T1-Based MR Thermometry Close to Metal

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Introduction

Currently there is no technique available for MR thermometry near metal implants or surgical clips. Commonly used gradient-recalled echo (GRE) based techniques such as mapping of the proton resonance frequency (PRF) shift [1] fail due to the strong signal dephasing and loss introduced by the associated field inhomogeneities (Fig. 1a). In this work, we propose MR thermometry near metal based on a multispectral imaging (MSI) approach and by exploiting the temperature dependence of the T1 relaxation time [2]. Initial feasibility is demonstrated in phantom experiments.

Methods

Pulse sequence: For inversion recovery (IR) T1 mapping, the recently proposed single-shot 2DMSI technique [3] was extended with a dedicated spatially selective inversion pulse matched to the excitation. 2DMSI enables fast artifact-reduced imaging near metal by reversing the selection gradient between excitation and refocusing pulses, resulting in the excitation of finite spectral and spatial regions, called bins, which can be imaged with minimal artifact and combined to build up the full image.

Data Acquisition: All data acquisition was performed on a 3T whole body MRI system equipped with an 8 channel receiver coil and with a phantom containing a total shoulder replacement with a titanium shaft embedded in doped agar gel. For each T1 map, a series of six IR-2DMSI images with varying IR time was acquired (TR/TE/TI: 2000/32 /50 - 1600 ms; FOV: 240 x 280 mm; slice thickness: 3 mm; matrix: 128 x 54 (half-Fourier and no parallel imaging); 12 bins, covering an excitation bandwidth of +/-5.4 kHz; duration per T1 map: ~4 min). A temperature gradient through the phantom was achieved by positioning a pillow heated by hot water on one side of the phantom. During a heating period of about 180 min, data for a total of 29 T1 maps was acquired. A fluoroptic temperature sensor with a precision of 0.1°C located both within the imaged slice and close to the metal implant monitored the temperature increase in the phantom.

Data Analysis: For each T1 map, fitting of the magnitude data was performed on a bin-by-bin basis using a three-parameter model also considering flip-angle imperfections [4]. To improve SNR for fitting, the data was smoothed with a 3x3 kernel in image space. The final T1 map was composed from the individual bin T1 maps with the local T1 value provided by the bin with maximum local image intensity.

Results

Figure 1b shows one of the IR-2DMSI images, demonstrating the capability of the 2DMSI technique for artifact-reduced imaging close to metal. The ROI (white box) marks the location of the temperature sensor. Figure 2 depicts the measured signal variation over TI for a voxel located within the ROI and the resulting fit. Figure 3 demonstrates the composition of the final T1 map from the individual bin T1 maps. Figure 4 shows the resulting change in T1 over the entire experiment for selected time points. The T1 increase starts from the side facing the heating pillow (top) and eventually spreads over the entire phantom. Figure 5 presents the resulting change of the average T1 within the ROI for all 29 experiments over the temperature provided by the temperature sensor. The T1 variation (standard deviation) within the ROI corresponds to about 2% of the baseline ROI T1 value. The uncertainty range of the temperature measurement of up to 0.8°C results from the ongoing heating during data acquisition. Assuming a linear increase of T1 over temperature [5], the results would support a temperature dependence of about 0.4%/°C. Within the GRE image (Fig. 1), there is negligible signal at the position of the ROI.

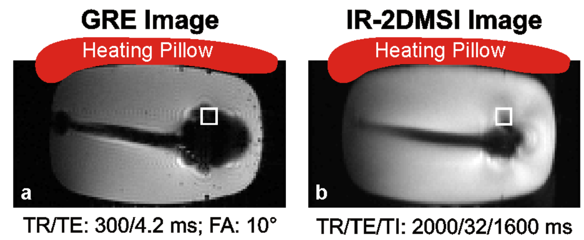

Fig. 1: GRE image (**a**) and IR-2DMSI image (**b**) of the phantom containing the metal shoulder replacement. The red shape marks the position of the heating pillow and the white box indicates the ROI placed around the temperature sensor.

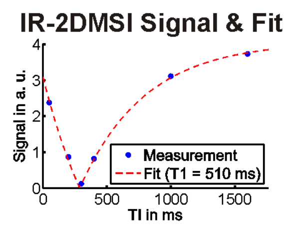

Fig. 2: Measured IR-2DMSI signal over TI for a voxel in the ROI and resulting fit.

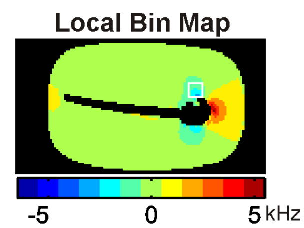

Fig. 3: Local bin map, showing the contribution of the individual bin T1 maps to the final T1 map.

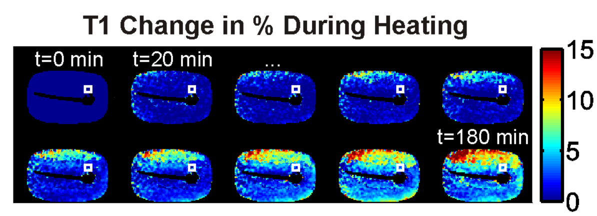

Fig. 4: Measured change in T1 during heating of the phantom for selected time steps corresponding to an interval of about 20 min. T1 increases with ongoing heating and the increase is strongest close to the heating pillow.

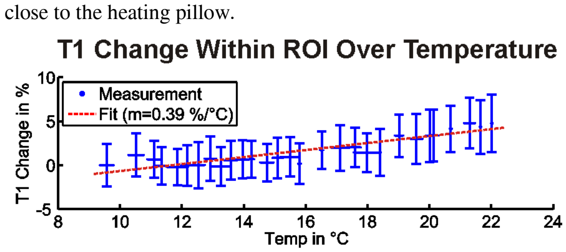

Fig. 5: Average change in T1 within the ROI located close to the metal implant plotted over the temperature provided by the temperature sensor. The fit assumes a linear increase over temperature and yields a dependency of 0.39 %/°C.

Discussion

This work shows the feasibility of MR thermometry close to metal and thus in regions where conventional methods such as PRF shift mapping fail. The underlying 2DMSI technique provides the basis for artifact-reduced imaging while maintaining acceptable acquisitions times. Although the current temporal resolution of about 4 min is still long, it might be further reduced by optimizing the number of bins and/or the number of TI measurements. The full IR measurement applied in this work is beneficial as it also takes into account the temperature dependency of the equilibrium signal. However, “reusing” the long TI measurements or using a proton-density-weighted signal are possibilities to accelerate acquisition. Although SNR is still a challenge and further improvements are required in order to also allow for the measurement of small temperature changes, the proposed MR thermometry technique is promising for monitoring larger temperature changes.

References [1] Rieke & Butts, JMRI 2008, 27:376; [2] Gensler et al., MRM 2012, 68:1593; [3] Hargreaves et al., Proc. ISMRM 2014, #615; [4] Barral et al., MRM 2010, 64:1057; [5] Nelson & Tung, JMRI 1987, 5:189;

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