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

Universitair Medisch Centrum
Utrecht

Chrit Moonen

Disclosures

- Research collaboration with Philips Medical Systems
- Research collaboration with Elekta

MRI guided High Intensity Focused Ultrasound

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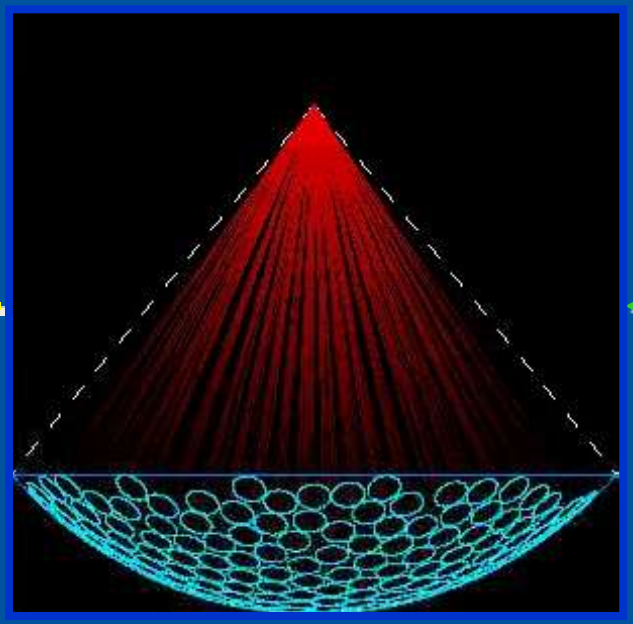
MRI with HIFU

anatomy and temperature mapping

PC

thermo-therapy

position and power control



TRANSDUCER

MRI temperature mapping based on the Proton Resonance Frequency of water

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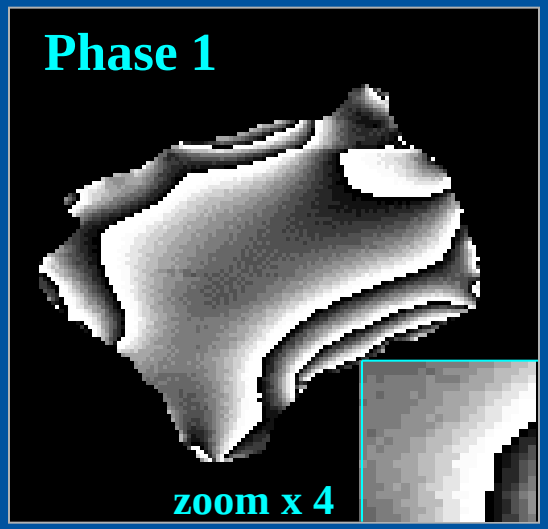
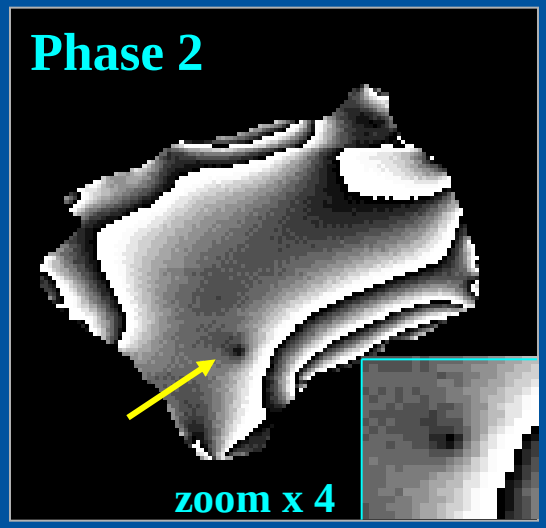
$d\sigma / dT = \beta = 0.01$ ppm/°C ± 5% $\Delta T = - \Delta \varphi / (\beta \cdot \gamma \cdot B_0 \cdot T_E)$

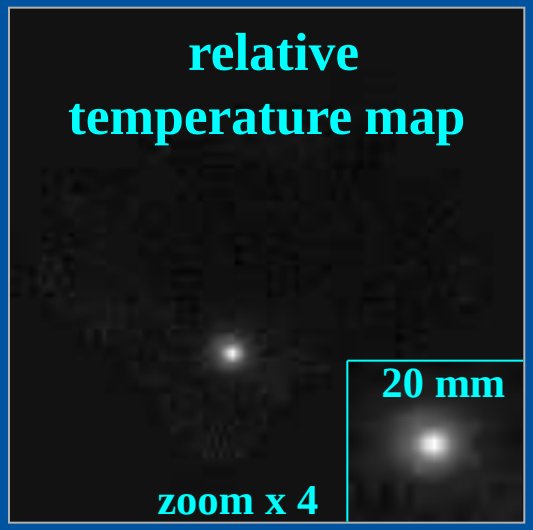
Linear / independant of tissue type (Peters, Henkelman et al, 1996)

RF-spoiled gradient echo





Phase 2 – Phase 1



Rapid temperature mapping in kidney and liver

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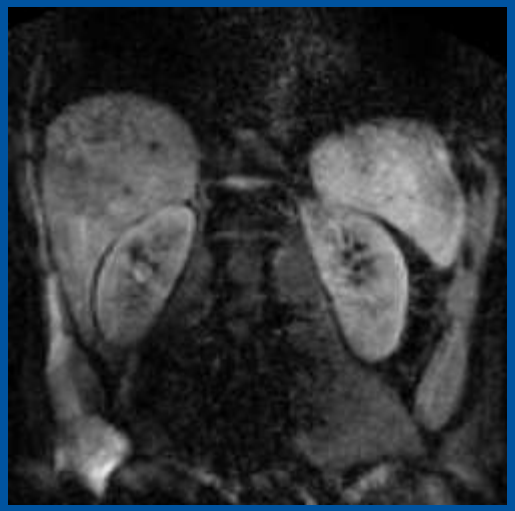
anatomy

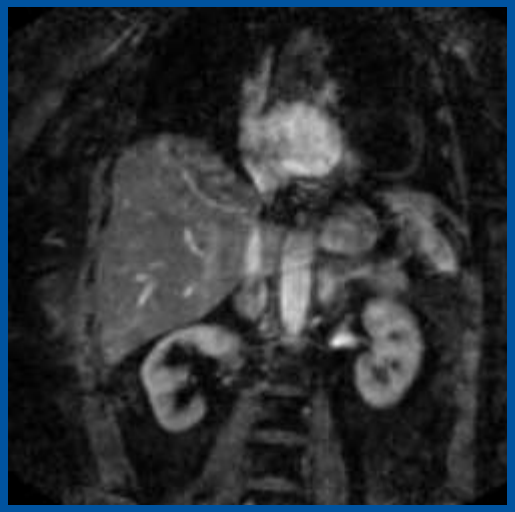
motion correction in pulse sequence only

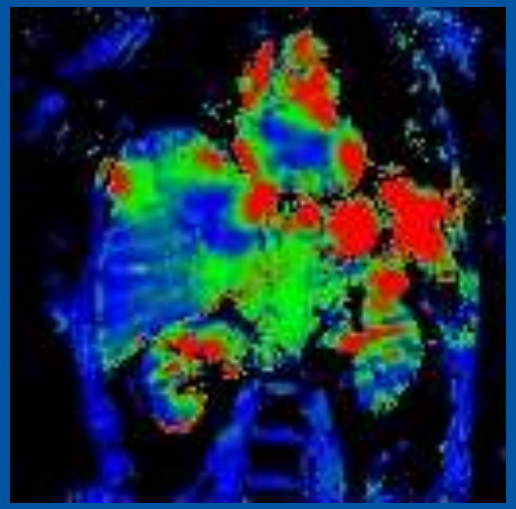
Sequence + Post-processing motion correction

