

MRI-GUIDED FOCUSED ULTRASOUND: APPLICATIONS FOR CANCER THERAPY

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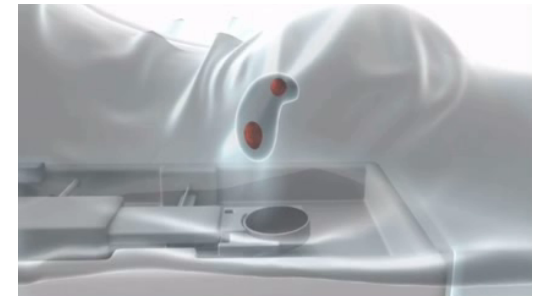
KIM BUTTS PAULY LAB

RSL/SCIT SEMINAR

JUNE 28, 2017

MRI-GUIDED FOCUSED ULTRASOUND SURGERY

- Ultrasound: targeted tissue heating (→ necrosis)
- MRI: visualize treatment (planning, monitoring)
- Less trauma to patient than invasive surgery

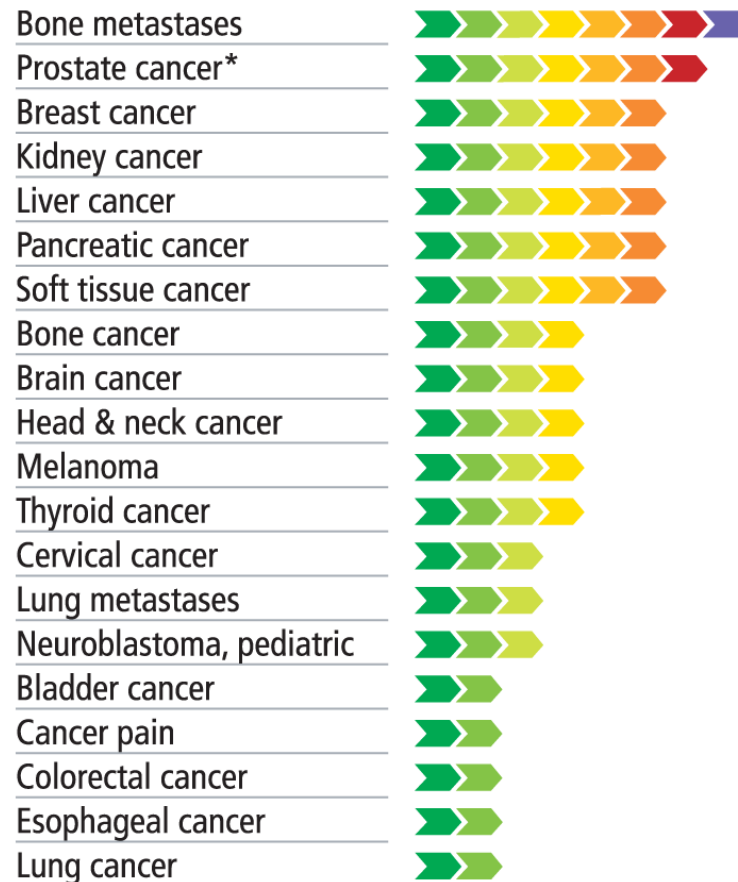


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MRI-GUIDED FOCUSED ULTRASOUND: ONCOLOGICAL APPLICATIONS



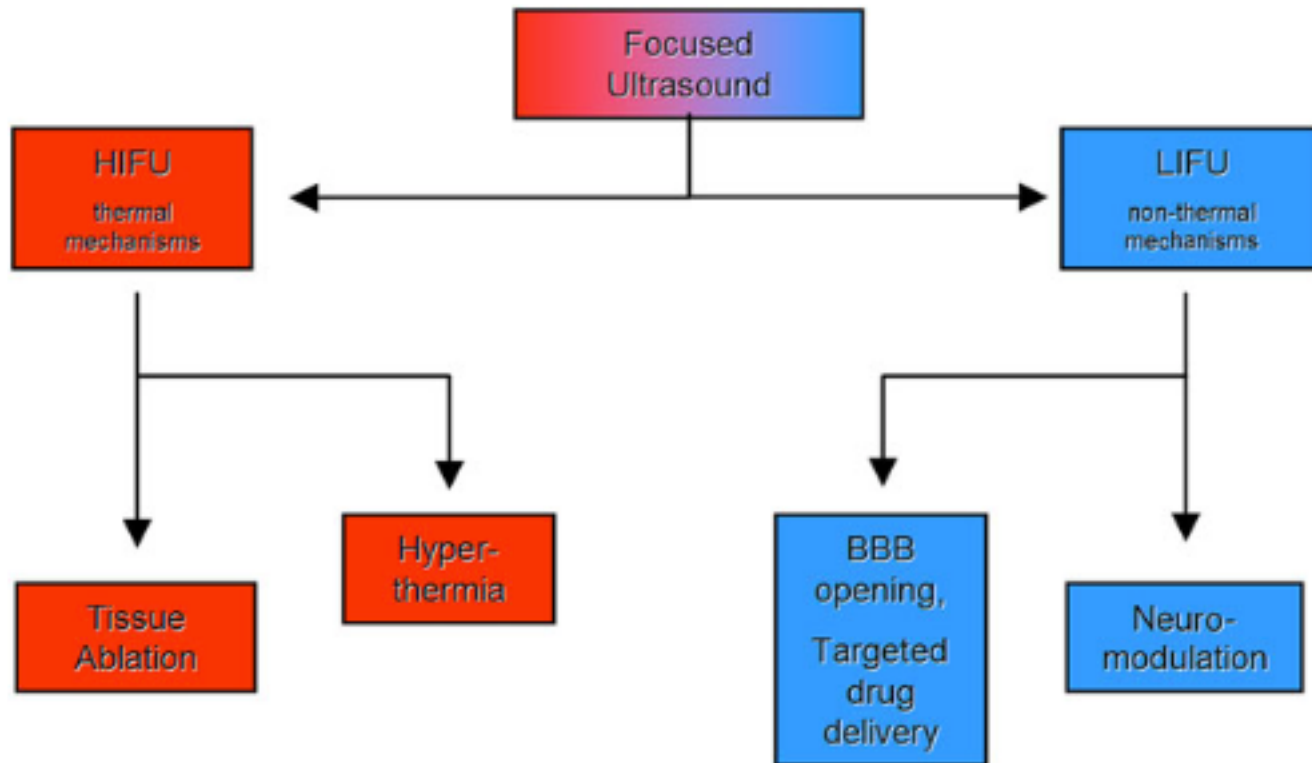
MRI-GUIDED FOCUSED ULTRASOUND NEWS

- 2012, Oct FDA Approves MRI-Guided Focused Ultrasound Ablation for Bone Metastasis Pain
- 2014, Mar **First noninvasive thermal ablation of a brain tumor with MR-guided focused ultrasound**
- 2015, Oct FDA Approves First Focused Ultrasound System for Treating the Prostate
- 2015, Nov **World first: blood-brain barrier opened non-invasively to deliver chemotherapy**
- 2017, Apr **First Focused Ultrasound Pediatric Brain Tumor Study Begins**
- 2017, Jun **Focused Ultrasound Foundation and Cancer Research Institute Partner to Advance Cancer Immunotherapy**

thermal ablation (tumor destruction)

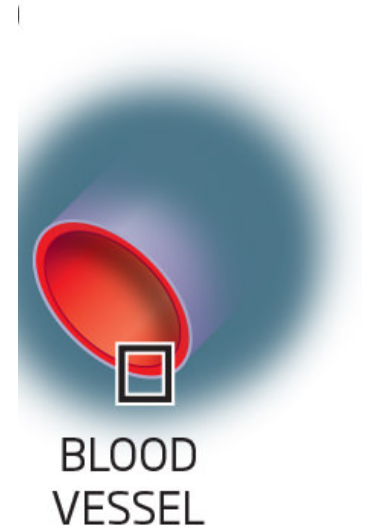
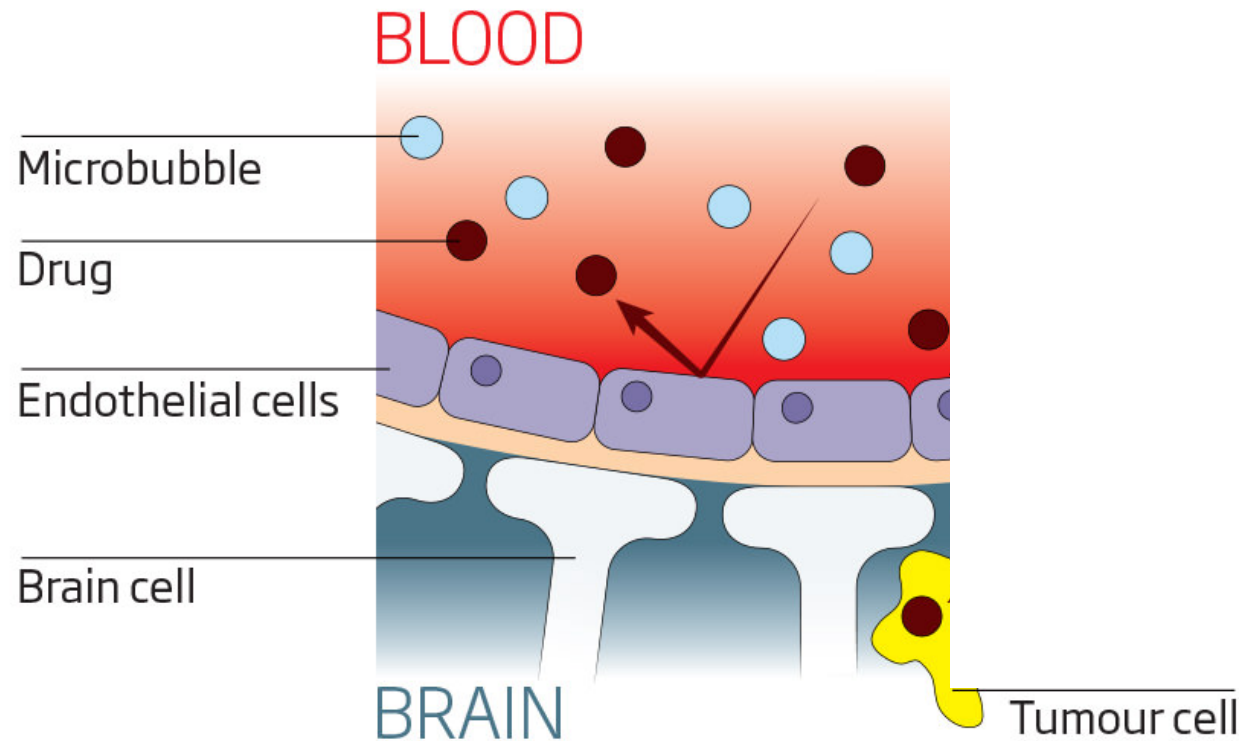
blood-brain barrier opening (chemotherapy)

