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

Histopathological Response

<table>
<thead>
<tr>
<th>Author</th>
<th>Lesions Treated</th>
<th>Complete Necrosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hynynen (2001)</td>
<td>11</td>
<td>55%</td>
</tr>
<tr>
<td>Huber (2001)</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Gianfelice (2003)</td>
<td>17</td>
<td>24%</td>
</tr>
<tr>
<td>Zippel (2006)</td>
<td>10</td>
<td>20%</td>
</tr>
<tr>
<td>Furusawa (2006)</td>
<td>28</td>
<td>54%</td>
</tr>
<tr>
<td>Khiat (2006)</td>
<td>25</td>
<td>31%</td>
</tr>
</tbody>
</table>

Gianfelice et al., Breast Cancer Res Treat 2003; 87.

Challenges identified

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

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

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

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

**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

<table>
<thead>
<tr>
<th>Udder Size</th>
<th>Mean (cm)</th>
<th>Range (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>10.61</td>
<td>7.6-13.25</td>
</tr>
<tr>
<td>Length</td>
<td>6.77</td>
<td>3.05-12.4</td>
</tr>
</tbody>
</table>

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

**Ablation strategy**

- **FUS trajectory**
  - Grid pattern: 1-2 planes (8-10 mm spacing)
  - 9-25 points/plane
  - $\Delta x = \Delta y = 2\ mm$
  - 24-70 acoustic W
  - $t_{satur} = 30-60$ seconds/point

**Temperature response**

- Maximum temperature projection in time

**Treatment outcome**

- TD (> 240 CEM)
- DCE-MRI (20 min.)
- DCE-MRI (14 days)
**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

- Disposable liner
- 8-channel RF coil
- RF pre-amp in base
- Tracking coils
- Tensioning wheel

Robb Merrill, designer

Tensioning device

- Improvement to nipple cover
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

\[ \sigma_{\text{volumetric}} = 0.31 ^\circ C \]

\[ \sigma_{\text{volumetric}} = 0.09 ^\circ C \]
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

Tracking coils

Gelatin phantom with inclusions

* = tracking coil prediction
Targeting accuracy

• Prediction of focal point location
  – MR slice assignment

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

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
• Clinical trial in final approval stages

Acknowledgments

Robb Merrill
Emilee Minalga
Rock Hadley
Bryant Svedin
Dennis Parker
Doug Christensen
Bob Roemer
Joshua de Bever
Chris Dillon
Henrik Odeen
Michael Beck
Scott Almquist
Sara Johnson
Urvi Vyas
Erik Dumont
Leigh Neumayer

Funded by NIH R01 CA172787 and R01 CA134599.