

# MR Safety: Fast T1 Thermometry of the RF-Induced Heating of Medical Devices

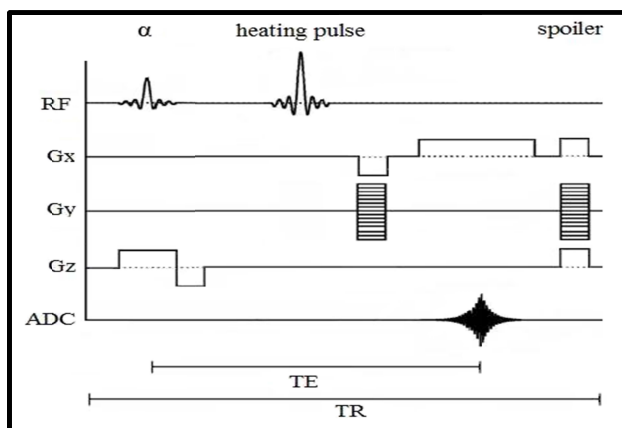
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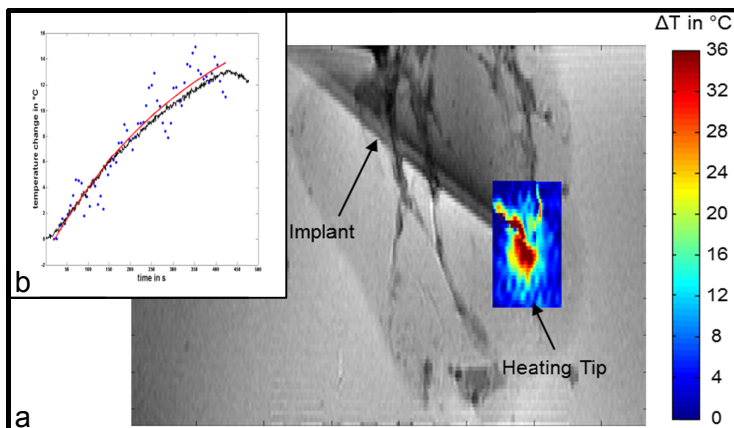
**Introduction:** Determining the MR compatibility of medical implants and devices is becoming increasingly relevant. In vitro, the heating of conductive implants due to radiofrequency (RF) excitation pulses is often measured by fluoroptic temperature sensors. A major drawback of these probes is that they can only measure the temperature at a single point [1]. Another common method to determine heating effects is MR-thermometry using the proton resonance frequency shift (PRFS). This method gives good results in homogeneous phantoms. However, in several cases the inhomogeneity of organic tissue and the susceptibility changes near an implant prohibits PRFS thermometry in in-vivo studies [2]. The intention of this work was to develop a fast T1-based method which allows controlled MR-related heating of a medical implant while simultaneously quantifying the spatial and temporal temperature distribution. For this purpose an Inversion Recovery sequence was implemented where the RF heating is caused by the MRI sequence itself. With this method a controlled dynamic heating of an implant is expected to be measurable even in inhomogeneous organic tissue. Therefore, it might be not only applicable for validation and in vitro studies, but particularly promising for in vivo temperature monitoring, e.g. during MR-guided interventions in the future.

