MR Temperature Measurements of Activities Outside the Magnet Using Image Registration and a Fixation Device

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Introduction

MR temperature measurements can be used to monitor thermal therapies such as laser interstitial thermal therapies (LITT), high intensity focused ultrasound (HIFU), or cryoablation. Existing MR temperature mapping techniques utilize the variation of a temperature-sensitive MR parameter such as the relaxation time T1, the diffusion constant *D*, or the proton resonance frequency ν (PRF). Unfortunately, all of these techniques can only assess temperature differences, because the temperature-sensitive MR parameters are also susceptible to a large variety of tissue-dependent factors. Thus, MR temperature measurements require at least two measurements to assess the temperature-induced parameter change. During the measurements all other experimental parameters need to be kept constant. This can be difficult, in particular for the widely used PRF temperature mapping method where the temperature information is extracted from a phase difference map. The local image phase is very sensitive to MR system instabilities and patient motion. Different correction techniques such as background phase subtraction need to be used to acquire meaningful temperature maps.

Fig. 1: Cooled leg after 30 min of thermal stimulation with a knee cuff.

Recently, temperature changes of up to 10 K have been measured invasively in the knee during sports activities such as skiing or running [1]. In this pilot study we propose a setup to assess temperature changes in the human knee with the PRF method. Since most physical exercises cannot be performed within the MR system, PRF data need to be acquired before and after exercise in exactly the same position within the MR system. To compensate for system instabilities as well as final alignment errors, three-dimensional PRF data are sampled, which are finally co-registered using linear shift model.

Materials and Methods

The PRF measurements were performed on a clinical 3 T MR system (Magnetom Tim Trio, Siemens, Erlangen) using the system's 8-element Tx/Rx knee coil. To provide a reproducible patient positioning, a wooden holder was constructed that fits precisely into the patient table top. The knee coil was screwed to the holder, which was additionally equipped with two U-shaped stands. For the pilot study a gypsum fixation (splint) was molded individually to the lower leg and knee of a volunteer. The fixation was screwed to the stands so that the knee was centered in the imaging coil. The upper part of the fixation was left open so that the volunteer could leave the MR system after acquisition of the reference temperature data set. For exact repositioning, marks were drawn on leg and fixation device.

PRF data were acquired before and after thermal stimulation using a 3D FLASH pulse sequence with the following parameters: TR = 21 ms, TE = 10 ms, $\alpha = 15°$, matrix = $186\times256\times64$, 15% partition oversampling, TA = 4 min 43 s, isotropic spatial resolution: 1 mm. After the initial reference PRF measurement the volunteer left the MR system, and the anterior part of the knee was cooled for 30 min using a commercial knee cryo cuff (AirCast, Vista, CA) filled with iced water. Then the volunteer was again positioned in the fixation device after careful alignment of leg and marks. Three-dimensional PRF data were acquired immediately after cooling and 10 min later.

For phase subtraction the complex image data were automatically aligned using a program implemented in IDL. Assuming that only linear shifts need to be corrected, the position difference was calculated in the Fourier domain using phase-only cross correlation, and the images were then shifted with sub-pixel precision by multiplying a linear phase.

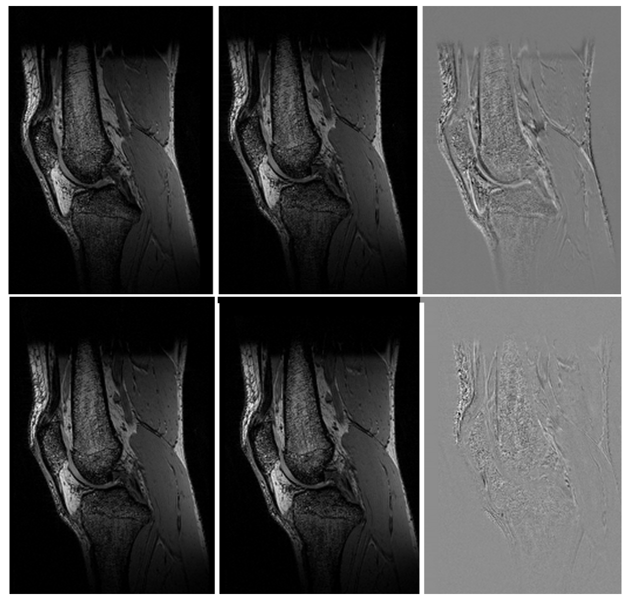

Fig. 2: Top: Reference (left) and first post-stimulation (right) 3D FLASH knee image together with the magnitude difference after image alignment. Bottom: For comparison the first and second post-stimulation data are shown without moving the volunteer.

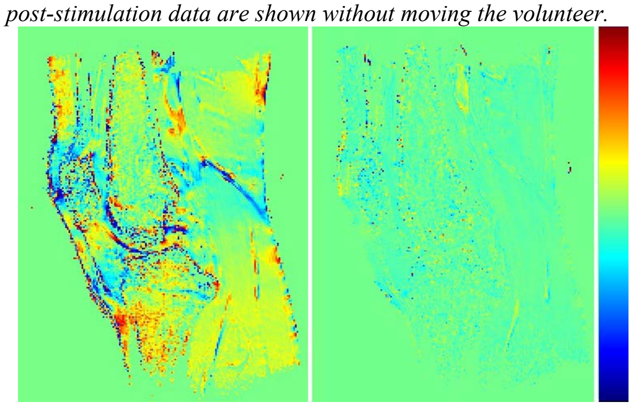

Fig. 3: Temperature difference images (left: post 1 – ref, right: post 2 – post 1). Color scale from –39 K (blue) to +39 K (red).

Results and Discussion

The comparison of the amplitude images before and after thermal stimulation (Fig. 2) show that an alignment of 4 mm precision can be achieved with the fixation. The linear shift algorithm detected a displacement of ($\Delta x/\Delta y/\Delta z$ = 0.36 mm/ 3.66 mm/ 0.09 mm) between reference and post-stimulation data. After automatic linear alignment, still residual differences from non-linear displacements and tissue shrinkage could be seen. In the phase difference (Fig. 3) the frontal cooled parts of the knee are clearly visible typical temperature changes in the cooled areas of about ΔT = -10 K. Residual unwanted phase differences at tissue boundaries can be explained by tissue susceptibility effects that are pronounced by an imperfect alignment of the data. Future refinements need to incorporate non-linear image mapping. However these preliminary data already indicate that temperature measurements with intermittent activities outside the MR system are feasible.

References [1] Becher C, et al. BMC Musculoskeletal Disorders **9**: 46 (2008)