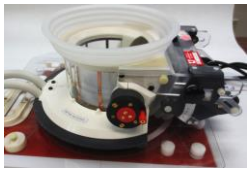


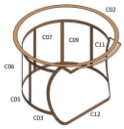
8-channel MRI receiving coil

Increased SNR allows for:

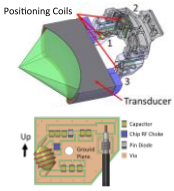
- Increased temporal resolution
- Increased spatial resolution
- Increased FOV
- $\sigma_T \sim 1/SNR$

HARDWARE: RADIOFREQUENCY COILS





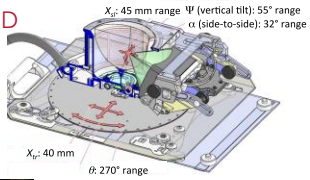
8-channel MRI receiving coil

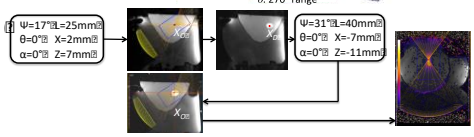


RF receive positioning coils

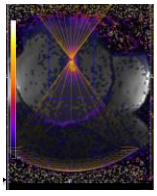
PLANNING: ULTRASOUND BEAM TARGETING

- Transducer has 5 degrees of mechanical movement
- Positioning algorithm + positioning coils compute transducer targeting



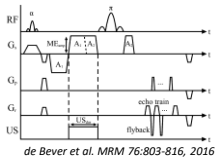


PLANNING: ULTRASOUND BEAM LOCALIZATION

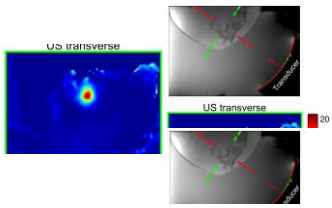


- Beam localization often done with low power interrogation pulses
  - Ineffective in fat
- MR-acoustic radiation force imaging uses low duty cycle to measure tissue displacement
  - Can measure displacement in any tissue type
- 3D acquisition has benefit of contiguous slices improving the accuracy of localization
  - Imaging time similar to an averaged 2D acquisition

PLANNING: MR-ACOUSTIC RADIATION FORCE IMAGING

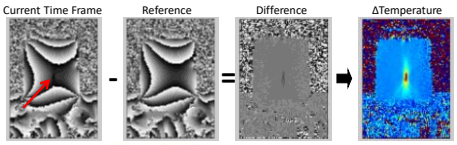


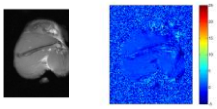
de Bever et al. MRM 76:803-816, 2016



MONITORING: MR TEMPERATURE IMAGING (MRTI)

The proton resonance frequency (PRF) decreases with temperature increase



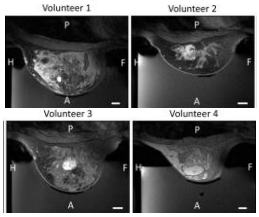


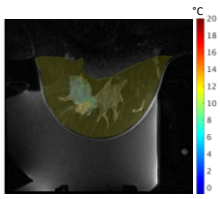
Not absolute temperature

$$\Delta T = \frac{\Delta\phi}{\alpha\gamma B_o TE}$$

MONITORING: BREAST MRTI

- PRF inaccurate in tissues with high lipid content

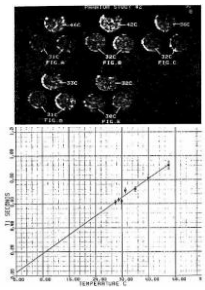




Farrer A. et al., Med. Phys. 43(3), 2016

MONITORING: BREAST MRTI

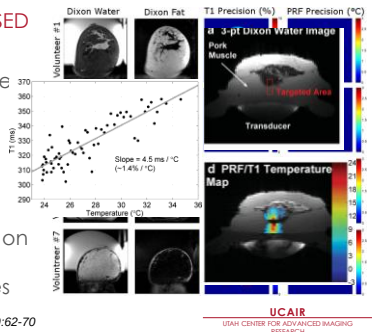
- PRF inaccurate in tissues with high lipid content
- Relaxometry methods were first used to demonstrate MR temperature imaging techniques
  - T2-based thermometry
  - T1-based thermometry



