High Speed MR Fingerprinting at 6.5 mT

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Purpose

High-field MRI instruments offer limited utility in field deployable and portable contexts. Our effort focuses on the critical challenges that must be solved to enable deployment of transportable MRI systems. This includes the development of robust low-field scanner hardware methodologies, the development of state of the art high-speed imaging strategies and work on advanced reconstruction methods. In recent work [1], we demonstrated high performance MRI at low magnetic field by making use of high-efficiency steady state free precession techniques (b-SSFP) [2] and undersampling for compressed sensing MRI. Earlier in 2013, a new imaging technique termed "magnetic resonance fingerprinting" (MRF) was proposed [3]. Unlike all other MRI sequence strategies, MR Fingerprinting allows the simultaneous quantification of multiple properties of a material or tissue in a single acquisition. In the present work, we show the first implementation of MR Fingerprinting at very low magnetic field in a multi-compartments phantom.

Methods

MRF at low magnetic field creates a rapid dynamic series of low signal to noise ratio (SNR) images where the magnitude of each voxel of each image changes at every time step. The TR and flip angle of each image in the time series is varied pseudo-randomly [5]. No steady state is reached, and image voxels with different relaxation times evolve differently, thereby generating unique magnetization trajectories. The time evolution of each voxel is simulated offline using the Bloch equations with the TR and flip angle patterns used for the imaging sequence over a wide range of tissue parameters, and a database (dictionary) of trajectories is generated. The measured voxel trajectory is compared to the dictionary and the best match is chosen, identically providing the T_1, T_2, and off-resonance frequency value of that voxel. MRF at high magnetic field benefits from high SNR and uses highly undersampled datasets over a high number of time steps (1000 time steps) to allow for good discrimination of T_1, T_2 and off-resonance among different species. Lack of SNR at low magnetic field required to use non-Cartesian acquisition of k-space and to redesign our sequence to lower undersampling rates and bigger flip angle range. The resulting sequence is a 200 time points, 50% undersampled, 20 spirals sequence. After an inversion pulse, flip angle ranges between 30 and 107°, TR varies between 46.1 ms and 52.7 ms. The dictionary was made of 2,751,975 signal time courses, each with 200 time points. MR total acquisition time was 13 min. The sequence was set with voxel size: 3×3×10 mm^3, FOV: 144×144×10 mm^3, number of average (NA): 6. The readout duration was 27.36 ms with 9356Hz bandwidth. The low field MRI scanner was previously described [6].

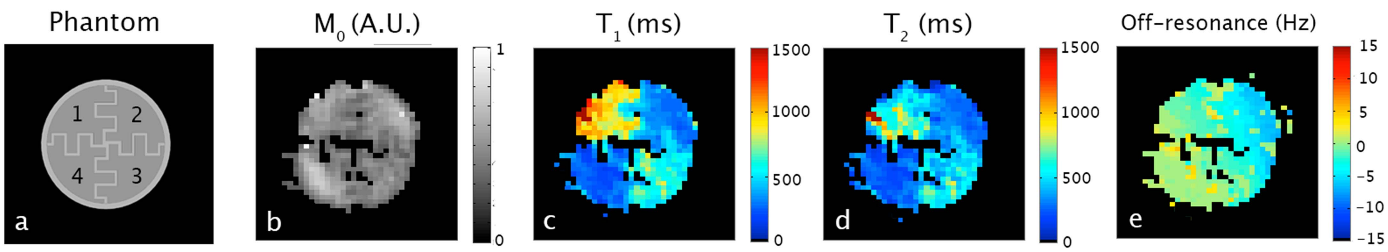

Figure 1: Slice selective MRF results obtained at 6.5 mT. The four-compartment liquid filled structured phantom shown schematically in (**a**). The compartments vary in relaxation properties. Each compartment had T_1 and T_2 measured in separate reference experiments (Inversion recovery & T2 CPMG respectively). 1: T_1=1046 ms, T_2=700 ms, 2: T_1=425 ms, T_2=418 ms, 3: T_1=600 ms, T_2=591 ms, 4: T_1=340 ms, T_2=286 ms. **b-e** show M_0, T_1, T_2, and off-resonance frequency, respectively.

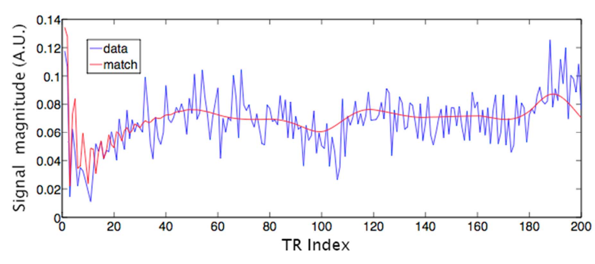

Figure 2: The magnetization trajectory of a single typical voxel over the 200 image fingerprinting sequence is shown (blue: data, red: best match from dictionary). All the parameters of the voxel (M_0, T_1, T_2, and off-resonance frequency) are determined once the trajectory match is made.

Results

Each image generated in the reconstructed fingerprinting set (Figure 1 b–e) reveals different information. The spin density (M_0) map of Figure 1.a is equivalent to traditional b-SSFP, and no visible difference between compartments is seen. However, Figure 1. c–d reveals that compartments 1-4 have very different T_1 and T_2 relaxation properties. The MRF images show good agreement with the reference measurements. Additionally, a map of the magnetic field homogeneity of the LFI scanner is also generated during the MRF sequence (Figure 1.e).

Conclusion

We have demonstrated MR Fingerprinting at low magnetic field, which results in simultaneous measurement of 4 quantitative parameters, and thus provides 4 different image contrasts in a single acquisition (proton density, T_1, T_2 and off-resonance) in less than 15 minutes. This technique is of particular relevance at low magnetic field where SNR and contrast are tied to long acquisition times. The combination of MRF with low field MRI scanners has great potential to revolutionize future transportable MRI systems.

References: [1] Sarracanie M *et al.* ISMRM 2013 #5322; [2] Scheffler K *et al.* Eur Radiol 2003 13:2409-18; [3] Ma D *et al.* Nature 2013 495:187-193; [4] Perlin K *et al.* Comput Graphics 1985 19:287–296; [6] Tsai LL *et al.* JMR 2008; 193:174-85.

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