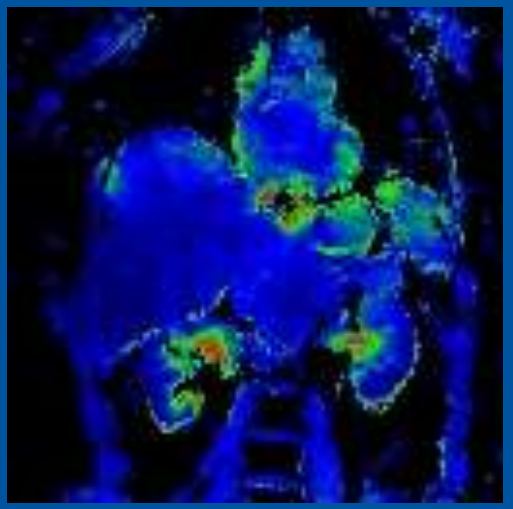
Example 1



Example 2







10°C

0°C

Correction of thermal maps : multi-baseline approach

[ICIP 2004]

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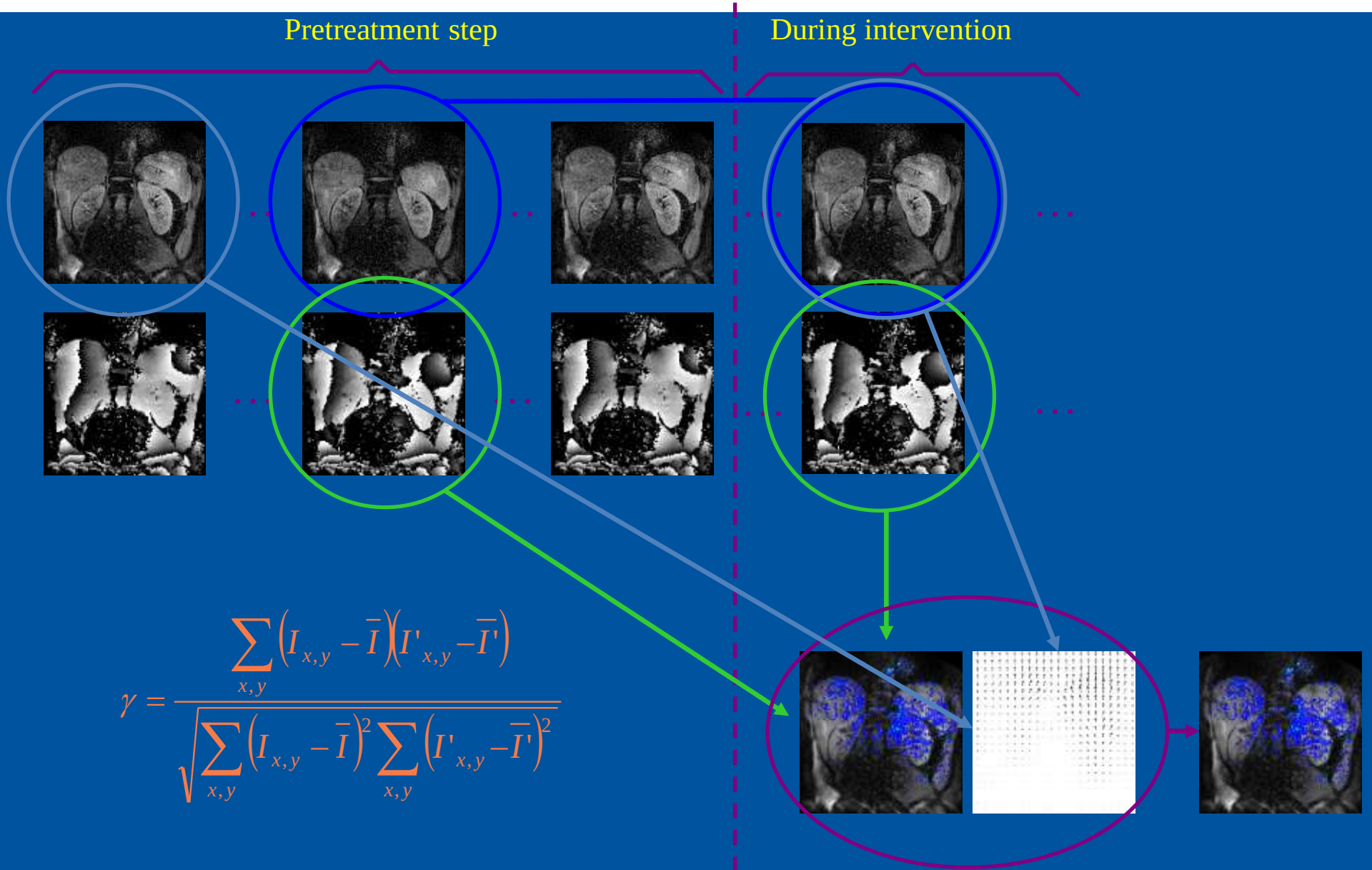

$$\gamma = \frac{\sum_{x,y}\left(I_{x,y}-\bar{I}\right)\left(I'_{x,y}-\bar{I'}\right)}{\sqrt{\sum_{x,y}\left(I_{x,y}-\bar{I}\right)^2\sum_{x,y}\left(I'_{x,y}-\bar{I'}\right)^2}}$$

Precision of MRI temperature mapping in breast tumor

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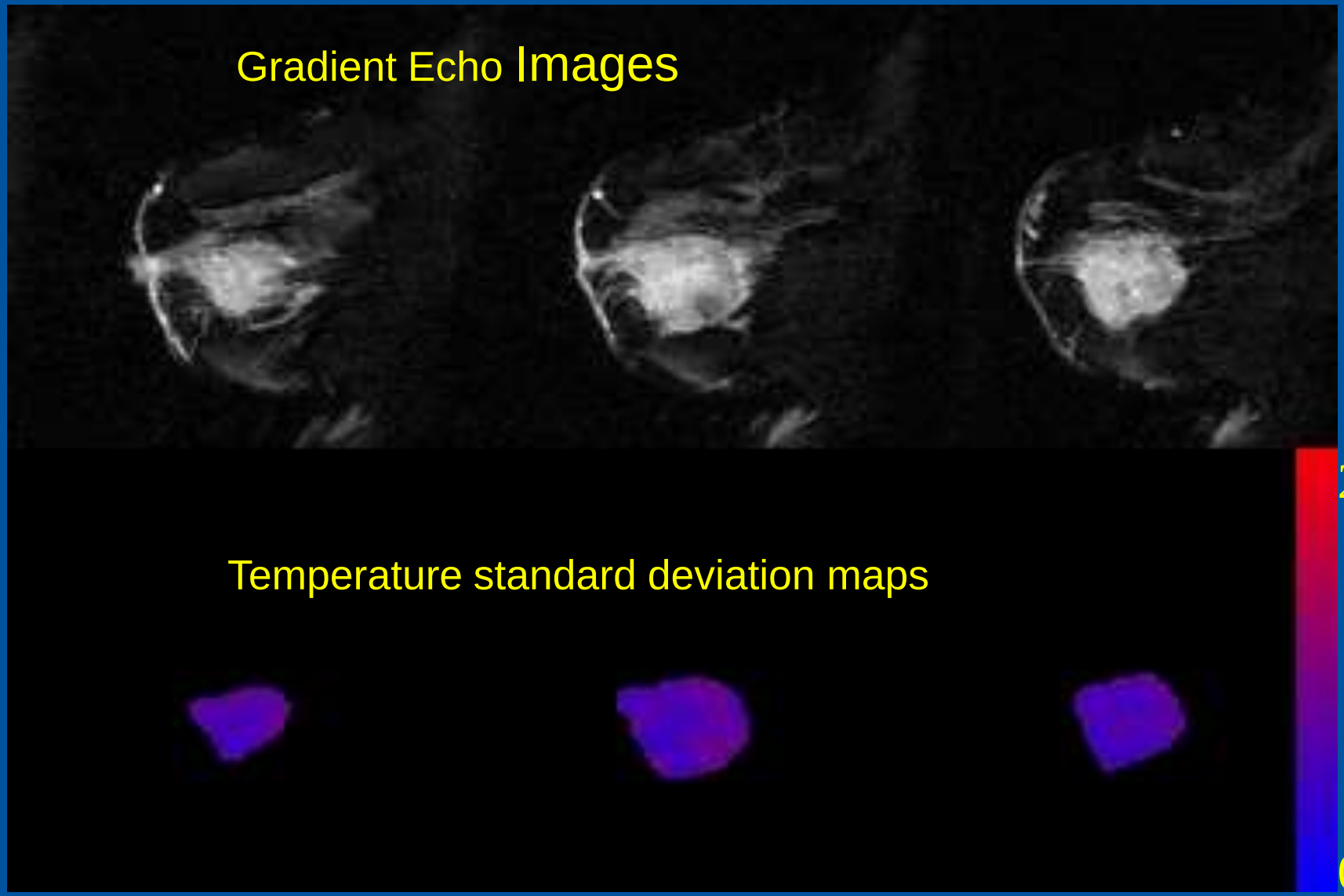