THERMAL ABLATION AND BBB OPENING: HIGH/LOW INTENSITY FOCUSED ULTRASOUND

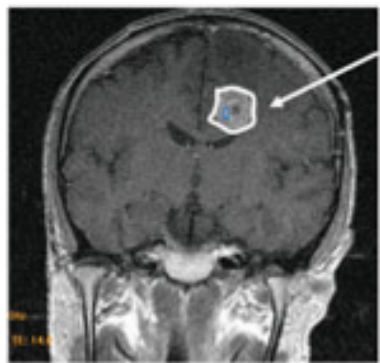


BLOOD BRAIN BARRIER (BBB) OPENING

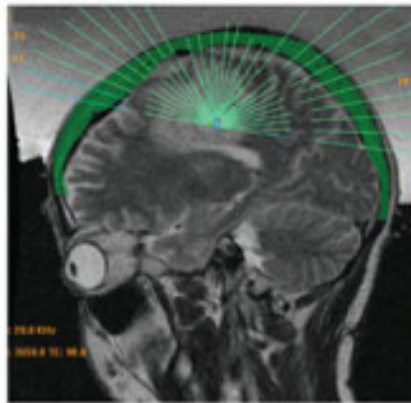
Microbubbles injected into the blood and then vibrated by ultrasound can force apart the protective endothelial cells that line the blood vessels in the brain. This enables drugs targeting tumour cells to breach the blood-brain barrier



THERMAL ABLATION AND BBB OPENING: HIGH/LOW INTENSITY FOCUSED ULTRASOUND

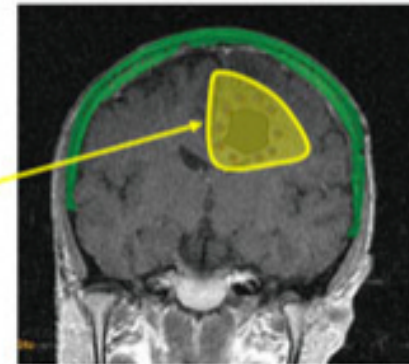


Tumor volume

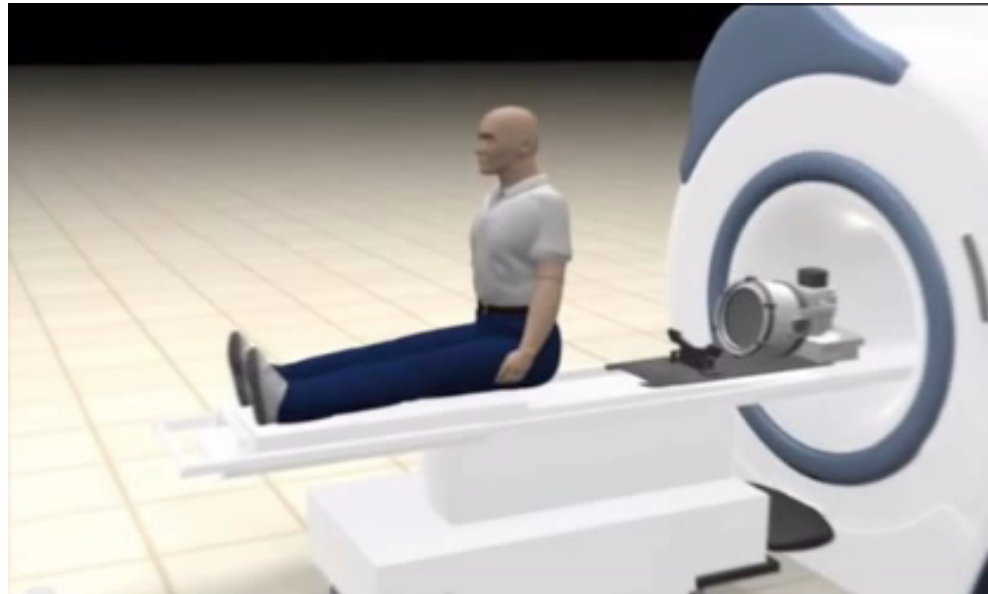


Non-invasive
HIFU ablation

BBB opening with LIFU for
adjuvant chemotherapy

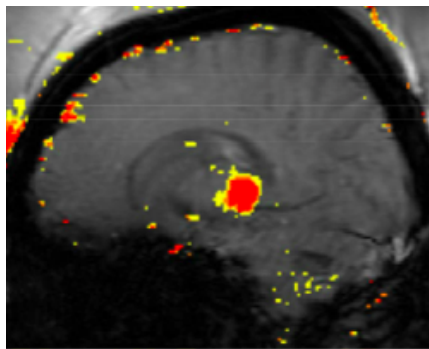


MRI-GUIDED FOCUSED ULTRASOUND: BRAIN



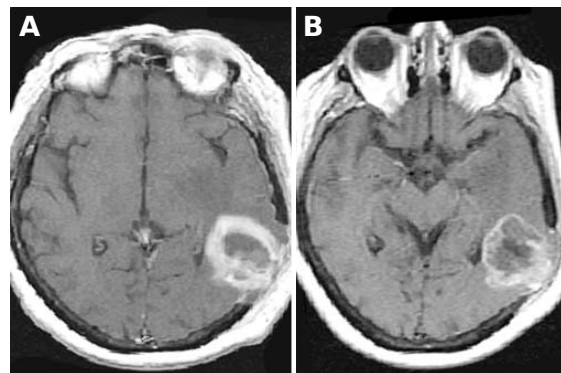
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MRI temperature monitoring



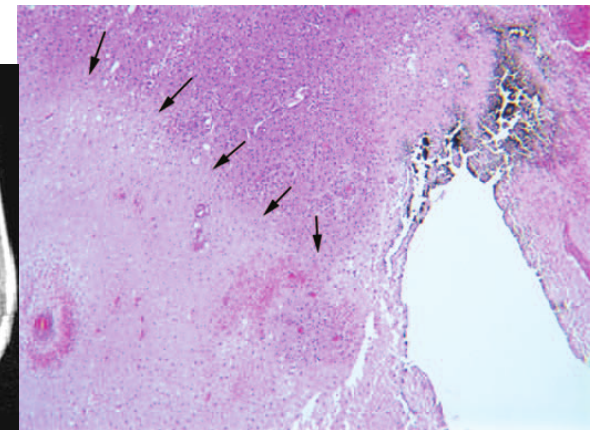
Rieke et al., JMRI 2013

T1-weighted MRI



Before
treatment

After
treatment



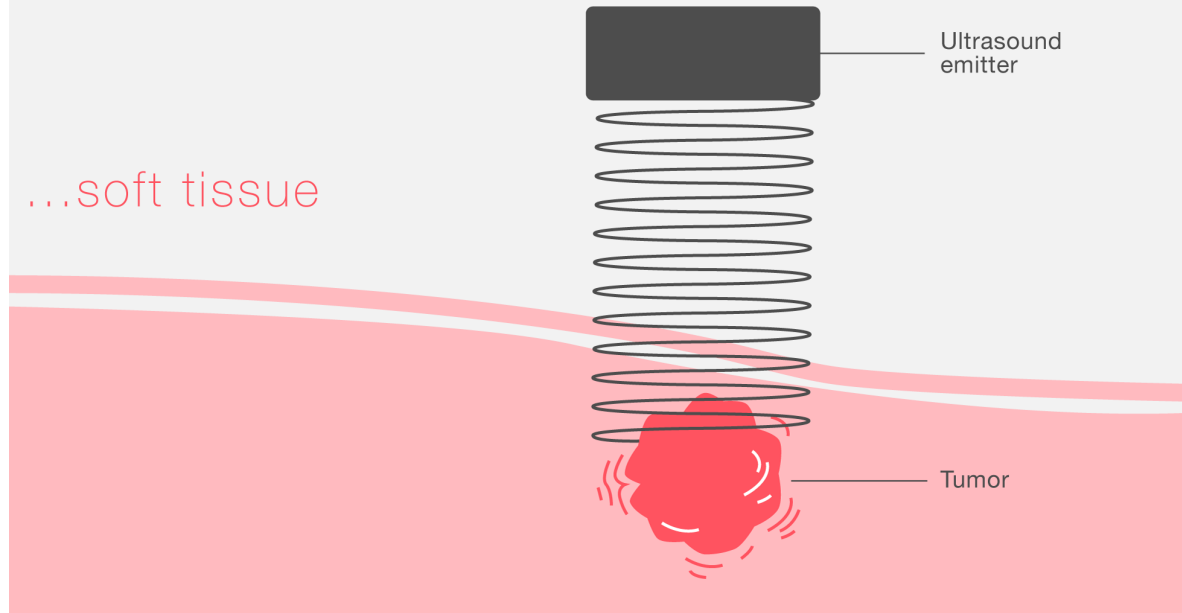
Micrograph of resected tumor shows
coagulative necrosis (arrows)

Ram et al., Neurosurgery 2006

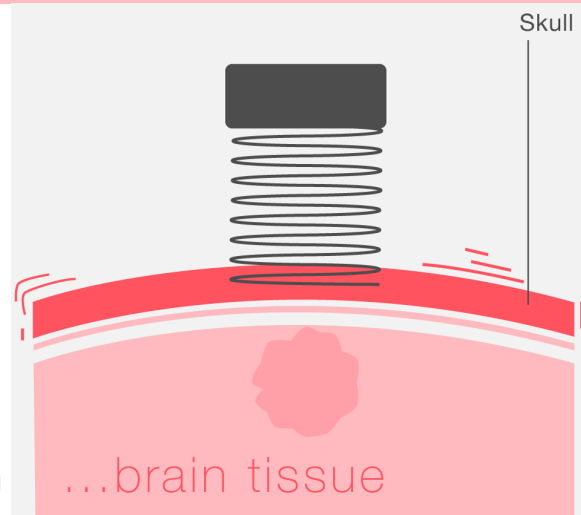
TUMOR ABLATION IN (NON-)BRAIN TISSUE

High-intensity focused ultrasound on...

