3D reduced-FOV MR thermometry with fat suppression using a hybrid method combining a 2DRF pulse, parallel imaging, and UNFOLD

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Introduction: MR thermometry measurements using the proton resonance frequency (PRF) shift method [1] can be corrupted by the presence of fat [2]. Furthermore, long scan times represent another difficulty, due to long TE values (comparable with T_2^* [3]). As a consequence, achieving accurate temperature measurements in 3D with good temporal resolution in the presence of fat can be considered a very challenging task. Previously, 2DRF pulses have been proposed to enable both fat suppression and rFOV imaging in 2D sequences [4,5,6]. In the present study, a 2DRF pulse was combined with UNFOLD and parallel imaging in a 3D sequence, enabling accurate temperature measurements in fatty tissue as well as reduced in-plane FOV 3D imaging. Temporal resolution and SNR were equal to those of (non-accelerated) single-slice 2D sequences.

Fig.1: a) Fat-water phantom imaged using a normal RF Pulse. b) Excitation profiles for the 11*1140μs 2DRF pulse, where fat is spatially separated from water.

Theory: A total of 11 sub-pulses, each with 1140μs pulse width and modulated with a Gaussian envelope, were used for the 2DRF pulse. Total duration of the pulse was 12.5ms. The 2DRF excitation profiles examined with a fat-water phantom on a GE Excite HD 3T scanner are shown in Fig.1, where the water and fat excitations were separated spatially. Fig.2 shows the excitation profile along the phase-encoding direction using the same 2DRF and a cheese phantom, with homogeneous mixture of fat and water (Original Velveeta, 21% fat, Kraft Foods Inc., Northfield, IL). The distance between fat and water lobes (1/4 FOV) was a multiple of the rFOV size (1/8 FOV) so that in rFOV images the fat lobes and the tails of water lobe were aliased on top of the central lobe. This aliasing could be removed by parallel imaging and UNFOLD [7].

Fig.2: Excitation profile in a cheese phantom. The distance between side lobes (fat) and center lobe (water) is a multiple of rFOV size (2.25cm). In rFOV images, aliasing could be removed by paralleling and UNFOLD.

Methods: GE product 2D and 3D spoiled gradient-echo (FSPGR) sequences were modified to incorporate the hybrid method. The 2D sequence was used to test fat suppression using the cheese phantom. The phantom was heated for 30s with focused ultrasound (FUS) (4W) and rFOV images were acquired during heating and cooling (TE/TR: 9.2/30ms, flip angle: 23°, BW: ±15.6kHz, matrix: 16x128, FOV: 2.25x18cm, and slice thickness: 3mm). Full FOV images (18cm) with the same 2DRF pulse (i.e. fat-suppressed) were also acquired for comparison. Imaging with the rFOV 3D sequence was performed in a gel phantom, which was heated for 30s with FUS (25W). The 3D rFOV images were acquired during heating and cooling (TE/TR: 20/40ms, flip angle: 30°, BW: ±15.6kHz, matrix: 8x192, FOV: 0.7x16cm, slice number: 24, and slice thickness: 5mm). All measurements were compared to those obtained using the FSPGR sequence without fat suppression, used clinically for temperature mapping.

Results: Results from the cheese experiment, with a 2D 8-fold accelerated sequence, are shown in Fig.3 and 4. These results featured high temporal resolution but also high noise levels. In Figs 3 and 4, temporal averaging was performed, to make the temporal resolution comparable to that of the targeted 3D application. A temperature map for the time frame with maximum heating is shown in Fig.3. The noise on the sides parallel to the FUS beam is due to the excitation tails of water lobe (Gaussian), as smaller signal magnitude leads to lower temperature SNR. Temperature changes at the hottest location are plotted in Fig.4. The discrepancy between the conventional sequence (magenta) and the non-accelerated fat-suppressed sequence (blue) shows how the presence of fat corrupts results when using a sequence without fat suppression. The accelerated fat-suppressed sequence (green) shows heating results similar to the non-accelerated fat-suppressed case, as expected. In Fig.5, rFOV 3D temperature measurements (solid lines) are compared to results using a conventional full FOV 2D sequence (dashed line). With the rFOV sequence, in-plane coverage is reduced by a factor of 24 and through-plane coverage is increased by the same amount. Accordingly, the ROI (focus) was imaged in 3D. The temporal resolution and SNR are the same as the conventional full FOV 2D sequence. Notice that the conventional sequence gave results similar to two slices near the center of our 3D volume (slices number 11 and 12, Fig.5).

References: [1] Y Ishihara, et al. MRM 34:814-823 (1995). [2] JA de Zwart, et al. MRM 42:53-59 (1999). [3] A Chung, et al. MRM 36:745-752 (1996). [4] K Sung, et al, 14th ISMRM 3010 (2006). [5] J Yuan, et al, 16th ISMRM 1388 (2008). [6] CS Mei, et al, 17th ISMRM 4395 (2009). [7] CS Mei, et al, 16th ISMRM 1234 (2008).
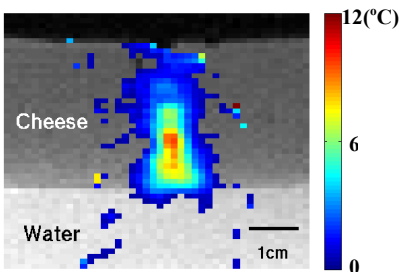
Fig.3: The temperature map of the time frame with the maximum heating obtained from accelerated fat-suppressed sequence in a cheese experiment. Spatial average of 9 voxels and temporal average of 8 frames were performed for the map.
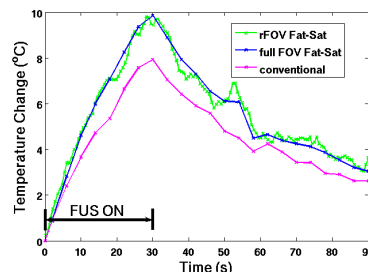

Fig.4: Temperature changes of the hottest voxel in 2D cheese experiments. While the conventional sequence (magenta) underestimated temperatures due to the presence of fat, the present method (green) suppressed fat and reduced imaging time by 8-fold. Green line is the result of temporal average over a sliding window of 8 time frames.
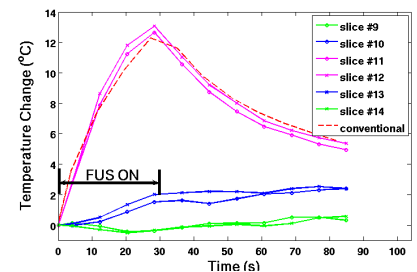

Fig.5: Temperature changes of the hottest voxel of 6 middle slices in 3D gel experiments were plotted in solid lines. Dashed line plotted the temperature measurements of a conventional sequence. The conventional sequence (red) gave the similar result to slice #11 and 12 (magenta) of the accelerated 3D sequence since they w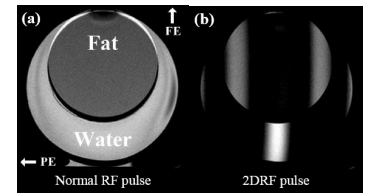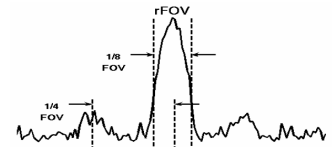ere around the same slice location.