Dedicated breast MR-HIFU system

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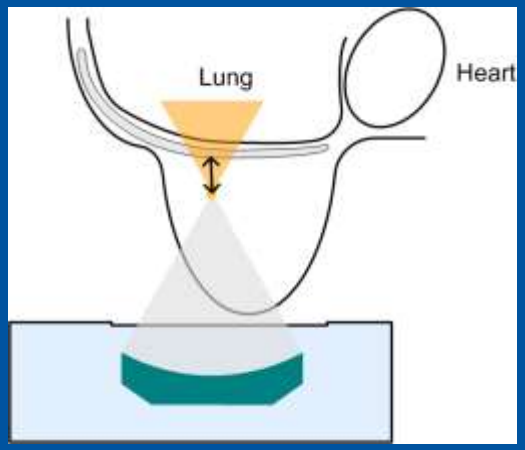
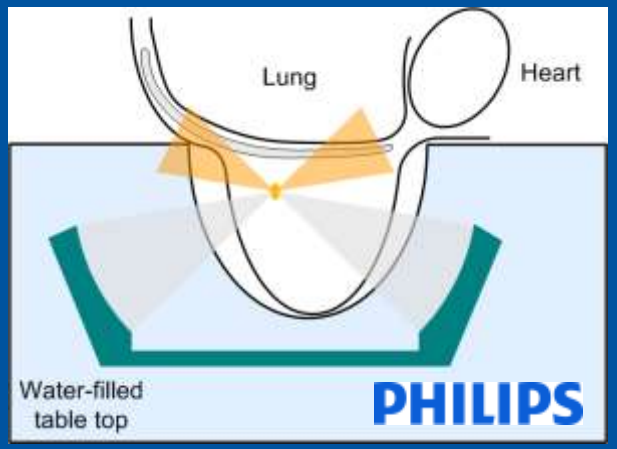
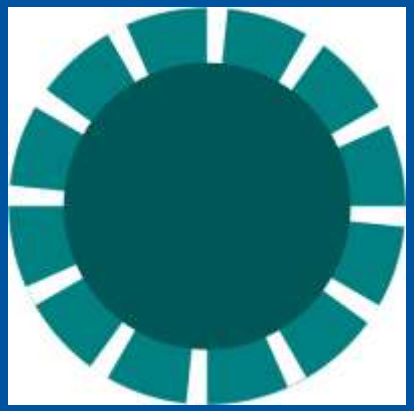
"Conventional" approach



Dedicated system
with lateral sonication





transducer top view

Dedicated breast platform

Sonalleve Breast MR-HIFU

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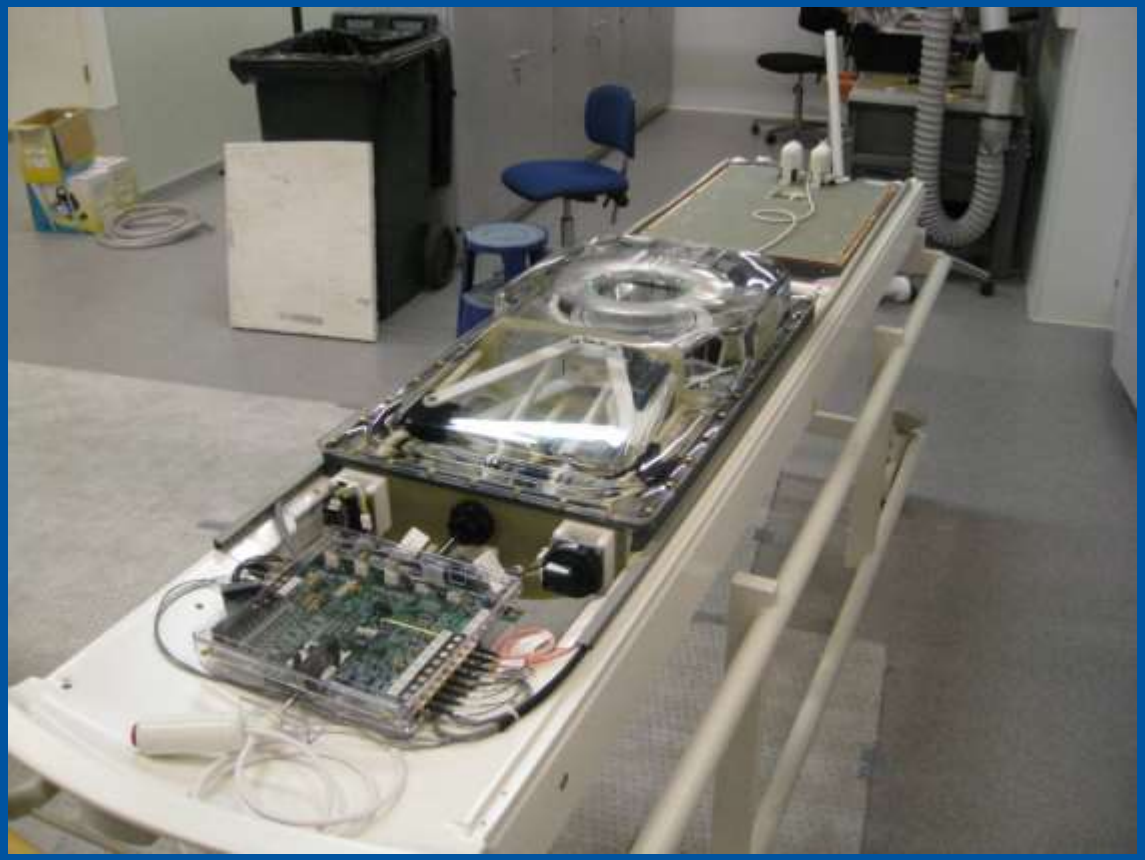