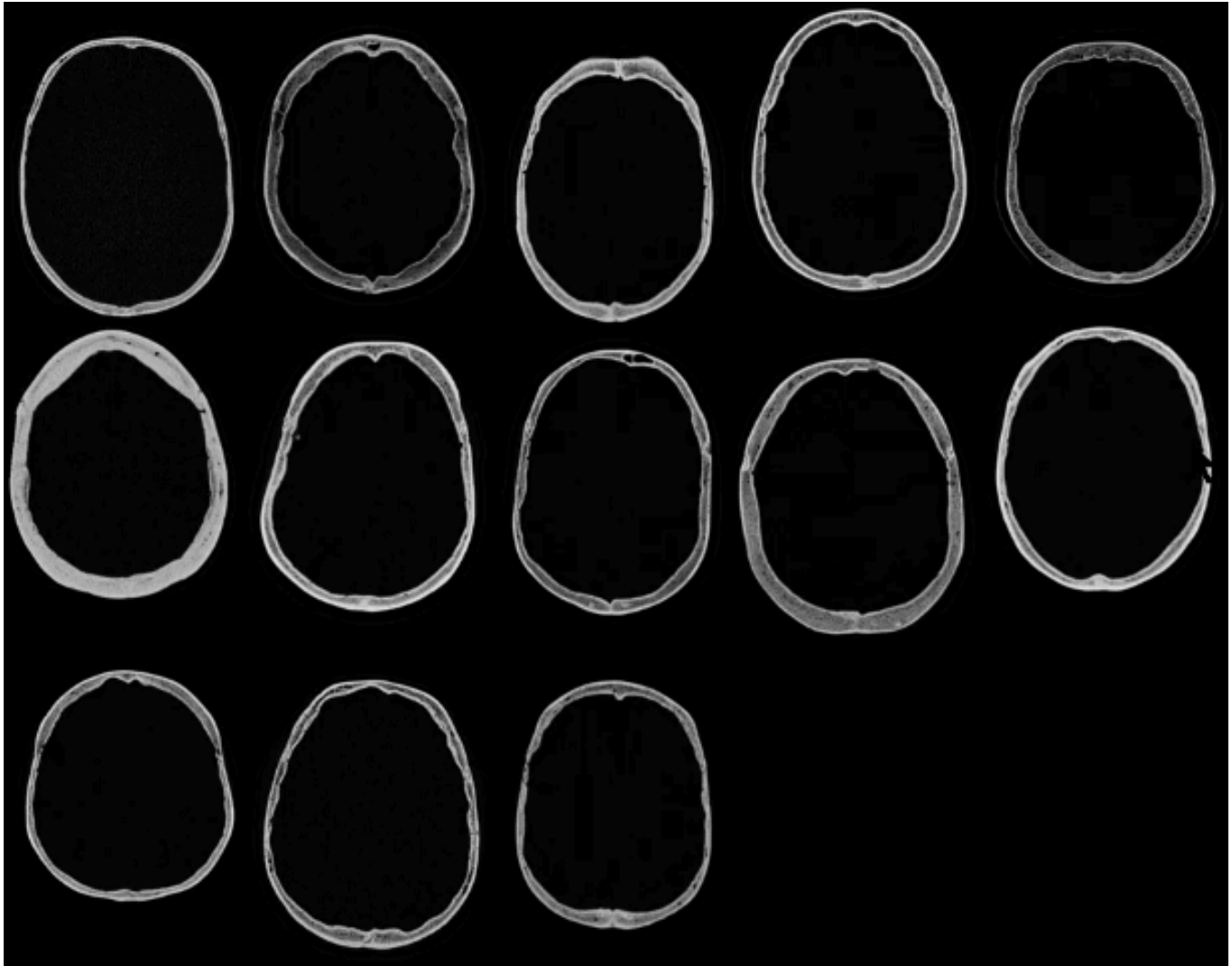
...soft tissue



Skull



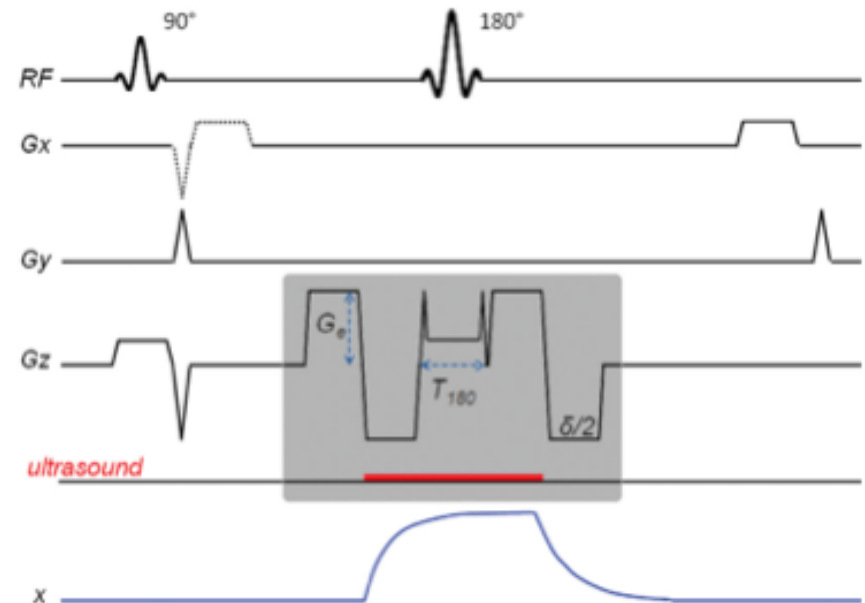
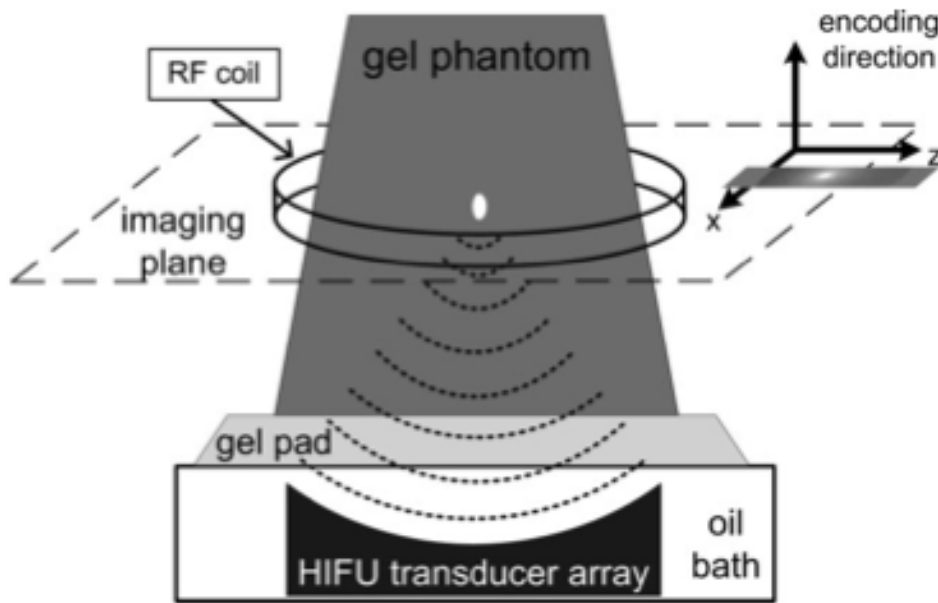
SKULL SHAPE, THICKNESS, COMPOSITION CAN DISTORT ULTRASOUND FOCUS



