MRI guided High Intensity Focused Ultrasound for tumor ablation in breast and liver

Chrit Moonen
Disclosures

- Research collaboration with Philips Medical Systems
- Research collaboration with Elekta
MRI guided High Intensity Focused Ultrasound

- MRI with HIFU
- anatomy and temperature mapping
- thermo-therapy
- position and power control
- PC
- TRANSDUCER

MRI guided High Intensity Focused Ultrasound
MRI temperature mapping based on the Proton Resonance Frequency of water

\[ \frac{d\sigma}{dT} = \beta = 0.01 \text{ ppm/}^\circ\text{C} \pm 5\% \]

\[ \Delta T = -\Delta \varphi / (\beta \cdot \gamma \cdot B_0 \cdot T_E) \]

Linear / independant of tissue type (Peters, Henkelman et al, 1996)

RF-spoiled gradient echo

Phase 1

Phase 2

(relative temperature map)

20 mm

zoom x 4

zoom x 4

zoom x 4
Rapid temperature mapping in kidney and liver

Example 1

Example 2

anatomy  motion correction in pulse sequence only  Sequence + Post-processing motion correction

10°C  0°C
Correction of thermal maps: multi-baseline approach

Pretreatment step

During intervention

\[ \gamma = \frac{\sum_{x,y} (I_{x,y} - \bar{I})(I'_{x,y} - \bar{I}')}{\sqrt{\sum_{x,y} (I_{x,y} - \bar{I})^2 \sum_{x,y} (I'_{x,y} - \bar{I}')^2}} \]
Precision of MRI temperature mapping in breast tumor

Gradient Echo Images

Temperature standard deviation maps
Dedicated breast MR-HIFU system

“Conventional” approach

Dedicated system with lateral sonication

transducer top view
Dedicated breast platform
Sonalleve Breast MR-HIFU

Table top without covers

Water box with transducer and motors

Close-up of breast cup, single-element RF coil, and transducer
Breast tumor 1: MRI planning
Results: MR-HIFU Breast tumor patient 1
Phase 1 Clinical trial (treat and resect)
Breast tumor patient 3
Patient 3: Pathology
Magnetic Resonance guided HIFU of liver

Challenges:
1. **motion**:
   - Artifacts in MRI thermometry
   - Target tracking/gated HIFU
2. **Presence of ribs**
   - Block propagation of HIFU
   - Burn risk in and around ribs
3. **Highly perfused organs**
   - Cooling due to flow/perfusion
   - High HIFU energy deposition
   - Burn risk in near and far field
Intercostal HIFU: Selecting HIFU transducer elements based on beampath

Determine shadowed fraction of area $A_s$

If $A_s >$ threshold:
Switch Element OFF

$$P_{elem} \leftarrow P_{elem} \frac{n_{total}}{n_{active}}$$
Intercostal HIFU: Selecting HIFU transducer elements based on beampath

Manual segmentation

projection

Element deactivated if $S_{\text{covered}} > 50\%$
Results

**HIFU**: Philips Sonalleve platform, 120 Watts, 30 sec

**MRI thermometry**: 2 orthogonal slices, TE/TR=22/200ms, Vox size =1.5x2.5x6
Power calibration animal 4

dose contours

Gd-enhanced contrast

shot pattern
MR-HIFU
Take home messages

- HIFU is noninvasive, does not use ionizing radiation
- MRI can be used for target definition and for temperature mapping
- Real-time MR imaging and feedback coupling are challenging but feasible
- At Utrecht, Phase I of MR-HIFU of breast tumors is ongoing: Phase 1 ablation of liver tumors will probably start in Q1 of 2014

- MR-HIFU is a relatively new approach
- Conceptual similarities with radiotherapy with the following differences:
  No apparent cumulative dose issues for nearby healthy tissue (so long as thermal dose is controlled): procedure can be repeated
  Rapid effect (seconds for coagulative necrosis, up to 1 day for apoptosis)

Real-time imaging during the procedure is a central element of MR-HIFU: Similarities with new developments in Image Guided RT
Radiotherapy

- Standard-of-Care for many types of cancer
- High-Precision Treatment (Gamma-knife, linear accelerator, proton beam)
- Pre-planning is image guided
  - Definition of Gross Tumor Volume (GTV)
  - Definition of Clinical Target Volume (CTV)
  - Identification of Organ At Risk (OAR)
- Until now, treatment itself is usually not (real-time) image guided
- Therefore, it is difficult to treat mobile organs with RT
- University Medical Center Utrecht moves towards real-time MR image guidance
Vision behind the Center for Image Guided Oncological Interventions

- **MRI guidance of RadioTherapy and MR guided HIFU will set the next stage in high-precision tumor therapy**
- **Synergy in development** (motion descriptors, target tracking)
- **MR-LINAC will be the next standard-of-care in RadioTherapy**: Combination with MR-HIFU is promising
- **MR-HIFU offers many complementary features and may be added to the Surgical, RT and Chemo therapies**
- **MR-HIFU may lead to Image Guided ChemoTherapy**
Centre for Image Guided Oncological Interventions (CIGOI)

MR-LINAC
MRI guided brachytherapy
MR-HIFU

HDR robotic brachytherapy

HIFU

MRI linac
MRI with ring gantry (UMCU-Philips-Elekta)
• With MRI we see the GTV and we can follow/track tumours
• The GTV is hard to track with present day radiotherapy
• Tumour infiltrations are relatively well visualized
• MRI can be used to better track the GTV and spare OAR

Conclusion UMCU: MRI guided cancer treatment, seeing what you treat
## Present indications Cancer Therapy

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![Diagram showing CTV and GTV relationships](image-url)
## Development MR-HIFU and MR-LINAC

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Imaging Division, UMCU; Jan Lagendijk, Marco van Vulpen, Bas Raaijmakers, Baudouin Denis de Senneville, Mario Ries, Clemens Bos, Anna Yudina, Wilbert Bartels, Gert Storm, Maurice van den Bosch, Willem Mali et al

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