Table top without covers

Water box with transducer and motors

Close-up of breast cup, single-element RF coil, and transducer

Breast tumor 1: MRI planning

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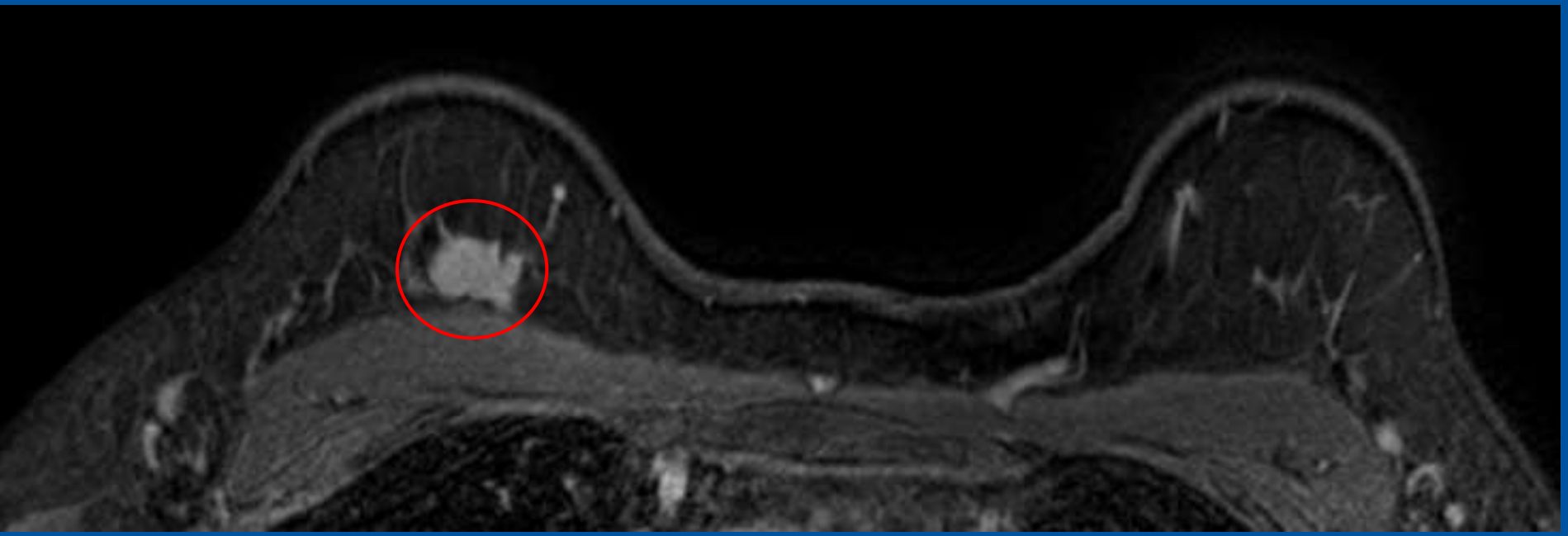

Results: MR-HIFU Breast tumor patient 1
Phase 1 Clinical trial (treat and resect)

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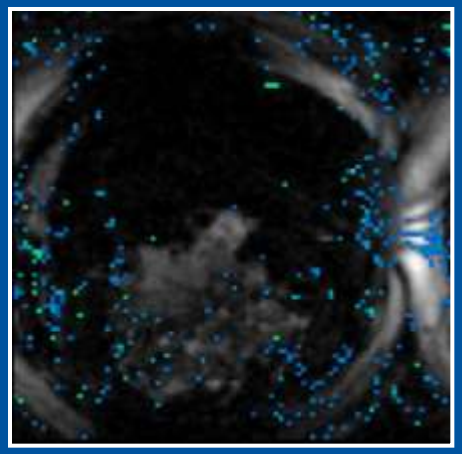
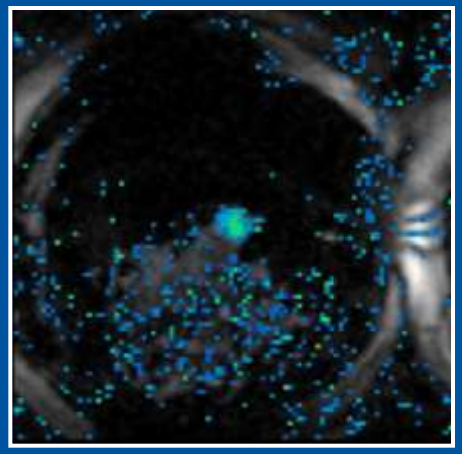
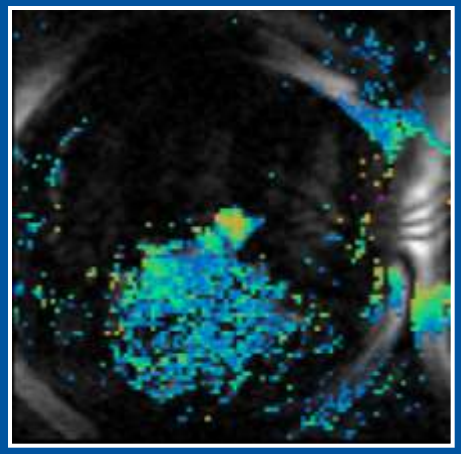
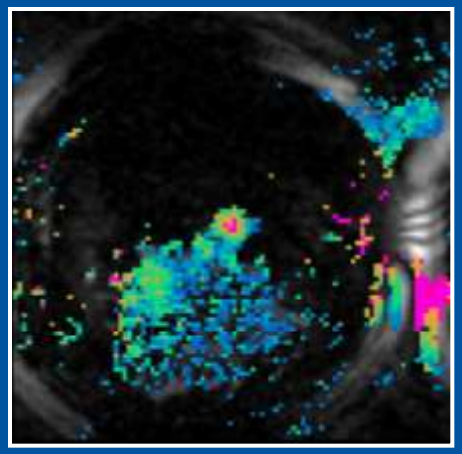