CORRECTING FOR SKULL DISTORTIONS IS AN ACTIVE AREA OF RESEARCH

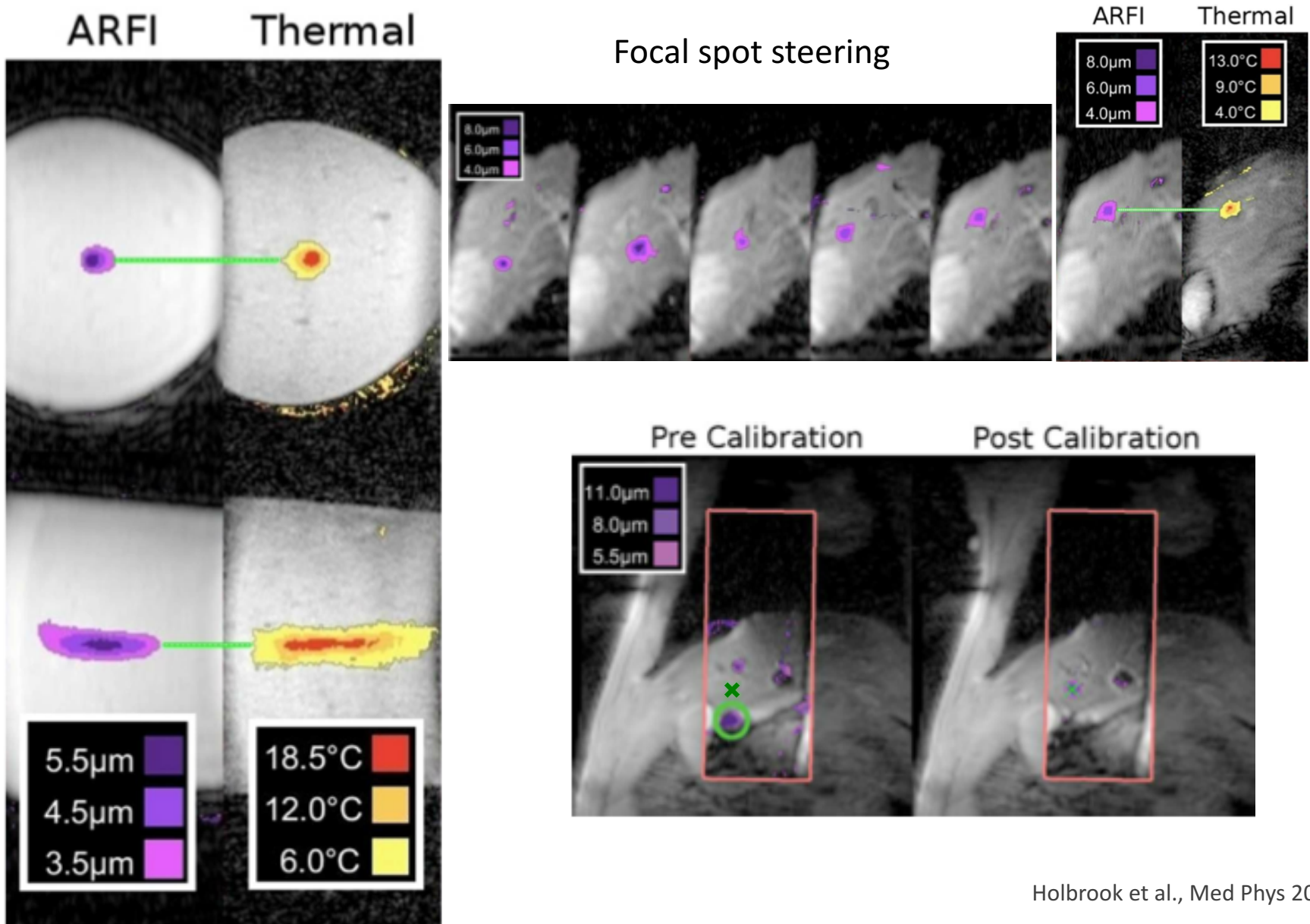
- Simulation-based methods
 - Estimate ultrasound transmission based on CT images
- Imaging-based methods: MRI acoustic radiation force imaging (ARFI)
 - visualize focal spot via tissue displacement
 - adjust transducer phase delays to improve focal spot

MR-ARFI ENCODES TISSUE DISPLACEMENT FROM ULTRASOUND



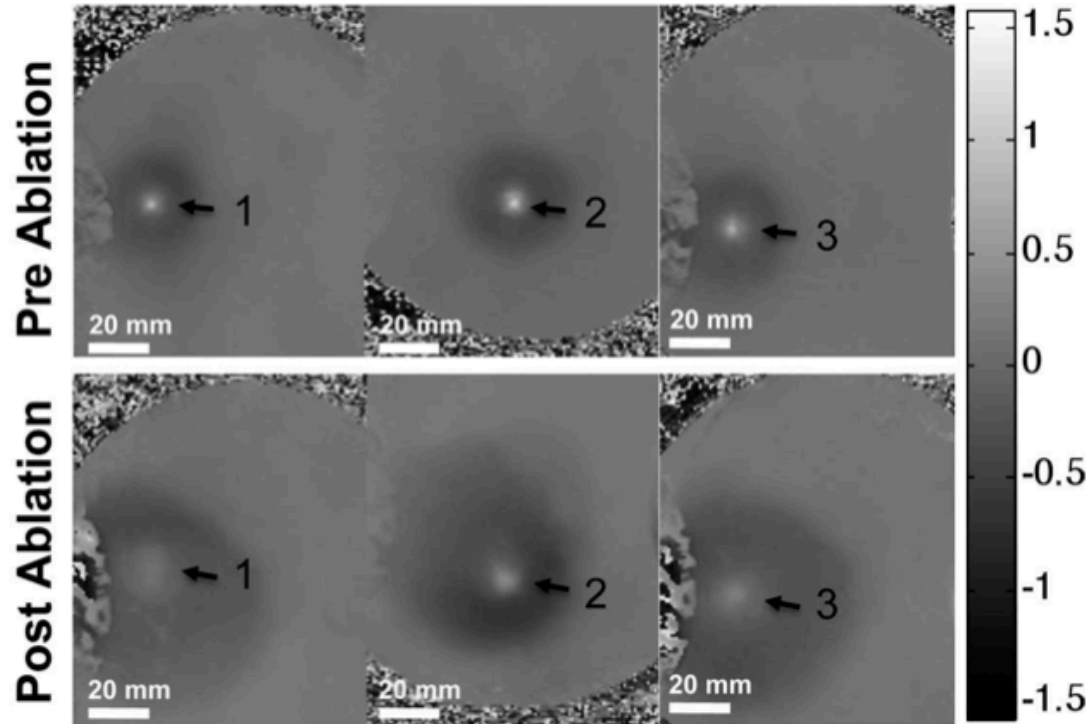
Tissue displacement is measured by change in MR image phase

VALIDATE FOCAL TARGETS BEFORE HEATING

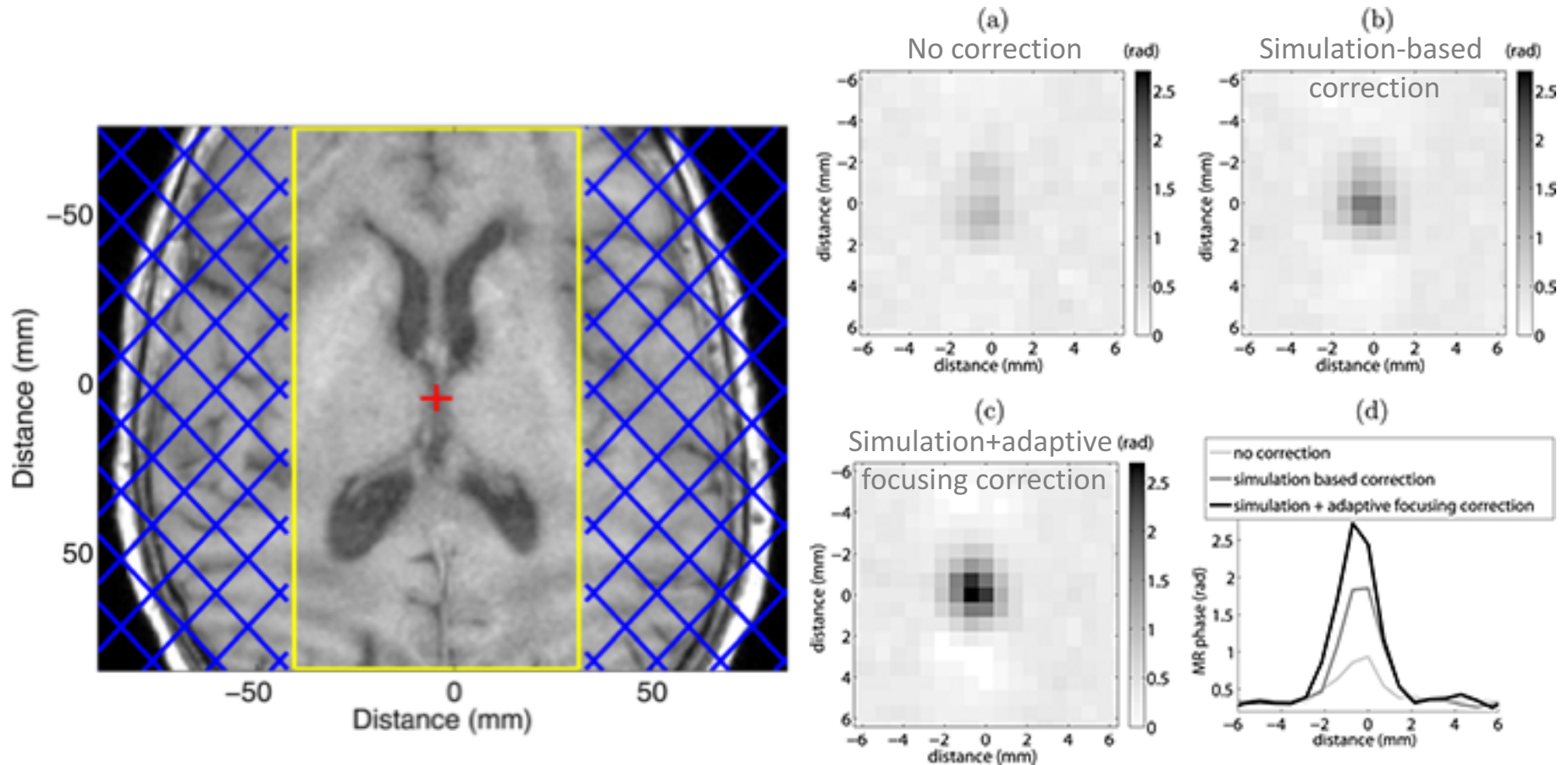


CONFIRM ABLATION BY CHANGE IN TISSUE STIFFNESS

Displacement at three ablation sites



ADAPTIVE FOCUSING FOR IMPROVED CORRECTION THROUGH SKULL

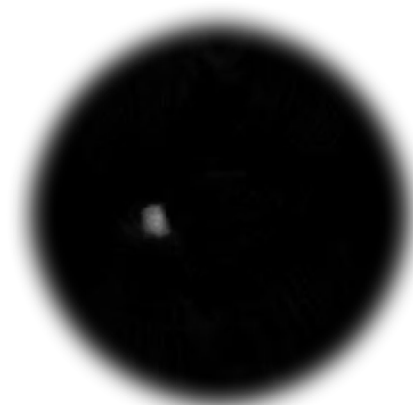


TRANSCRANIAL MR-ARFI EXPERIMENT

Sheep skull (replica)



