Towards Noninvasive Thermal Ablation by MR-guided Focused Ultrasound

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Introduction: Local hyperthermia has been suggested for many purposes, e.g. tumor ablation, control of gene therapy, local drug delivery, heat-activated chemotherapy. Focused ultrasound (FUS) with a wavelength of about 1mm is capable of non-invasively depositing energy in a target area deep within the body. However, FUS energy absorption and heat conduction depend on tissue composition and physiological processes like perfusion. Hence continuous thermometry of the target area is necessary. MRI is an ideal tool for guiding FUS because of its unique temperature mapping capabilities, and its soft tissue contrast for target definition.

Temperature MRI: Temperature MRI can be used for guidance of FUS based on the temperature dependence of T1, diffusion, or the proton resonance frequency (PRF) of water. Here, fast PRF-based temperature mapping methods were employed with lipid suppression, motion artefact suppression and real time data-processing and visualization using a Philips Intera 1.5T MRI. Calculation of temperature maps and visualization of the procedure was performed on a workstation under a rapid communication protocol with the MR system. Motion artifact reduction techniques were used to provided reliable temperature maps even for mobile organs such as liver and kidney.

Focused Ultrasound: Phased-array ultrasound transducers allow rapid electronic steering of the focal spot and proper focusing of the beam even for inhomogeneous tissues. A non-magnetic focused ultrasound transducer was incorporated in the bed of the MR system. MR compatible materials and filtering methods allow simultaneous MRI and high power ultrasound transmission.

Automatic FUS heating with real-time MRI feedback control: Automatic feedback controlled FUS guarantee a predefined temperature trajectory in the FUS focal point. Combined with regional heating based on rapid electronic displacement of the focal point over the volume of interest, temperature control can be realized in the complete heated reagion. This unique spatio-temporal control method leads to increased safety and increased efficacy, and thus to short treatment durations.

Breast cancer, MR compatible, FUS platform: The technologies described above were adapted towards a specific platform for breast cancer therapy. The unique feature of this platform is the FUS transmission avoiding high power US deposition towards lungs. An ellipically shaped FUS transducer with 256 elements was designed with minimized secondary lobe intensity. The patient is lying prone. The transducer is positioned under the patient bed for optimal targeting.

Summary: Specific FUS-MRI methods were designed for cancer treatment. Phased array technologies, sideways FUS transmission, and spatio-temporal temperature control in the complete region of interest, were combined for a novel therapy approach with enhanced safety and afficacy.