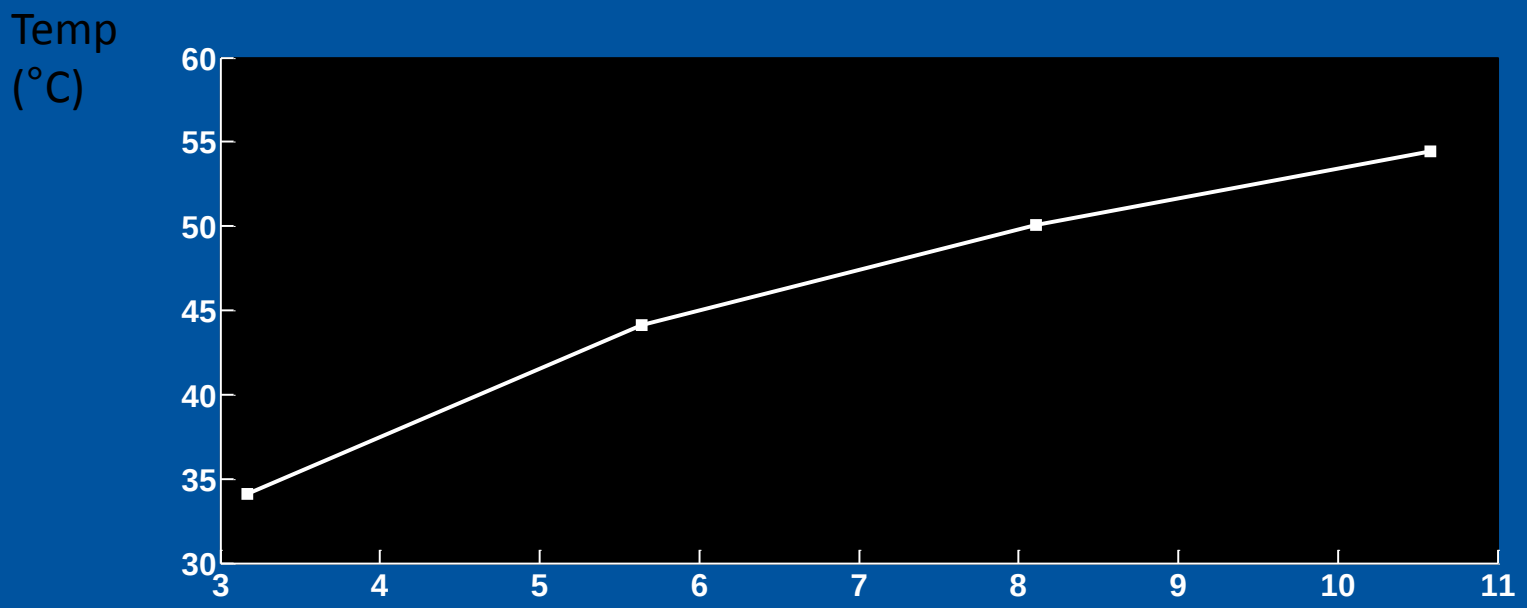

Breast tumor patient 3

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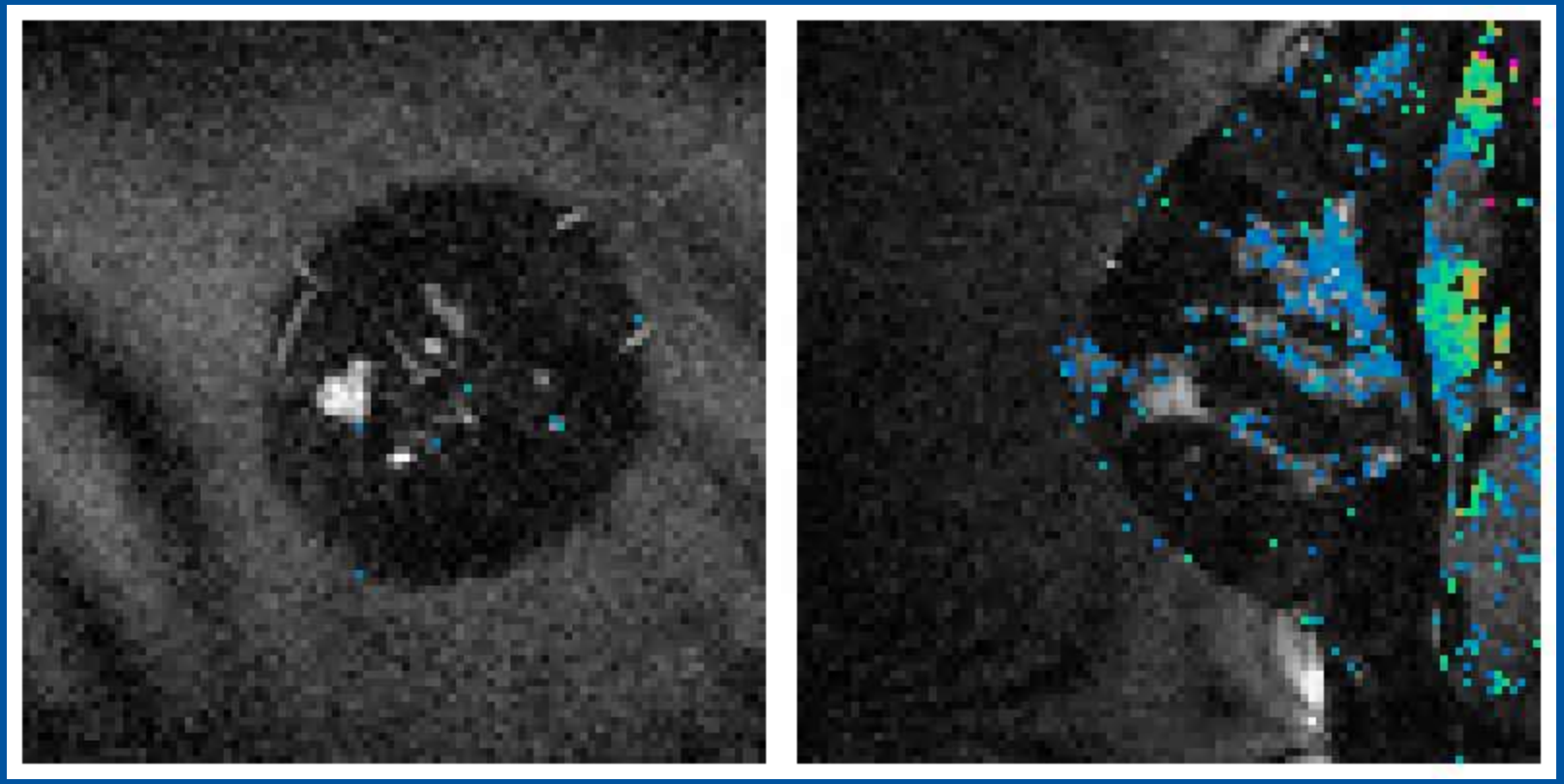

Patient 3: Pathology

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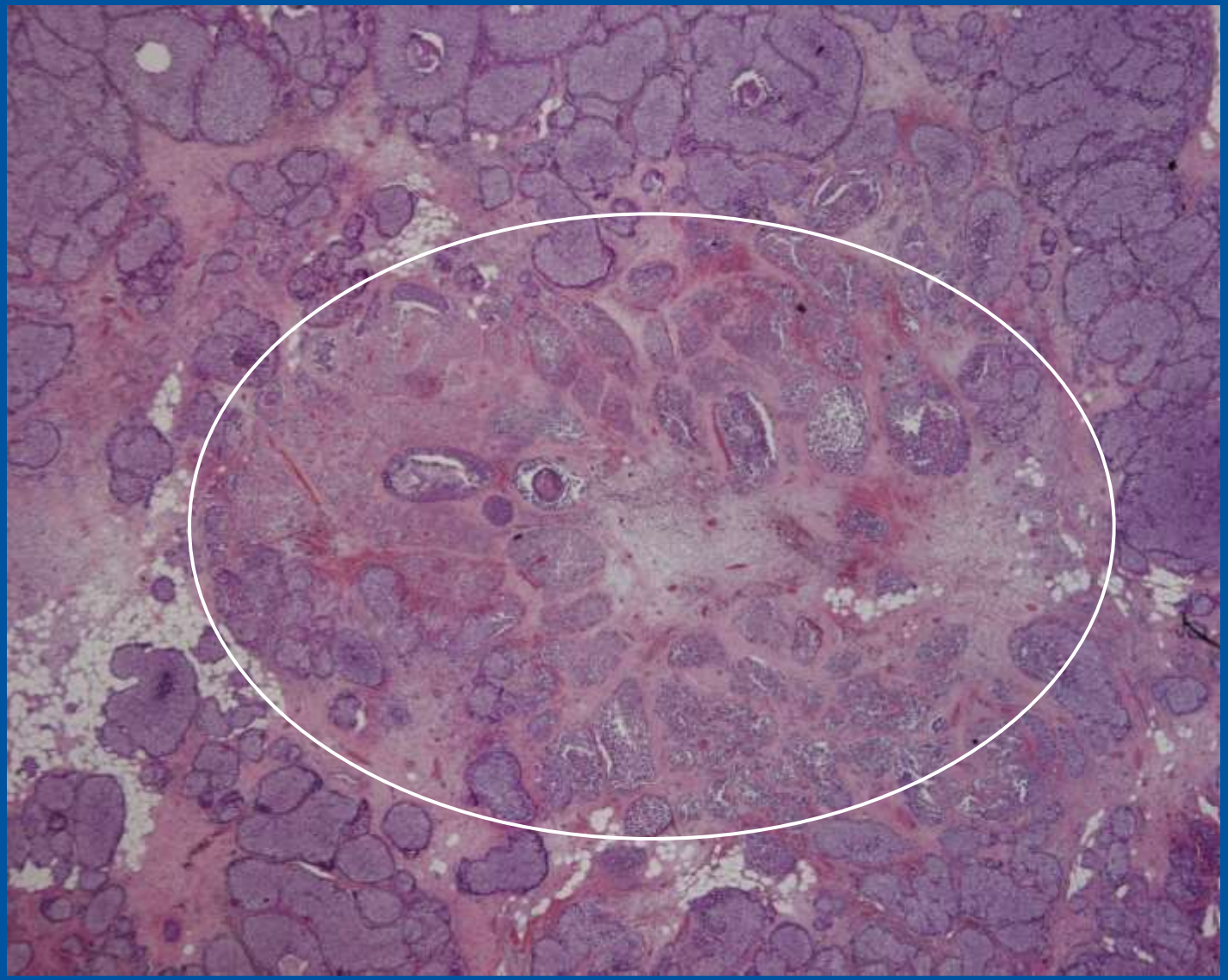