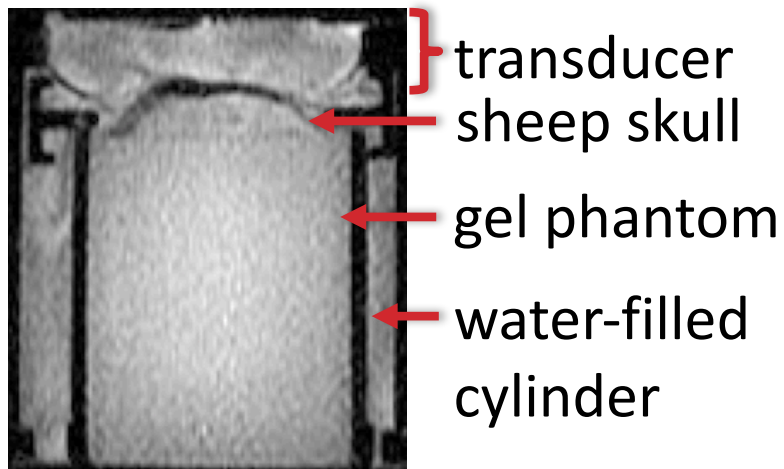
CT of skull cap



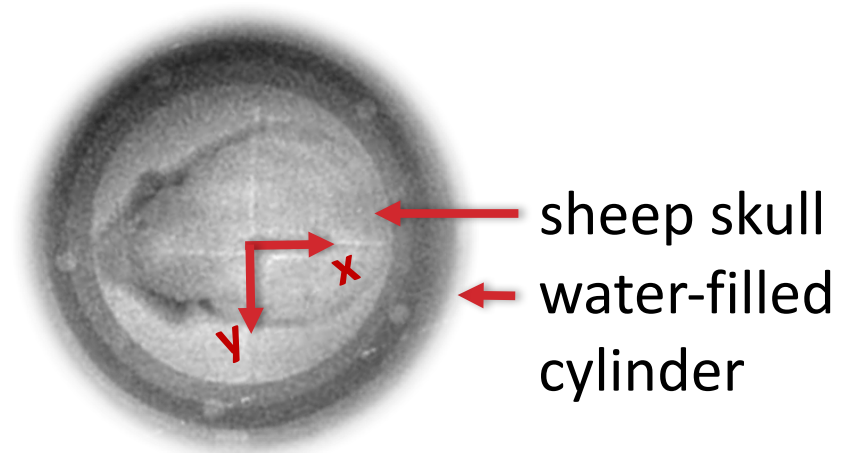
Transducer



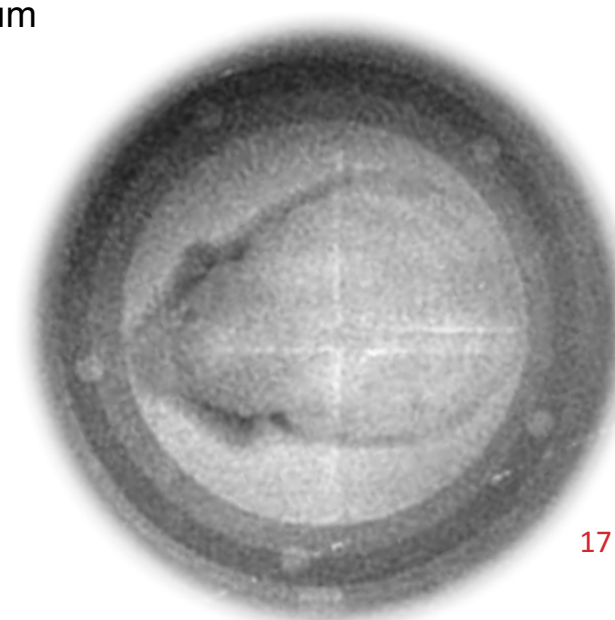
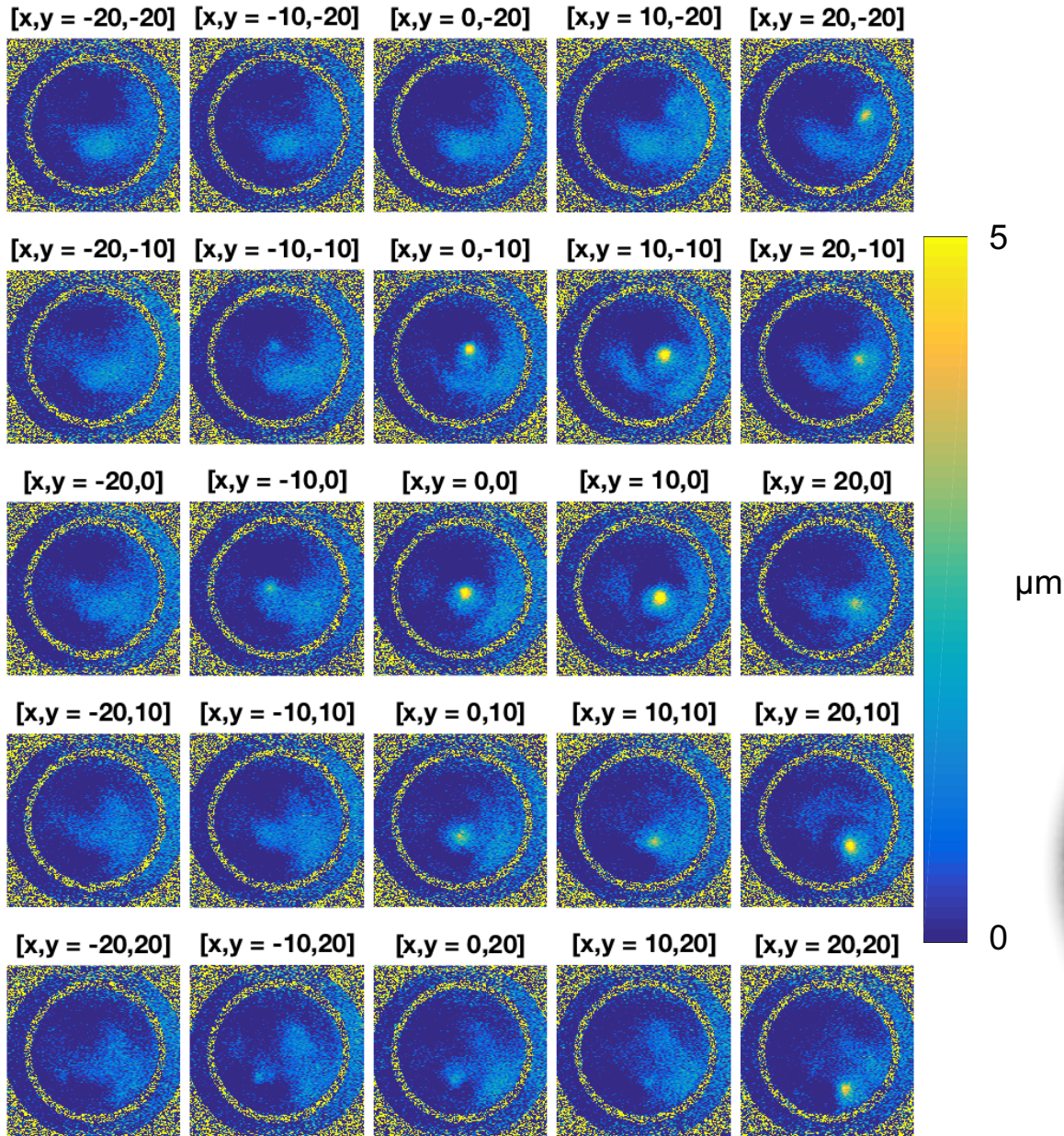
Phantom set-up



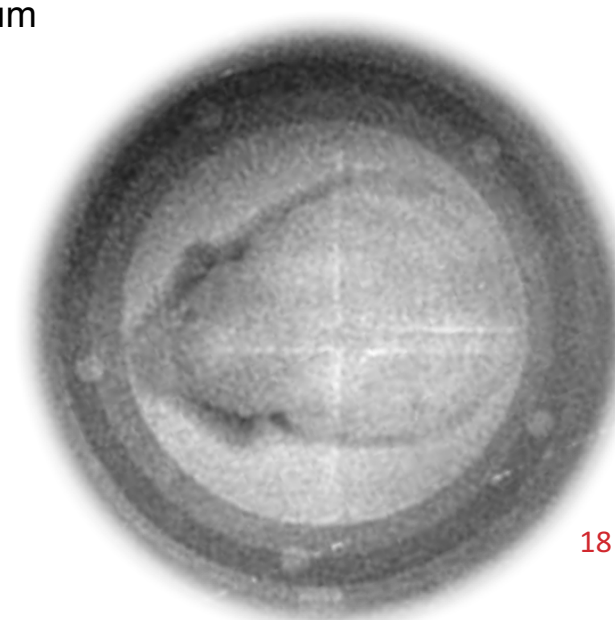
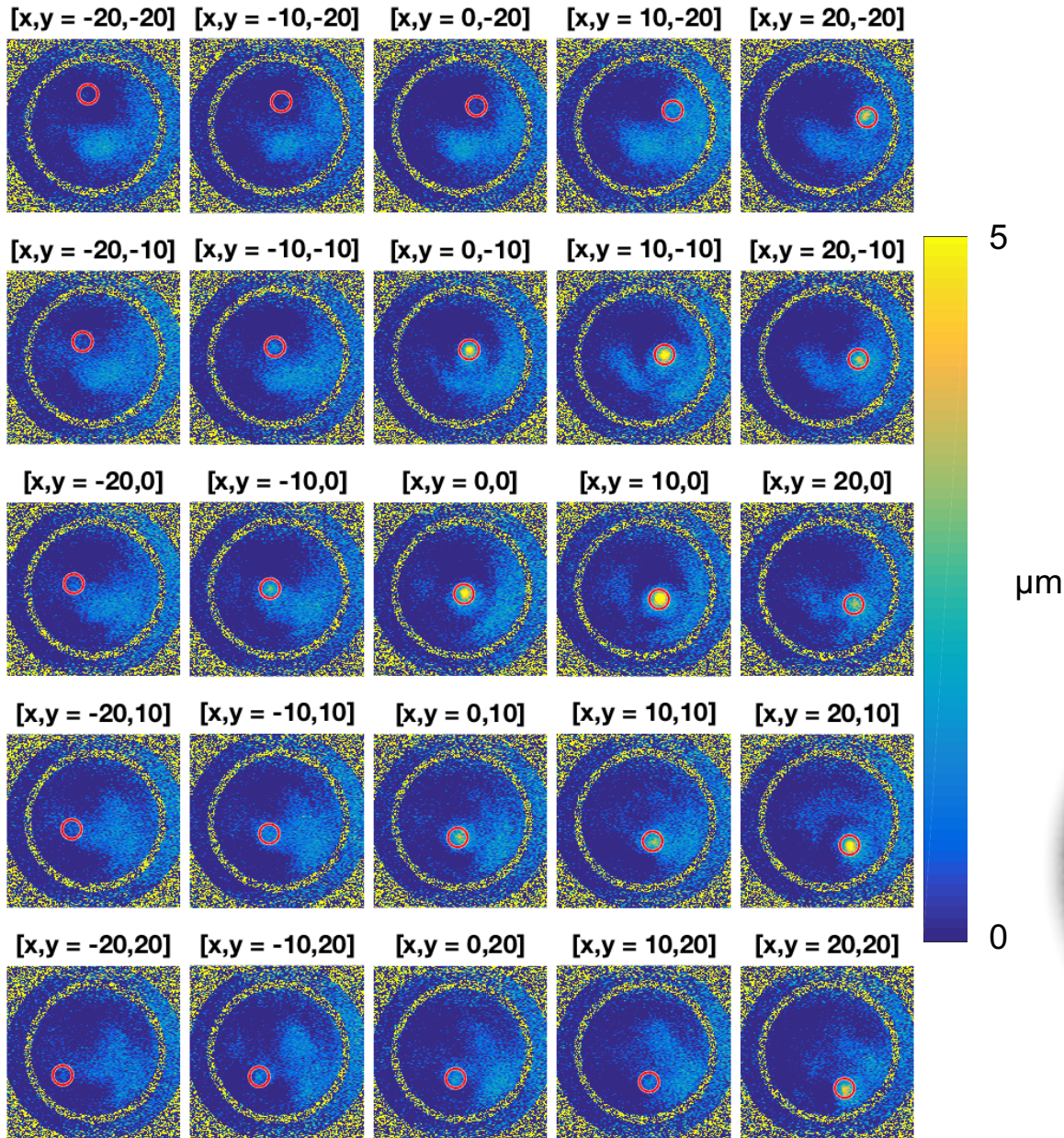
Top-down view