Parker D. et al., Med. Phys. 10(3):321-325, 1983

MONITORING: T1-BASED THERMOMETRY

- Variable flip-angle spoiled GRE sequence
- Hybrid PRF/T1 thermometry measurements
- Calibration done on excised human breast fat samples



Todd et al., Mag Reson Med, 2013, 69:62-70

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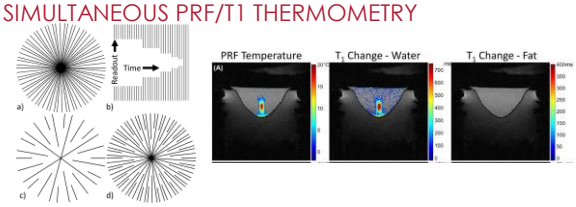
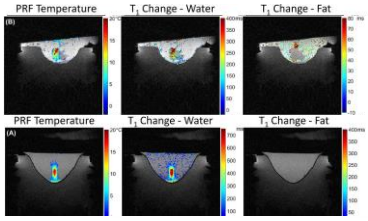
MONITORING: RAPID, VOLUMETRIC SIMULTANEOUS PRF/T1 THERMOMETRY



- Multi-echo pseudo golden angle stack of stars acquisition
- K-space weighted image contrast (KWIC) reconstruction
- Single reference variable flip angle T1 calculations

Svedin et al., MRM 2019, 81: 3138-3152.
Svedin et al., MRM 2018, 79: 1407-1419.

MONITORING: RAPID, VOLUMETRIC, SIMULTANEOUS PRF/T1 THERMOMETRY



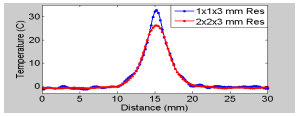
Svedin et al., MRM 2019, 81: 3138-3152.

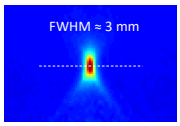
MONITORING: MRTI TECHNICAL SPECS

Spatial Resolution: **1 x 1 x 3 mm**

Temporal Resolution:

Signal-to-Noise:





Todd et al., MRM 2011, 65:515-521

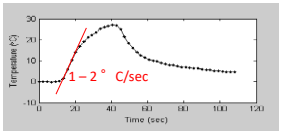
MONITORING: MRTI TECHNICAL SPECS

Spatial Resolution: 1 x 1 x 3 mm

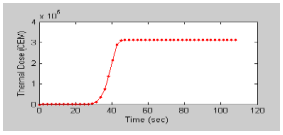
Temporal Resolution: **2 sec/acquisition**

Signal-to-Noise:

Temperature Plot



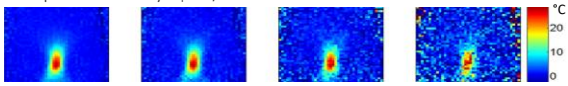
Thermal Dose Plot $TD(t) = \int_0^t R^{43-T(t)} dt$



MONITORING: MRTI TECHNICAL SPECS

Spatial Resolution: 1 x 1 x 3 mm
Temporal Resolution: 2 sec/acquisition
Signal-to-Noise: > 25

Temperature accuracy: $\sigma_T \sim 1 / SNR$



SNR = 47 σ_T = 0.5°C
SNR = 26 σ_T = 0.7°C
SNR = 10 σ_T = 1.4°C
SNR = 5 σ_T = 2.5°C

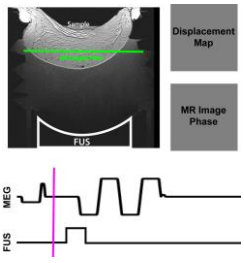
ASSESSMENT: ELASTOGRAPHY TECHNIQUES

- Tissue stiffness a known marker of disease
  - Malignant tumors > benign tumors > healthy tissue
- Ultrasound shear wave elastography + B-mode imaging increases diagnostic accuracy
  - Increases prediction of NACT pathological response
- MR elastography + MR imaging increases specificity
- Tissue stiffness changes with thermal treatments

Sewell CW, Radiologic clinics of North America. 1995;33(6):1067-80.
Acharya UR et al., Comput Biol Med. 2017;91:13-20.
Lorenzen J et al., Rofo. 2001;173(1):12-7.

