MRI-GUIDED FOCUSED ULTRASOUND: APPLICATIONS FOR CANCER THERAPY

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MRI-GUIDED FOCUSED ULTRASOUND SURGERY

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

- Bone metastases
- Prostate cancer
- Breast cancer
- Kidney cancer
- Liver cancer
- Pancreatic cancer
- Soft tissue cancer
- Bone cancer
- Brain cancer
- Head & neck cancer
- Melanoma
- Thyroid cancer
- Cervical cancer
- Lung metastases
- Neuroblastoma, pediatric
- Bladder cancer
- Cancer pain
- Colorectal cancer
- Esophageal cancer
- Lung cancer
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

Martin et al., Curr Radiol Rep 2013
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.

https://www.newscientist.com/article/mg22229742-400-human-brains-ultimate-barrier-to-open-for-first-time
THERMAL ABLATION AND BBB OPENING: HIGH/LOW INTENSITY FOCUSED ULTRASOUND

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

Ram et al., Neurosurgery 2006

Micrograph of resected tumor shows coagulative necrosis (arrows)

www.insightec.com
TUMOR ABLATION IN (NON-)BRAIN TISSUE

High-intensity focused ultrasound on...

...soft tissue

http://www.pbs.org/wgbh/nova/next/body/hifu

...brain tissue
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

Chen et al., MRM 2010
Kaye et al., MRM 2013
VALIDATE FOCAL TARGETS BEFORE HEATING

Focal spot steering
CONFIRM ABLATION BY CHANGE IN TISSUE STIFFNESS

Displacement at three ablation sites

Pre Ablation

Post Ablation
ADAPTIVE FOCUSING FOR IMPROVED CORRECTION THROUGH SKULL

No correction

Simulation-based correction

Simulation + adaptive focusing correction

Marsac et al., Med Phys 2012
TRANSCRANIAL MR-ARFI EXPERIMENT

Sheep skull (replica)

CT of skull cap

Transducer

Phantom set-up

- transducer
- sheep skull
- gel phantom
- water-filled cylinder

Top-down view

- sheep skull
- water-filled cylinder
MR-ARFI THROUGH SKULL

Peak displacement, normalized to \([x,y]=[0,0]\)
MR-ARFI THROUGH SKULL

Peak displacement, normalized to [x,y]=[0,0]
MR-ARFI THROUGH SKULL

Peak displacement, normalized to \([x,y]=[0,0]\)
MR-ARFI THROUGH SKULL

Peak displacement, normalized to $[x,y]=[0,0]$
COMPARE MEASUREMENTS WITH SIMULATION MODEL RESULTS

Simulated ultrasound intensity

Simulated intensity through sheep skull

Focus at (0.0, 0.0, 50.0) mm

More transparent → greater intensity loss

Images courtesy of Ningrui Li

Normalized Intensity (dB)

Axial (mm)

Lateral (mm)

Elev. (mm)
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