Magnetic Resonance guided HIFU of liver

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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

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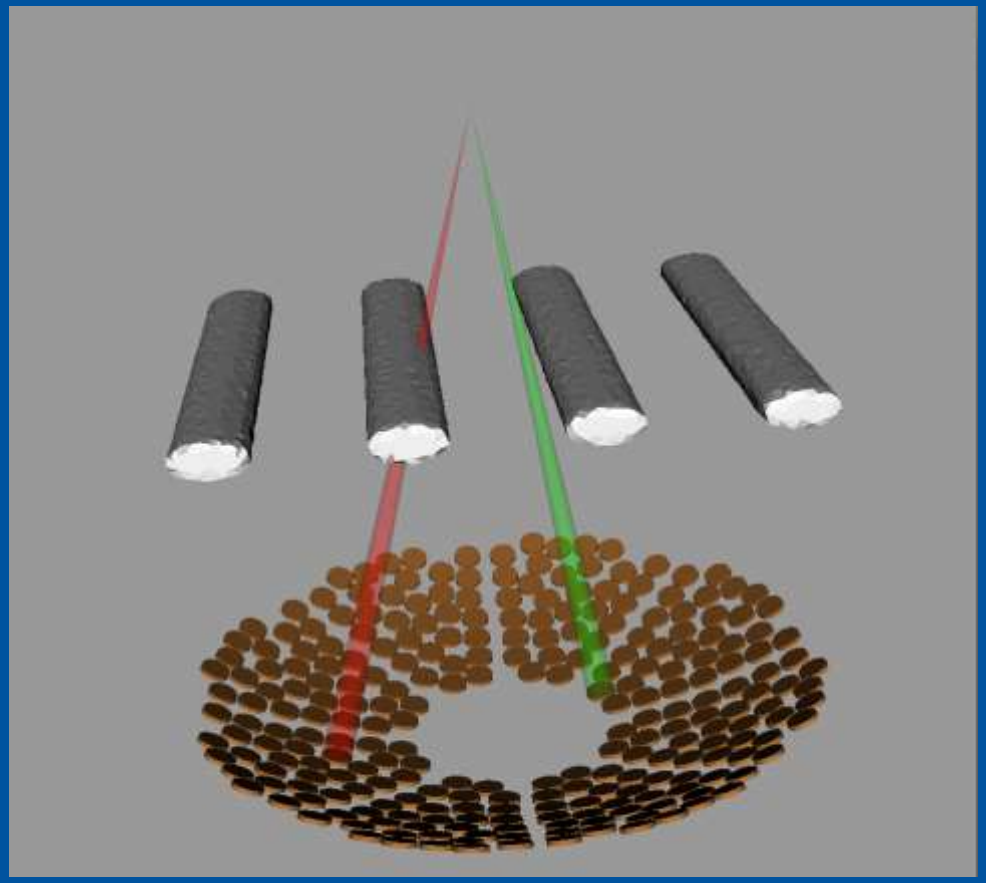


Determine shadowed fraction of area A_s

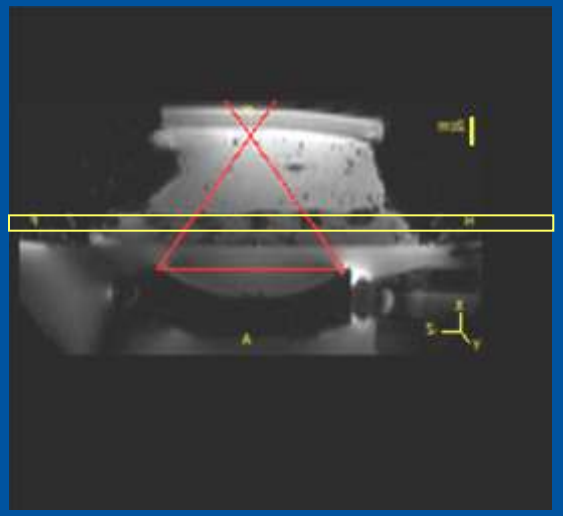
If A_s > threshold:

Switch Element OFF

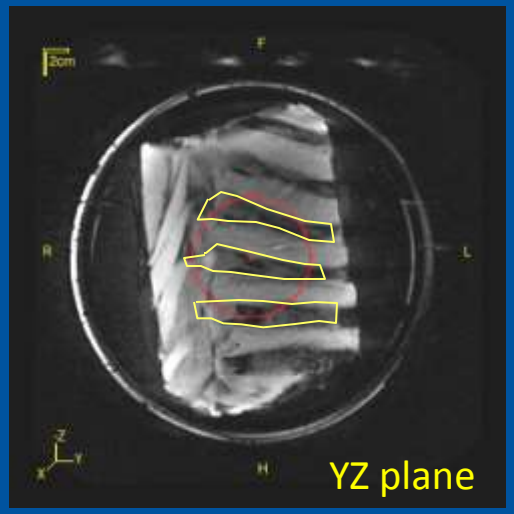
$$P_{elem} \leftarrow P_{elem} \frac{n_{total}}{n_{active}}$$

Intercostal HIFU: Selecting HIFU transducer elements based on beampath

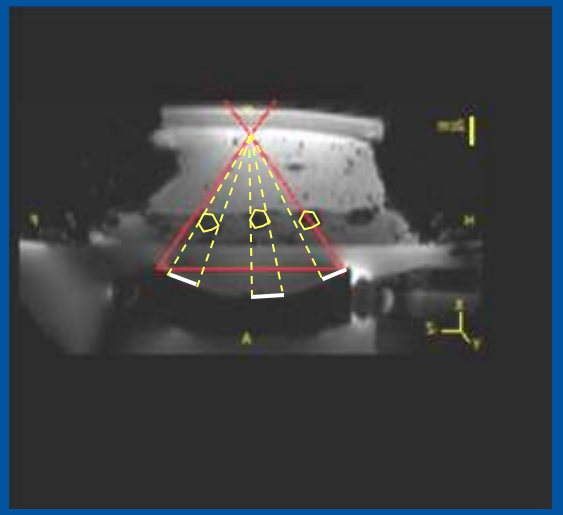
University Medical Center Utrecht



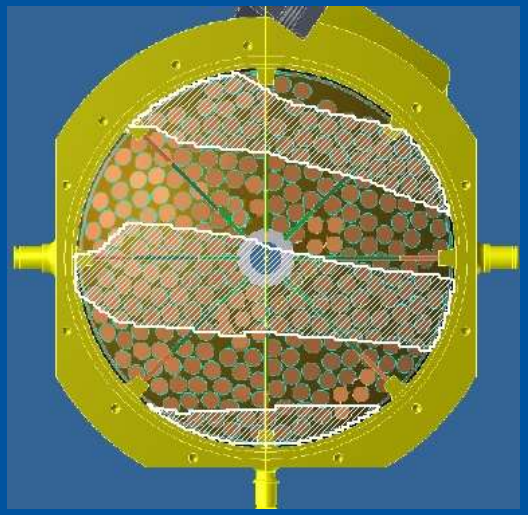
Manual segmentation



projection



Element deactivated if $S_{covered}$ > 50%



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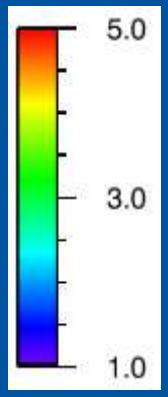
Results