**Materials and Methods:** All measurements were performed on a 1.5 T whole-body imaging system (Magnetom Avanto, Siemens). For signal detection a 6-channel surface coil was used. After initial investigations in homogeneous phantoms, measurements were transferred to organic tissue. For this purpose a piece of pork muscle in an acrylic glass box, filled with hydroxyethyl cellulose gel, was examined. For a dynamic heating experiment a 20 cm titanium biopsy needle was used as implant. To determine the MRI-induced heating a fluoroptic temperature sensor was used as reference. For temperature imaging a modified inversion recovery snapshot FLASH (IRSf) sequence with off-resonant high power heating pulses was implemented. Each TR cycle included one off-resonant heating pulse [3] (see Figure 1). By adjusting the power of the off-resonance pulses, the average RF power and thus the specific absorption rate (SAR) could be chosen. As an example for a dynamic heating experiment, the implant was measured with the implemented IRSf sequence for about 7 minutes. Using the T1-acceleration method presented by Arnold et al. [4] and a sliding window technique, a new T1-map could be generated every 6.4 s. This resulted in 66 temperature maps and one reference T1-map. The sequence parameters were as follows: field of view = 260 x 130 mm<sup>2</sup>, resolution: 128 x 72, TR = 5.55 ms, TE = 3.18 ms, FA = 8°, segments = 3, Nr of images with different TI = 24, slice thickness = 5 mm, TA = 443 s, BW = 300 Hz/pixel, NEX = 1, repetitions = 23. The flipangle of the heating pulses was set to 107°, which amounted to a power of P = 100.0 W. The temperature images were computed by subtracting the T1-maps from the reference T1-map (first T1-map), acquired before heating the implant. This allowed the dynamic quantification of a defined temperature change.

**Results:** Figure 2a shows, as an example of a dynamic measurement, an overlay of a temperature map after about 7 minutes heating on a localizer image (FLASH, field of view = 300 x 170 mm<sup>2</sup>, resolution: 384 x 192, TR = 150 ms, TE = 5 ms, FA = 25°). The heating at the tip of the implant can be clearly seen. The obtained temperature values were validated with a fluoroptic temperature sensor. In Figure 2b the temperature change versus time from the fluoroptic temperature sensor (black line) and the MR-thermometry data (blue dots) are demonstrated. The MRI-data were taken from the single voxel corresponding to the position of the fluoroptic probe. The MRI-data show excellent agreement with the data from the fluoroptic probe with a standard deviation of the obtained MR-thermometry data of 1.37 °C to the fitted curve.



**Fig. 1** Pulse sequence schematic of one TR-cycle. After the excitation pulse  $\alpha$ , an off-resonant heating pulse is applied. The heating pulses are also applied during the intermediate delay time between the last snapshot FLASH image and the next inversion pulse. With the power of the heating pulses, the average power and thus the specific absorption rate (SAR) can be varied.



**Fig. 2a)** Overlay of a temperature map after 7 minutes heating on a localizer image. Only the relevant part of the implant is covered by the temperature map. The heating at the implant tip can be clearly seen. **2b)** Temperature change versus time at the position of the fluoroptic sensor. Fluoroptic data (black line) and MRI-data (blue dots) show excellent agreement. The red curve illustrates an exponential fit to the MRI-data.

**Discussion and Conclusion:** The presented T1-based temperature quantification allows measuring the dynamic, RF-induced heating of an implant with high spatial and temporal resolution. This is the major advantage in comparison to a single point measurement, e.g. with a fluoroptic probe. More important, these experiments demonstrate that this method is capable of spatially quantifying temperature changes in organic tissue. Hence it is possible to analyze the spatial temperature distribution of an implant in organic tissue by a single measurement, or even get a spatially resolved temperature time course. As shown, the obtained temperature values show excellent agreement with the data from the fluoroptic probe. Certainly, a drawback of the presented technique is that there are implicit demands on the implants under investigation. In general, implants cannot be tested with the proposed method if susceptibility artifacts proscribe temperature quantification near the measured device. On the other hand, using the presented method susceptibility differences, e.g. between the heart and lung or in presence of implants, are far less disturbing as compared to PRFS-techniques which can be used as an alternative. In conclusion the presented technique provides the opportunity to spatially and temporally quantify the RF-induced heating during an MRI examination in presence of medical devices or implants. Moreover, the results from the presented investigations proof its applicability in organic tissue. Hence, the technique provides a powerful tool for noninvasive MRI safety measurements. As the proposed method has been shown to be applicable also in inhomogeneous organic tissue, it is promising for quantifying heating effects also in in-vivo situations such as for surveillance purposes during interventional MR procedures.

## References:

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