Non-invasive thermometry with reference to the practical application in a clinical environment

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During hyperthermia treatments, temperature control inside the target tissue of the patient is absolutely essential. The tumor tissue should be heated and the healthy tissue should be optimally spared from overheating. Besides, hot spots due to boundaries between muscle, fat and bone have to be prevented. Invasive temperature probes as fiber-optic sensors or thermistors (e.g., bowman probes) can be used locally. But always only a local temperature information can be given. Non-invasive measurements are possible superficially with an infrared camera and inside the patient with computer tomography techniques, with the disadvantage of unnecessary dose, or with magnetic resonance (MR) techniques. Different analysis techniques have been reported in literature, such as measurements of proton density, T1 or T2 relaxation time, assignment of temperature sensitive contrast agents, or proton resonance frequency shifts (PRFS).

Currently, the PRFS measurement is the gold standard for non-invasive temperature measurements in the clinical routine. In Erlangen a BSD-2000/3D/MR (BSD Medical Corporation, Salt Lake City, Utah, USA) combined with a Magnetom Symphony 1.5T MRI scanner (Siemens, Erlangen, Germany) is used for the hyperthermia treatment combined with the MR thermometry. The PRFS method needs a start image for the calculation of changes in temperature. The start image at t_0 is calculated as difference between two successive MR sequences. Every ten minutes (at t_i) during the hyperthermia treatment new 3D MR images are measured. The phase shift between two different time steps can be used to determine the in- or decreasing of temperature in each voxel of measured 3D MR images. Silicon oil tubes, implemented inside the hyperthermia applicator, are used for the drift correction of magnetic field inhomogeneities.

Hyperthermia treatments result in very promising 3D temperature distributions with the PRFS method, particularly in treatments of upper leg sarcomas. Also the thermometry of pelvic tumors is possible with this method. But artefacts due to involuntary patient movement and motion of internal organs can lead to spatial mismatch between the reference voxel at t_0 and the same voxel at t_i ($t_0 < t_i < 2h$). In addition, changes in blood flow, a normal effect in hyperthermia, can generate artefacts. Already the start image can include artefacts. Pancreatic tumor treatments can be evaluated with the PRFS method as well, but unfortunately breathing artefacts complicate the temperature analysis extremely.

Missing reference temperature in the region of interest for absolute calibration, motion and field inhomogeneities during a measurement are thus the main disadvantages of the PRFS method. Alternative absolute temperature measurement techniques are investigated for these reasons. Respiratory triggering could be one possibility against the breathing artefacts, but with the drawback of measurement time extension. Registration of the 3D MR images of different time steps could be another optimization to reduce artefacts. Also the MR spectroscopy technique is a possible alternative. The frequency spectrum is evaluated with respect to the position difference of water and fat peak in one investigated voxel. Inhomogeneities in the magnetic field do not influence the difference of these two peaks, since both peaks are equally affected. Since almost only the resonant frequency of water is temperature dependent, the peak difference yields the absolute temperature if a calibration is established.

The contribution will provide an overview of the techniques with an emphasis on PRFS and MR spectroscopy.