DISPLACEMENT MAPS

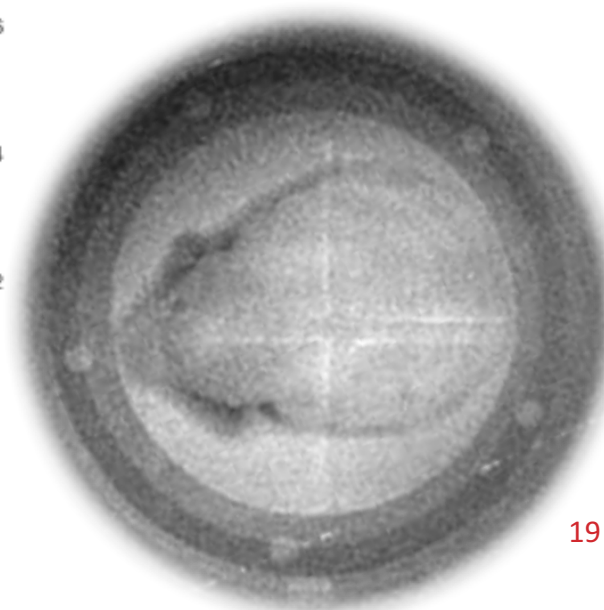
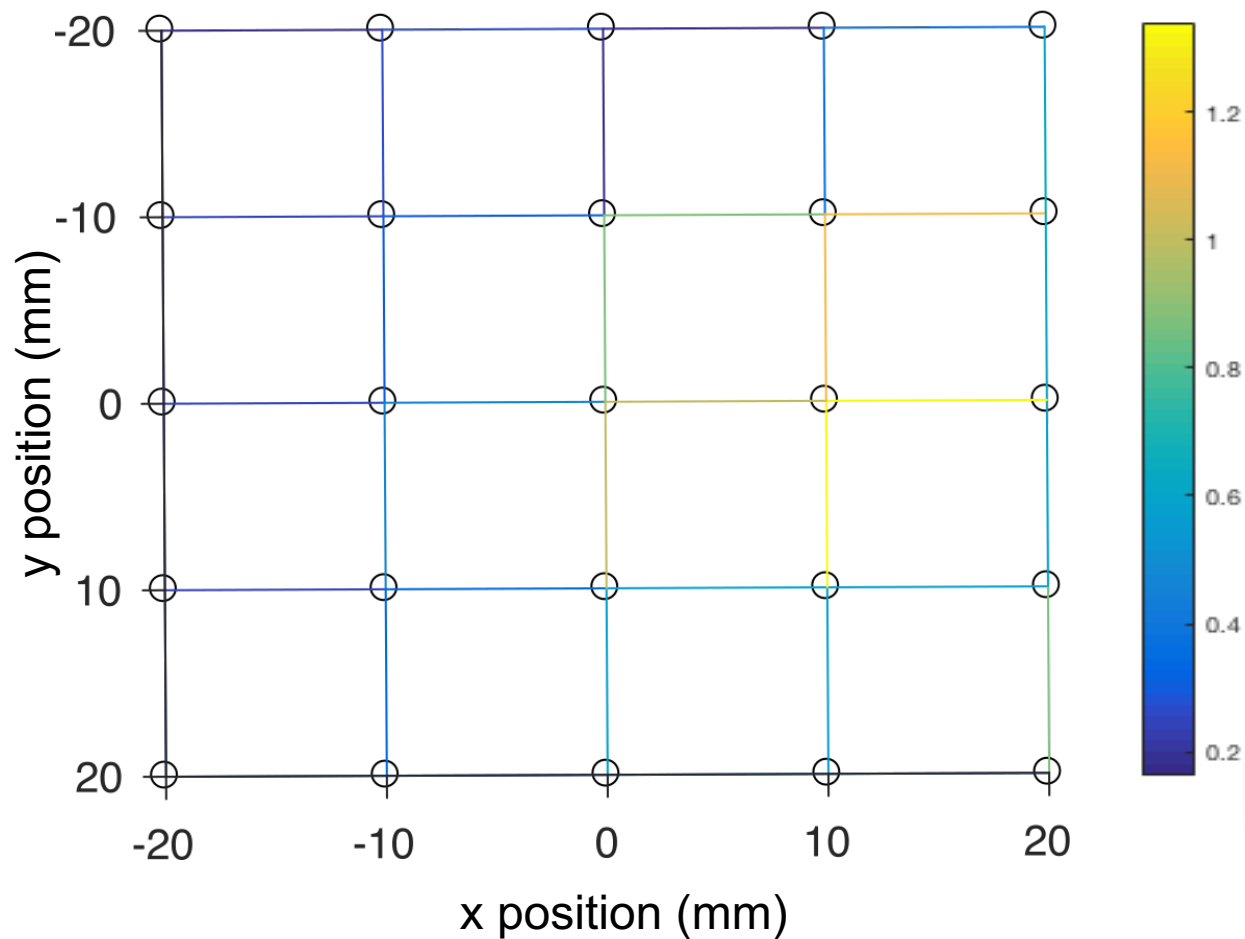


DISPLACEMENT MAPS



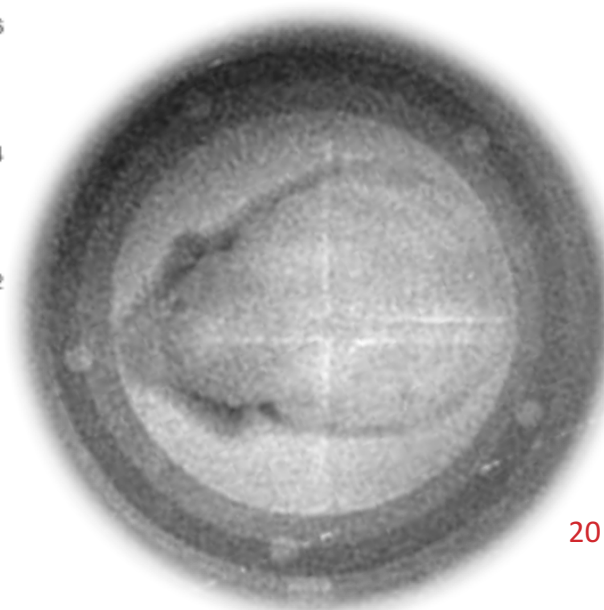
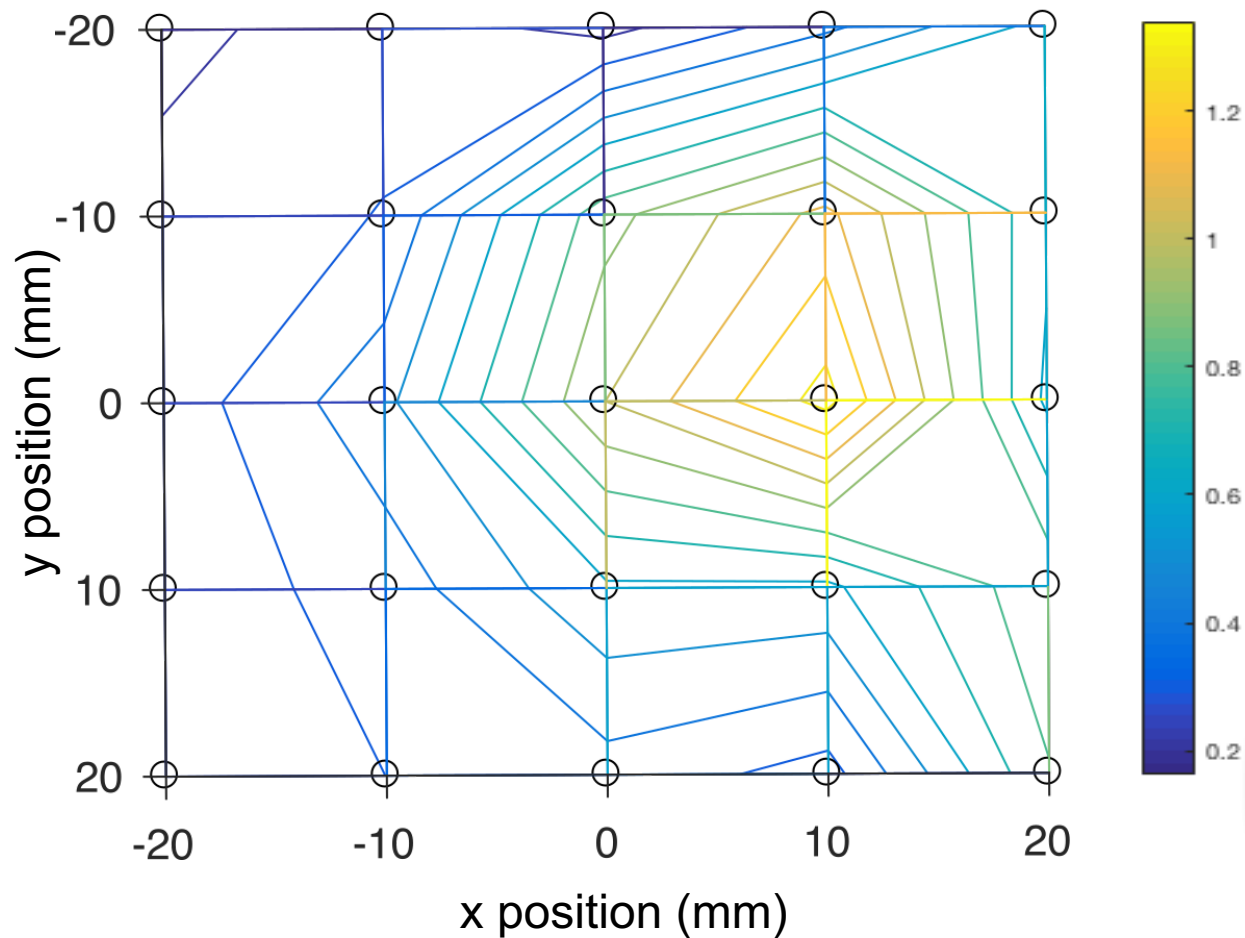
MR-ARFI THROUGH SKULL