MR IMAGING OF PROPAGATING SHEAR WAVE

- Modified 3D gradient echo EPI sequence
  - 4 motion encoding gradient lobes
- Synchronized, short (3 ms) acoustic radiation force pulses
- Position of initial acoustic radiation force pulse and propagating shear wave encoded in phase image



Hofstetter et al. MRM 2019;81:3153-3167

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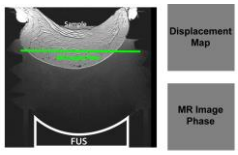
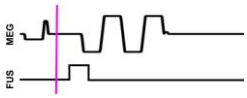
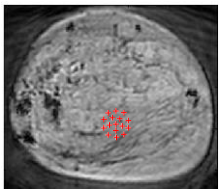
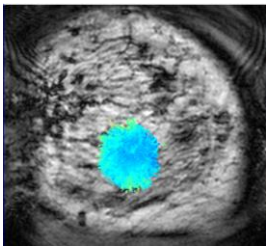




Hofstetter et al. MRM 2019;81:3153-3167

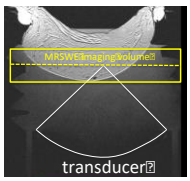
ACOUSTIC RADIATION FORCE, TRANSIENT SHEAR WAVE ELASTOGRAPHY

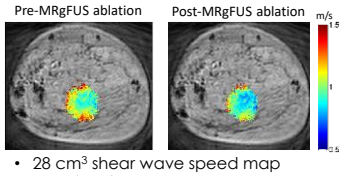




Odéen et al. MRM 2019;81;1104-1117
Hofstetter et al. MRM 2019;81:3153-3167

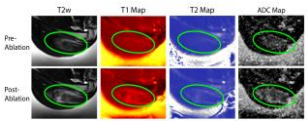
ASSESSMENT: STIFFNESS CHANGE WITH MRGFUS



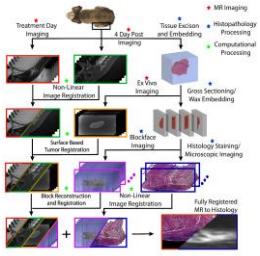


- 28 cm^3 shear wave speed map acquired in 85 seconds
- Detected 10% reduction of speed due to MRgFUS ablation

LOOKING FORWARD: MRI TO HISTOLOGY CORRELATION

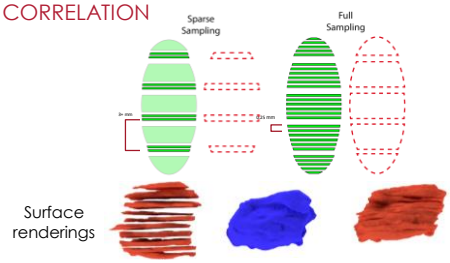


- Multi-parametric quantitative data can potentially determine tissue status
- Validation of metrics requires registration of MR images to histology is required



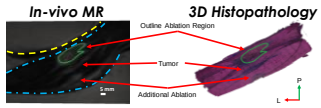
End-to-end processing pipeline

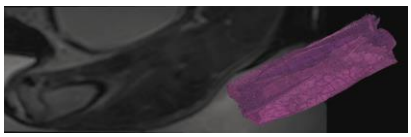
LOOKING FORWARD: MRI TO HISTOLOGY CORRELATION



Excised tissue

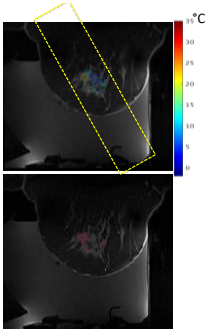
LOOKING FORWARD: MRI TO HISTOLOGY CORRELATION



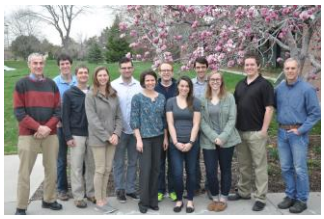


CONCLUSIONS

- Volumetric imaging can be used efficiently in MRgFUS treatments
  - Proper hardware and protocols do not increase treatment times
- Multi-plane reformatting allows for more accessible data and treatment assessment
- Advanced, quantitative metrics are allowing for correlation to histological data



ACKNOWLEDGEMENTS



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Siemens Healthcare

Image Guided Therapy