AN EXPLORATION IN TRANSCRANIAL MRI-GUIDED FOCUSED ULTRASOUND

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SCIT SEMINAR
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MRI-GUIDED FOCUSED ULTRASOUND

- Ultrasound: targeted tissue heating (→ necrosis)
- MRI: visualize treatment (planning, monitoring)
- Less trauma to patient than invasive surgery
**MRI-GUIDED FOCUSED ULTRASOUND: ONCOLOGICAL APPLICATIONS**

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<tr>
<th>Cancer Type</th>
<th>Conceptual</th>
<th>Pre-clinical</th>
<th>Anecdotal</th>
<th>Pilot Trials</th>
<th>Pivotal Trials</th>
<th>Outside US Approvals</th>
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<th>US Reimbursement</th>
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<td>Bone metastases</td>
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[www.fusfoundation.org](http://www.fusfoundation.org)
MRI-GUIDED FOCUSED ULTRASOUND: ONCOLOGICAL APPLICATIONS IN BRAIN

- Tumor volume
- Noninvasive tumor ablation
- Blood-brain barrier opening for adjuvant chemotherapy

Figure adapted from Martin et al., Curr Radiol Rep 2013
MRI-GUIDED FOCUSED ULTRASOUND: BRAIN

MRI temperature monitoring

Rieke et al., JMRI 2013

T1-weighted MRI

Before treatment

After treatment

Micrograph of resected tumor shows coagulative necrosis (arrows)

Ram et al., Neurosurgery 2006
TUMOR ABLATION IN (NON-)BRAIN TISSUE

High-intensity focused ultrasound on...

...soft tissue

Skull!

...brain tissue

http://www.pbs.org/wgbh/nova/next/body/hifu
SKULL SHAPE, THICKNESS, COMPOSITION CAN DISTORT ULTRASOUND FOCUS
VISUALIZE FOCAL SPOT USING MR-ARFI (ACOUSTIC RADIATION FORCE IMAGING)

Skull distorts ultrasound beam errors in focal spot position and intensity

MR-ARFI for non-invasive, non-thermal focal spot imaging

Figure adapted from Mougenot et al., 2016
MR-ARFI EXPERIMENT SETUP

Phantom set up
- Transducer & water membrane
- Sheep skull cap
- Gel phantom
- Water-filled cylinder

Top-down view
- Sheep skull cap
- Water-filled cylinder

Sheep skull (replica)
CT of skull cap
Transducer
FOCAL SPOT STEERING ACROSS THE SKULL: 5X5 GRID OF FOCAL SPOT LOCATIONS

Composite image showing ex vivo skull cap boundary, gel phantom, and transducer axes

Contour map of peak displacement ratio with/without skull cap at each focal spot location

Max ratio: 0.32
Max ratio: 0.33
Max ratio: 0.29
SKULL CAP MEASUREMENTS

Skull cap thickness averaged over medial and lateral measurements

4.5 mm
2.5 mm → “3.5 mm”

a) Skull + Transducer Setup

Gaur et al., ISMRM 2018
HYDROPHONE MEASUREMENTS

Measured peak negative pressure vs applied acoustic power

<p>| Ex vivo skull | Relative transmitted | Simulated |
| cap thickness | pressure (compared | relative |</p>
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<th>(mm)</th>
<th>to water) at 42.5 W</th>
<th>pressure</th>
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<td>3.5</td>
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<td>7</td>
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<td>Water only</td>
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~20%  
~17%

Gaur et al., ISMRM 2018
SKULLS VARY IN SHAPE, THICKNESS, AND COMPOSITION

What metrics can we use to predict focal spot intensity?

Thickness?  FUS (MR-ARFI)?  Simulation?
MEASUREMENTS VS HYDROPHONE INTENSITY

Thickness?

FUS (MR-ARFI)?

Simulation?

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<tr>
<th>Skull cap thickness (mm)</th>
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<th>65</th>
<th>80</th>
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<th>Peak relative displacement (MR-ARFI)</th>
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<th>Simulated relative pressure</th>
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Hydrophone measured intensity (W/cm²)

- 3.5 mm
- 5.35 mm
- 5.4 mm
- 7 mm

Gaur et al., ISMRM 2018
HU DISTRIBUTION ACROSS SKULL CAPS

Top right: % of voxels corresponding to skull (HU > 500), similar to thickness
IN VIVO MR-ARFI

Magnitude Image

Transducer

Water Membrane

MR-ARFI image plane

MR-ARFI Focal Spot

Simulated Focal Spot

6.4 mm

4 mm

Displacement (µm)

Normalized Pressure

Gaur et al., ISMRM 2018
SUMMARY

MRI-guided focused ultrasound is a viable treatment option for brain cancer patients.

Skull thickness measures are a starting point for estimating acoustic pressure at a given power level but not completely sufficient.

MR-ARFI provides additional information relating to focal spot intensity, including variations with each skull’s shape and thickness.

Simulations can provide important pre-treatment information and account for variations in bone composition.

MR-ARFI can be used in vivo for non-invasive, non-thermal focal spot targeting.
ACKNOWLEDGEMENTS

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