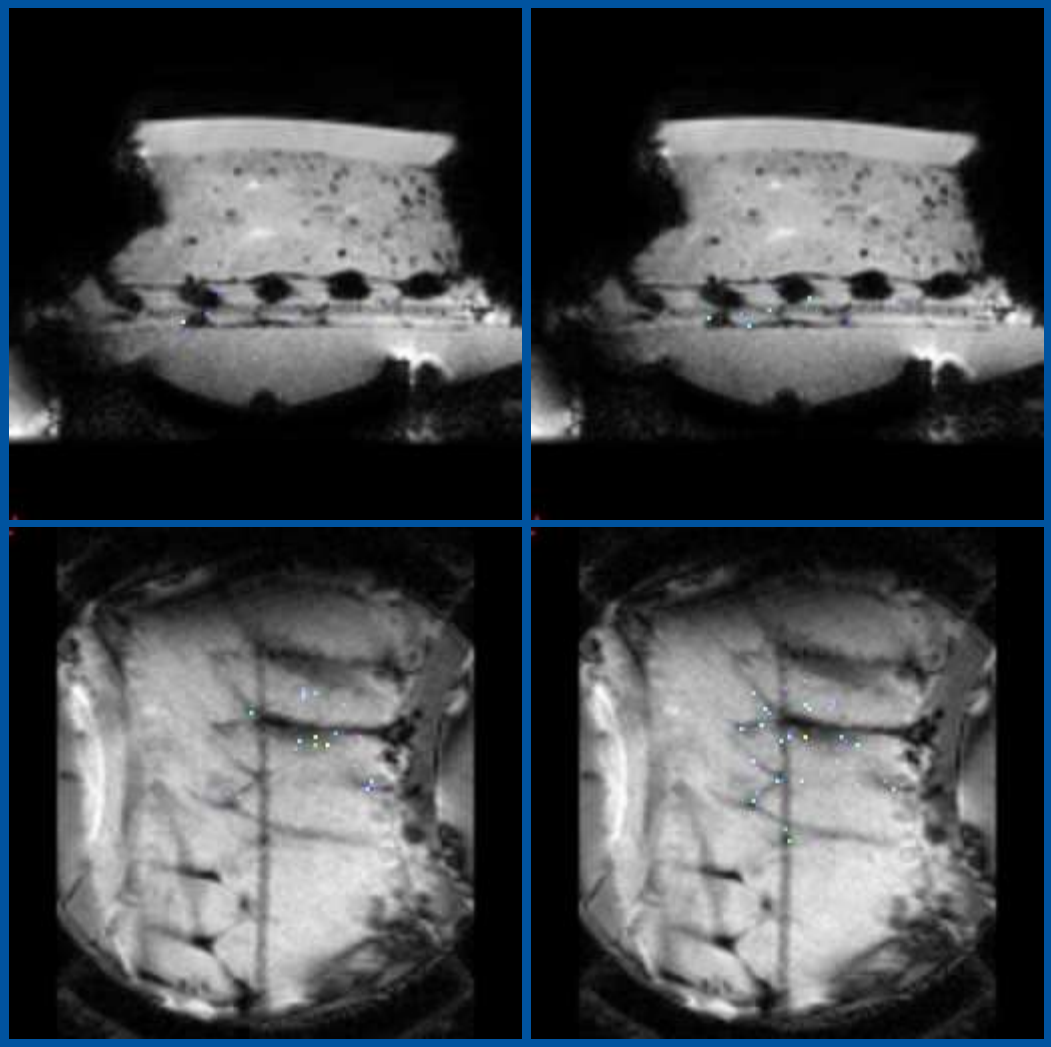
HIFU : Philips Sonalleve platform,
120 Watts, 30 sec