Peak displacement, normalized to $[x,y]=[0,0]$



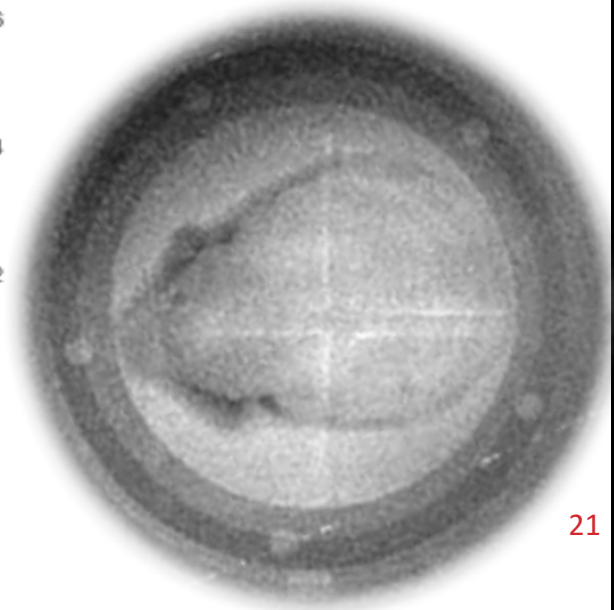
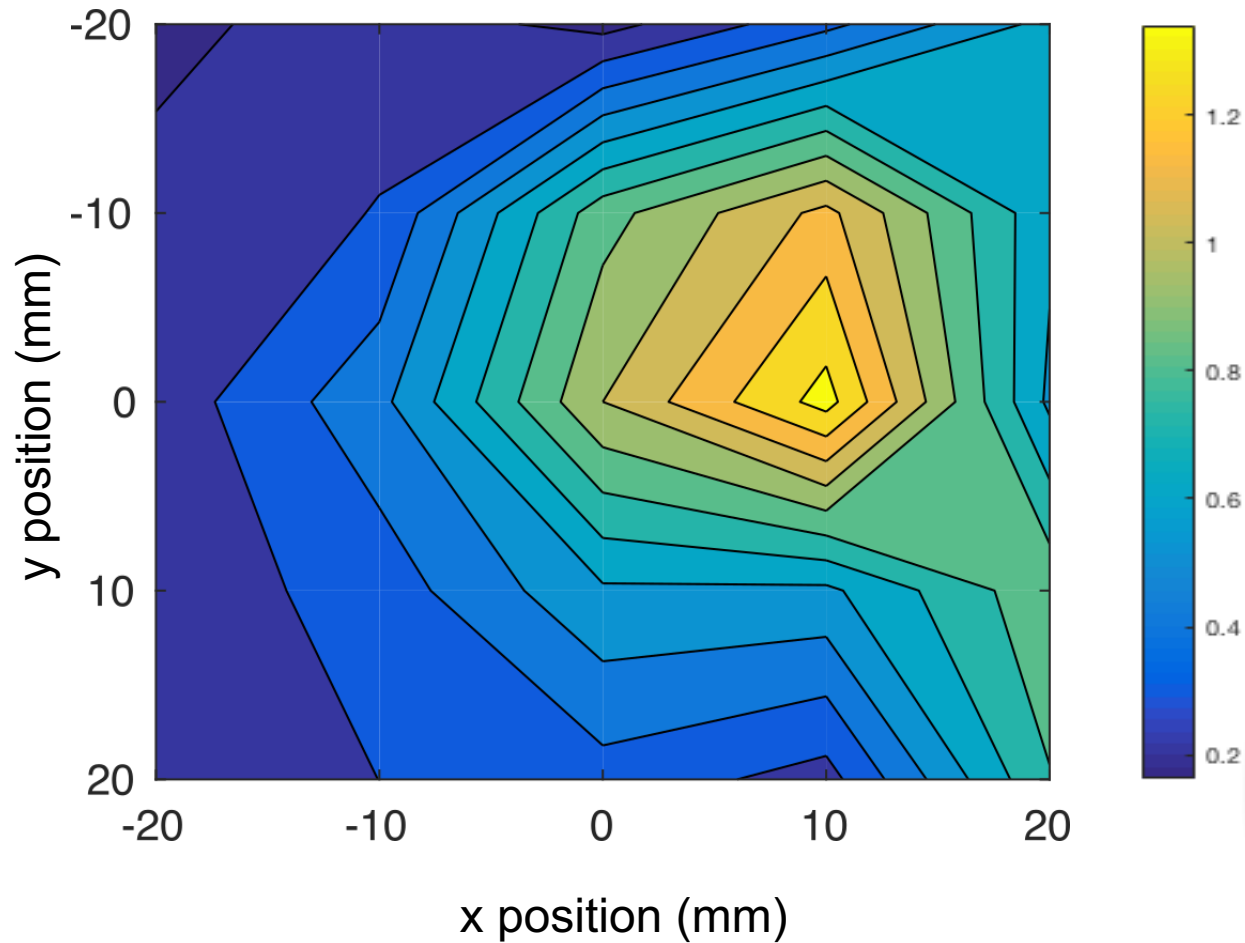
MR-ARFI THROUGH SKULL

