Radial MRI - A Motion Insensitive Temperature Mapping Method

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Introduction
In the last years interventional MRI methods were developed to support minimal invasive ablation procedures like laser, radiofrequency (RF) or focused ultrasound (FUS). FUS can either be used for thermo-ablation or for local induction of gene expression [1]. MRI can provide both detailed anatomical information and temperature maps. Among other parameters the proton resonance frequency (PRF) shows a dependency of the temperature (0.01 ppm/K) and results in a very accurate measurement. A temperature map based on the PRF method can be calculated from the phase difference obtained from two gradient-echo images [2]. The main drawback of the phase difference method is its sensitivity to motion. Two different effects have to be considered: 1. Interview motion - the object motion occurring between the acquisition of the two images can result in phase differences that are not caused by temperature effects (especially in regions of high susceptibility gradients). 2. Intraview motion - the object motion during the acquisition results in artifacts that influence the phase of the image. The artifact behavior strongly depends on the acquisition scheme. In this work we evaluate the use of radial MRI for temperature mapping and compare the results obtained with spin-warp imaging.

Methods
Radial and spin-warp MRI were used to obtain gradient echo images at two different echo times (TE = 2.5 ms, 12.5 ms). The corresponding images were subtracted to determine phase-maps. The relative change of the temperature can be determined by subtracting phase maps obtained before an after heating. Phantom experiments were performed to study the influence of rigid body motion (sinusoidal motion) on the phase and temperature maps obtained with radial and spin warp MRI. In vivo experiments were performed obtaining temperature maps of the abdominal region of a healthy volunteer during heavy breathing. A water bottle at two different temperatures (AT = 35 K) was placed on the abdomen of the volunteer. In radial MRI the profile order with successive profiles acquired nearly anti-parallel was used. Prior to a gridding-reconstruction a linear phase correction was performed to correct for small gradient delays. All images were obtained on the 1.5 Tesla MR scanner (Gyroscan, ACS-NT15, Philips Medical Systems).

Results
The moving phantom results indicate that the motion sensitivity of spin-warp imaging results in a linear phase-error along the read-out direction and ghosts along the phase-encoding direction. Furthermore, the phase maps strongly depend on in which motion state the center of k-space was acquired. Therefore the phase maps are not reproducible and after subtraction of the phase maps a temperature effect is mimic. Phase-maps obtained with radial MRI result in a blurring along the motion direction and streaking artifacts. However, the phase maps are reproducible and temperature effects are quantitatively determined which match the adjusted temperature. Figure 1 shows the temperature maps of the in-vivo experiments. Temperature maps 1a and c were obtained without any heating whereas the bottle was heated in the maps 1b and d. The temperature maps obtained with spin-warp imaging (Fig.1a, b) result in large errors in the temperature estimation. Only minor artifacts are visible in the maps obtained with radial MRI (Fig. 1c,d) and the temperature difference can be determined to ΔT = 35 K.

Discussion
In spin-warp imaging motion during the acquisition of one profile results in phase errors along the readout direction. Motion during the acquisition of the k-space center profile results in a global phase shift and would thus mimic a global temperature shift. The difference between two phase maps strongly depends at which motion state the k-space centers have been obtained and will thus be prone to errors. Motion during the acquisition of different profiles results in ghosts along the phase-encoding direction. Ghost-like artifacts result in local phase errors and thus mimic a local temperature change. In radial MRI each profile traverses the k-space center and phase error are thus canceling out. Furthermore, the profile order was chosen in way that successive profiles were measured anti-parallel. Therefore phase errors along the readout direction will cancel out. Furthermore motion during the acquisition of different profiles result in streaking artifacts with less amplitude and will thus only reduce the accuracy of the temperature estimation a little bit. Interview-motion between the acquisition of images will still result in phase errors. Apart from image processing methods, navigators were proposed to reduce these effects [3]. However, in radial MRI correction of rigid body [4] and even complex motion [5] can be applied without the use of any additional measurements.

We demonstrated that radial MRI can significantly reduce the influence of motion on temperature mapping. A profile order was proposed that reduces the influence of motion during the read-out phase. Therefore, radial MRI provides a reliable thermometry, even under strong motion and may be used to monitor ablation procedures in the future.

References