WM Proposal - Transcranial MR guided Focused Ultrasound for Non-Invasive Treatment of Brain Diseases

Dr. Silke Lechner-Greite, Lead Scientist, GE Global Research, Munich, Germany
Thermal Treatments

**High Intensity FUS**
- kills tissue directly (ablation)
- $>>55^\circ C$
- ~ 15 minutes treatment
- heated regions:
  - ~ 0.1 to 1 cm in diameter
  - ~ 1 to 5 cm in length
- Temporal resolution: ~3 s

**Deep Region RF Hyperthermia**
- enhances radiation & chemo therapy
- 40-43°C
- ~60 mins
- heated region:
  - ~5 to 10 cm diameter
- Temporal resolution: ~6-10 min

**Other thermal therapies**
- MR-guided laser-induced thermal therapy (LITT)
- Radio frequency ablation (RFA) (kHz)
- Microwave ablation (MWA) (GHz)
- Cryotherapy
- Nanoparticles heating

- Transcranial MR guided FUS (clinical setup and procedures)
- Treatment planning & monitoring with MR thermometry
- Problems, challenges, and potential goals of WM
Why MR guided Focused Ultrasound

- Non-invasive
- Local therapy
- Immediate result
- No late effects, e.g. delayed necrosis
- No dose accumulation effects
- No long term toxicity
- Repeatable

But:
- Long exam duration (~6h)
- Restricted to certain area in the brain
- Treatment area limited by size of hot spot
- Some steps of the therapy need a more confident guidance (treatment area localization, hot spot tracking, etc.)
- New treatment studies are difficult to be introduced – regulatory issues

Key objective: ... at any phase of the treatment, the surgeons need **reliable guidance** through the procedures and the **confidence** that the focal spot of the treatment is identical to the predefined target and that no other healthy tissue is getting harmed by the procedure ...
System Details @ University Children’s Hospital

- InSightec ExAblate 4000 Neuro system
- Hemispherical 1024-element phased-array transducer operating at 650 kHz
- Discovery MR750w 3.0T, GE Healthcare
- Stereotactic frame to immobilize the patient
- Degassed water used for acoustic coupling & cooling of skull surface
- CT-based acoustic modeling
- PRFS-based MR thermometry

CT-based Modeling

CT – based modeling

Skull deflects the ultrasound beam

Phase correction

Transducer

RF signals

Courtesy of Beat Werner, Childrens Hospital Zurich
Treatment Planning - Drawbacks

- CT based modeling for phase correction:
  - exposure to ionizing radiation
  - ~30% of the patients are not treatable:
    - porosity of bone
    - Geometry
- Target area is selected based on a brain atlas
  - no individual adaptation is possible

Images - Courtesy of Beat Werner, Childrens Hospital Zurich
Treatment Monitoring – PRFS based MR Thermometry

The Phase of the water signal is temperature dependent.

Lower Temperature – “ice-like” H-bonded state

Higher Temperature – “free” H₂O molecules

Higher Proton Resonant Frequency

Lower Proton Resonant Frequency

$$\Delta T = T_2 - T_1 = \frac{\phi(t_2, T_2) - \phi(t_1, T_1)}{\alpha \gamma B_0 TE}$$

$$\alpha = -0.00909 \text{ ppm/°C}$$
Treatment Planning - Drawbacks

- Only 2D MR thermometry clinically available
  - Fast MR thermometry protocols needed:
    - single shot, parallel imaging, compressed sensing, etc.
  - BUT: system interactions of transducer <-> MR scanner

- Accurate temperature mapping:
  - Robust MR thermometry protocols: corrected PRFS, fat-referenced PRFS, hybrid methods, etc.
  - BUT: it is difficult to introduce new methods

- Track the heat in bone → consider other MR contrasts for temperature mapping
Minimizing eddy currents induced in the ground plane of a large phased-array ultrasound applicator for EPI-based MR thermometry.
Robust MR thermometry techniques

Fat-Referenced MRT

- Automatic fat-water separation using 3-echo Dixon method.
- Uses spatial fitting of fat phase difference signals ($B_0$ drift).
- Does not require fat and water to be in the same voxel

$$\Delta \hat{\phi}_f (\vec{r}) = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 y^2 + \ldots$$

Fat-Referenced MRT

Mixed fat-water phantom (cream)

Water Image  Fat Image  SPGR

Motion Map

Fat-Referenced

Conventional PRFS

RMSE = 2.8 °C

RMSE = 4.5 °C

Joint T1 and PRFS using balanced SSFP

Clinical Application:
- RF hyperthermia as sensitizer for radiotherapy and chemotherapy
- BSD-2000/3D applicator for treatment in pelvis

Technical Goal:
- Accurate MR temperature mapping for accurate dose delivery
- Motion insensitive
- Cover muscle & adipose tissue within 3D volume
- Increase patient comfort

Technical Description:
- T1 temperature mapping for MRT in adipose tissue
- combined with balanced SSFP: high SNR, high accuracy
- combined with inversion recovery: fast T1 mapping (~20s)
- extracting phase information from bSSFP: PRFS in muscle

Wu et al., 23rd ISMRM, Toronto, 2015, #3579
Automated Research MRT Platform

**Description:**
- Easy-to-use graphical user interface
- Flexible programming environment (MATLAB) to allow rapid integration of new thermometry algorithms
- Technique comparison mode available
- First prototype comes with PRFS & fat-referenced methods

[Diagram of Automated MR thermometry platform]

- Thermal Applicator
- MR scanner console
- Automated MR thermometry platform
- Network link
Silent MRI

- Zero TE imaging
- Based on RUFIS (Madio 1995)
- **non-selective** hard pulse excitation
- 3D center-out radial k-space sampling
- **min. grad. ramping:** silent, robust
- **fast:** TR~0.6ms
- **low FA~1...4deg** → PD weighting

log(1/image) scaling results in CT-like contrast

BW=±62.5kHz, FA=1.2deg, FOV=22cm, res=0.86mm, ~6min

Wiesinger et al., MRM 2015: DOI 10.1002/mrm.25545
Zero TE head

BW=±125kHz, FA=1.0deg, FOV=32cm, res=1.0mm, ~8min

- Very good bone contrast – useful for treatment monitoring?

- 3D coverage – for dose planning?

Wiesinger et al., MRM 2015: DOI 10.1002/mrm.25545
Zero TE head: threshold-based segmentation
WM Proposal

- Implement a **single modality planning workflow** → shorter treatment times, replace CT scan?
- Investigate in **fast but accurate MR thermometry techniques** to
  - monitor 3D thermal dose during treatment
  - achieve high-res anatomical imaging for treatment planning and response monitoring.
- Investigate in **other MR signal contrasts** → monitor temperature not only in tissue but also in bone.
- **Calibrate the transducer** (pre-emphasis, higher order eddy current compensated image reconstruction (magnetic field camera))
- **Simplify sequence testing** (easy-to-use toolbox)
- Increase **predictability of treatability**: tissue property simulations
- Support **treatment area identification**: probabilistic atlas, functional probing
Innovation @ GE Global Research

Global Research Center
Niskayuna, NY

India Technology Center
Bangalore, India

China Technology Center
Shanghai, China

Global Research Europe
Munich, Germany

Advanced Manufacturing &
Software Technology Center
Ann Arbor, MI

Global Software Center
Silicon Valley, CA

Brazil Technology Center
Rio de Janeiro, Brazil

• ~2000 scientists/engineers, nearly two-thirds PhDs.
• 3,615 US patents filed by GE in 2011
• One of the world's most diversified industrial research organizations, providing innovative technology for all of GE's businesses
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References