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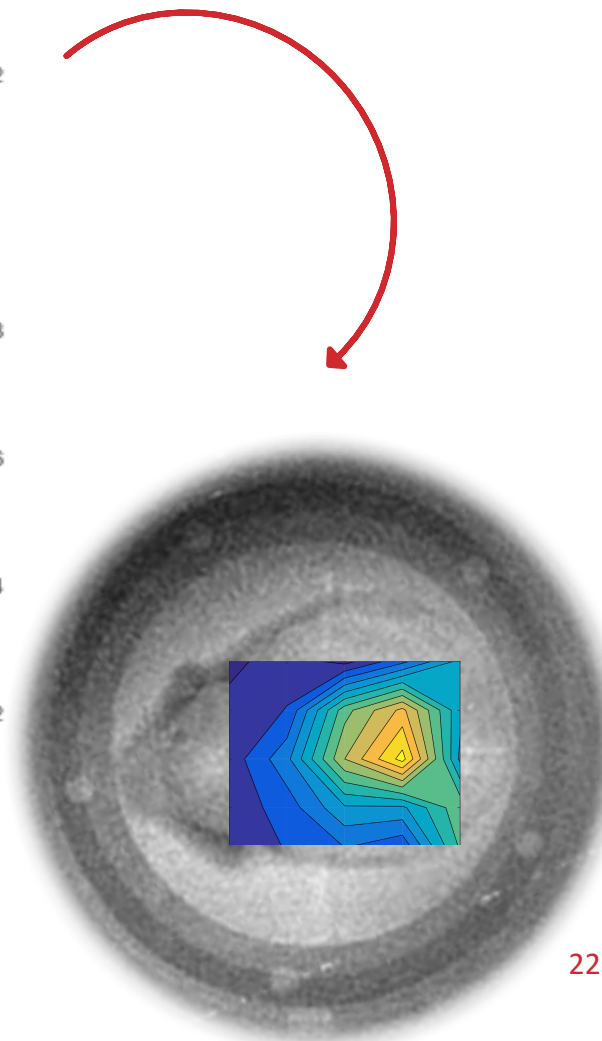
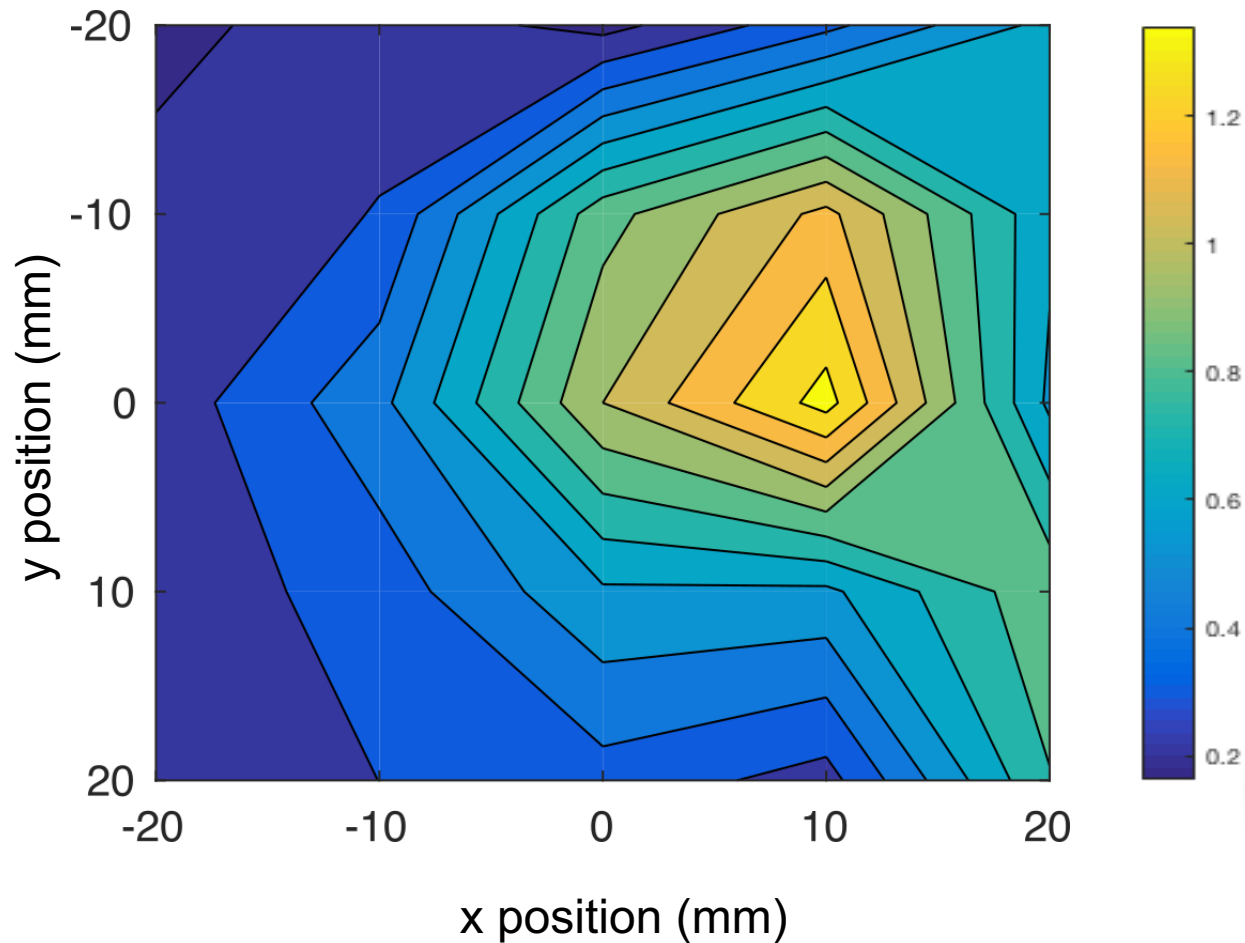
MR-ARFI THROUGH SKULL

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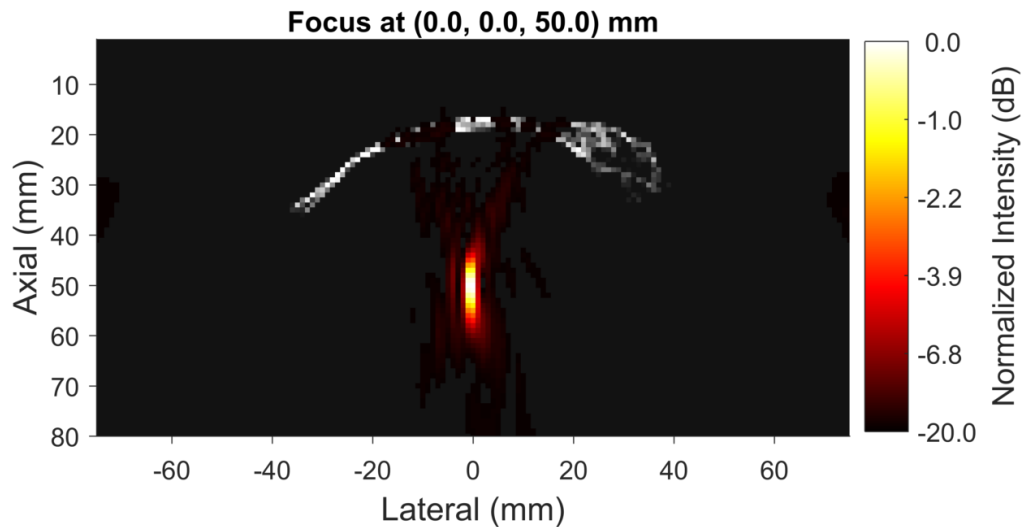
MR-ARFI THROUGH SKULL

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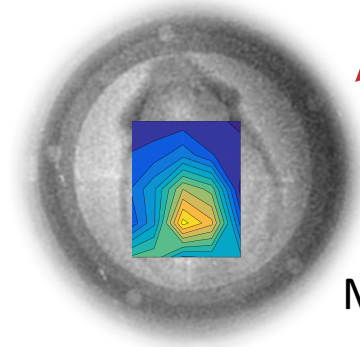
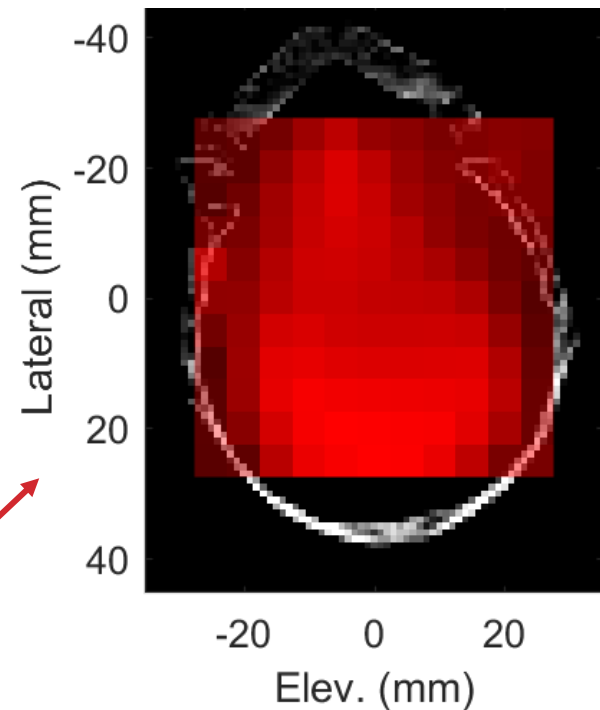


COMPARE MEASUREMENTS WITH SIMULATION MODEL RESULTS

Simulated ultrasound intensity



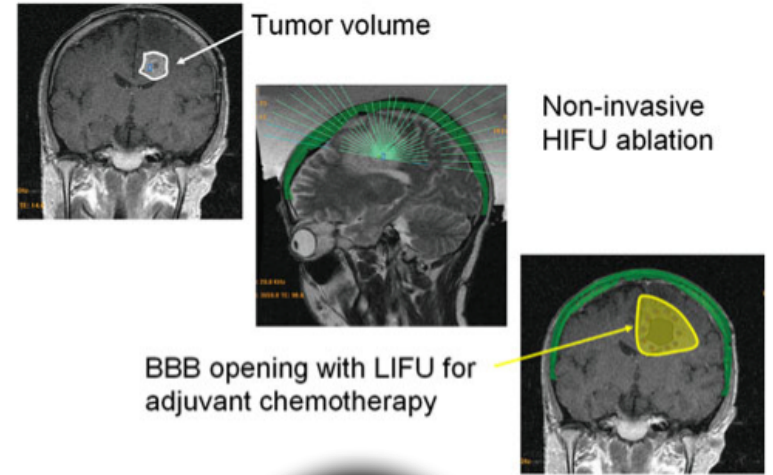
Simulated intensity through sheep skull



More transparent → greater intensity loss

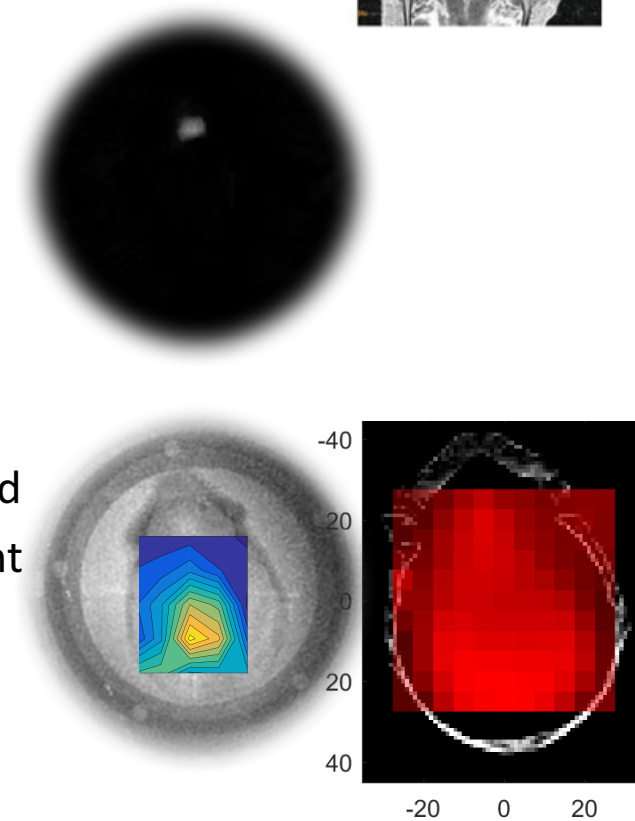
SUMMARY

- MRI-guided focused ultrasound for tumor ablation, BBB opening



- Challenges with treating through skull

- Focal spot measurements and simulations may
 - improve characterization of transcranial ultrasound
 - ultimately improve patient selection and treatment



ACKNOWLEDGEMENTS