MRI thermometry :
2 orthogonal slices
TE/TR=22/200ms
Vox size =1.5x2.5x6

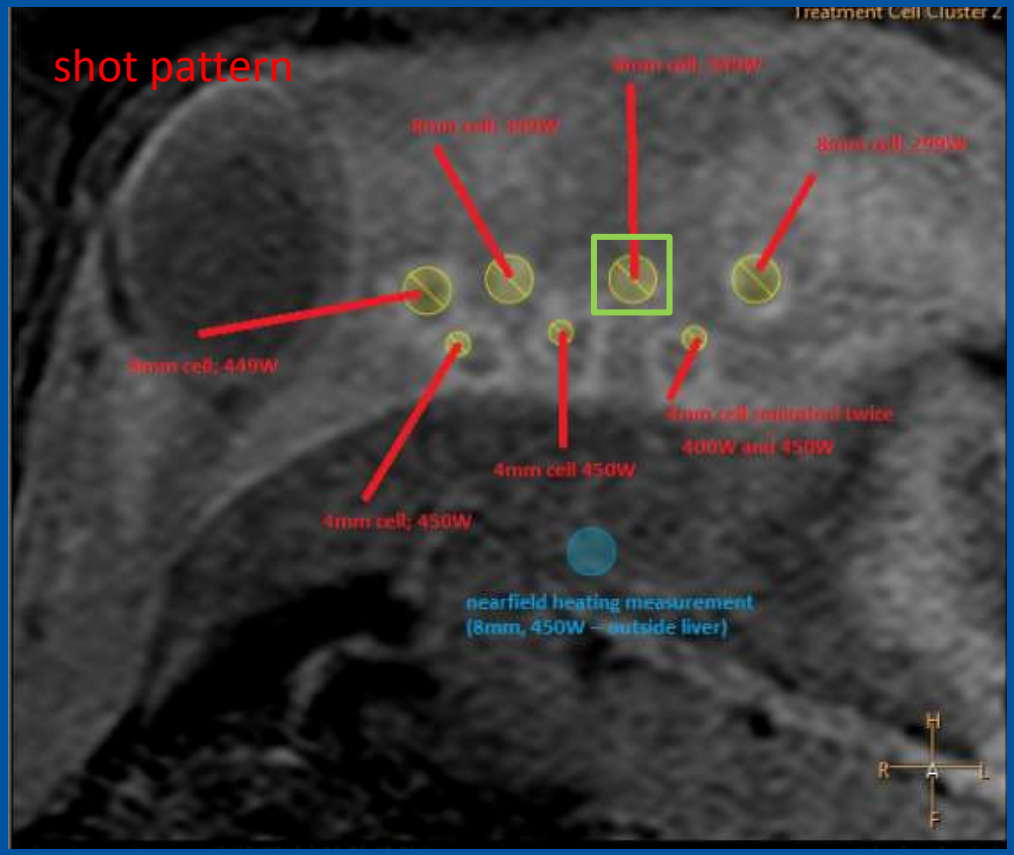


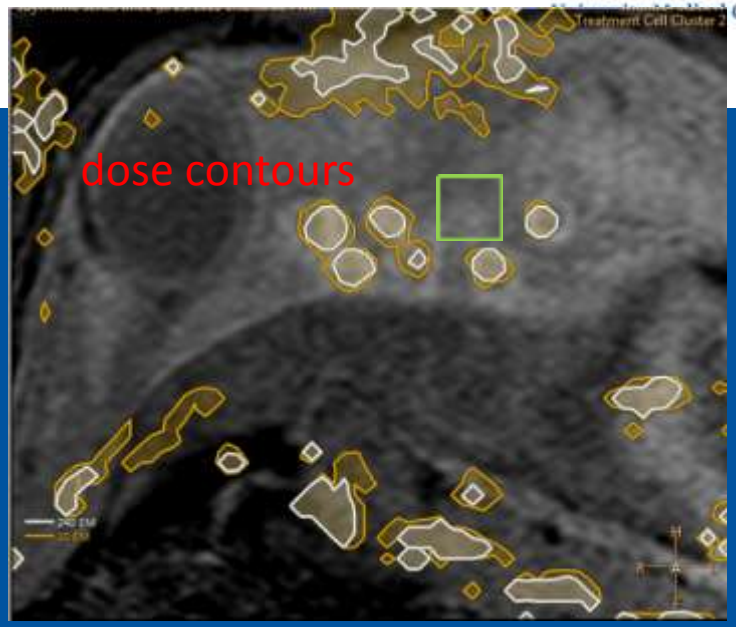
All elements

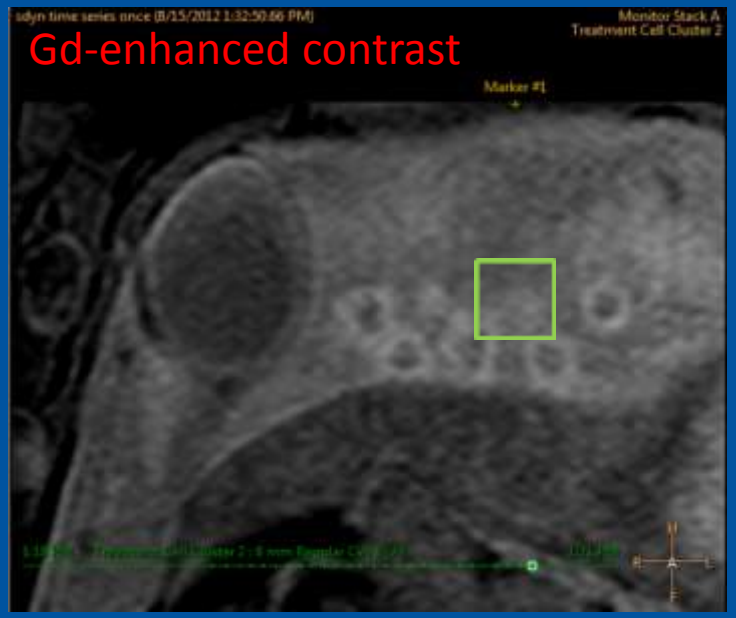
126 elements OFF



Power calibration animal 4







MR-HIFU
Take home messages

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- 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

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- 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

University Medical Center Utrecht

- *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 **I**mage **G**uided **O**ncological **I**nterventions (**CIGOI**)

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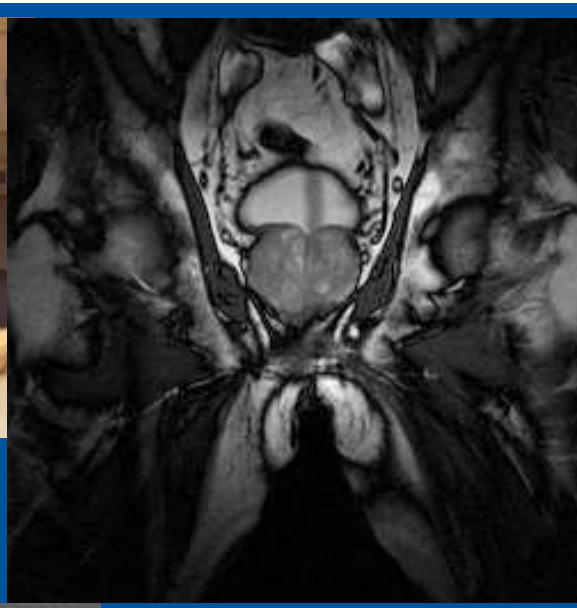
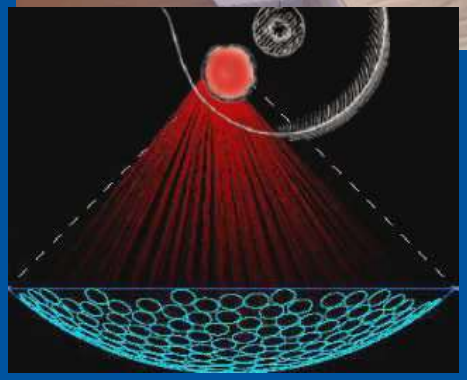
MR-LINAC

MRI guided brachytherapy

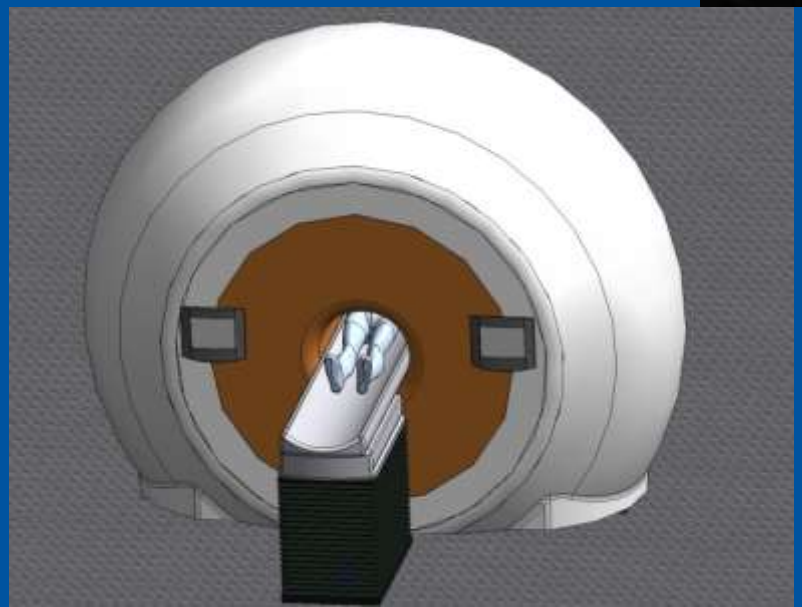
MR-HIFU



HDR robotic brachytherapy



HIFU



MRI linac

MRI with ring gantry (UMCU-Philips-Elekta)

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Vision

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- 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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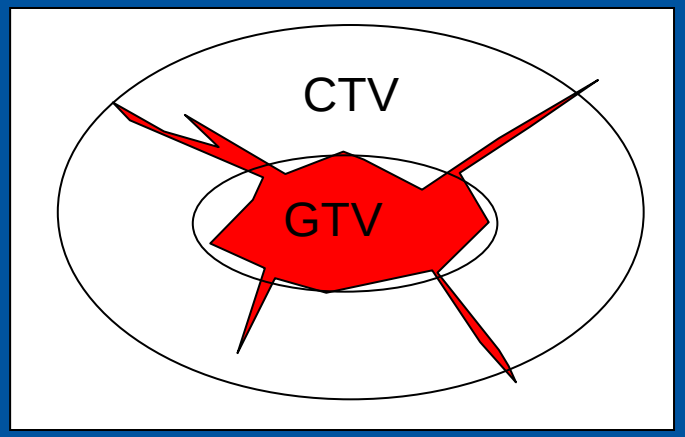
	distant	CTV	GTV
Chemo	+	+	-
RT	-	++	-/+
Surgery	--	-/+	+



Development MR-HIFU and MR-LINAC

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	distant	CTV	GTV
Chemo	+	+	-
RT	-	++	++
Surgery	--	-/+	+
HIFU	-	+	++

MR-LINAC

MR-HIFU

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SONODRUGS

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