MR Fingerprinting: Rapid Simultaneous Quantification of T1, T2, Proton Density and Off-resonance using a Spiral Trajectory

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Target audience: For those who are interested in quantitative imaging, pulse sequence design and fast imaging.

Purpose: The goal of this study is to rapidly and accurately quantify multiple relaxation parameters using MR Fingerprinting (MRF) in a short acquisition time. MRF is a novel approach that permits quantification of multiple important properties of a material or tissue simultaneously. In MRF, there is no a priori required shape of the signal evolution. The only desired properties of the signal are temporal and spatial incoherence. Once this is established, the signal evolutions from different materials or tissue types can be differentiated using pattern recognition algorithms. Previously, variations in sequence parameters such as flip angle (FA) and TR, during acquisition have been used to make the signal evolution temporally incoherent [1]. This study uses a rapid spiral sampling pattern in each acquisition block to improve the spatial incoherence. The interaction between these two properties provides new opportunities to accelerate image acquisition through rejection of under-sampling errors.

Methods: The MRF acquisition based on an inversion recovery balanced steady state free precession (IR-BSSFP) sequence was employed. As shown in Figure 1, one variable density spiral trajectory with 5.8ms readout time was used in each acquisition block (or TR). The spiral trajectory was designed to have zero and first moment gradient compensation using minimum-time gradient design[2]. The spiral trajectory was rotated by 7.5° from one TR to the next, so that each image has a slightly different spatial encoding. This variable density trajectory requires one interleaf to sample the inner 10x10 region, while 48 interleaves are required to fully sample the outer portions of k-space. The flip angle (range 5 to 60 degree), RF phase (0° and 180°) and TR (range 7.9 to 10.8ms) were also changed from one TR to next as shown in Figure 1. Highly undersampled images were reconstructed using NUFFT, and the signal evolutions from these images were used directly to quantify T1, T2, M0 and off-resonance simultaneously. Signal time courses with different sets of T1, T2 and off-resonance values were simulated through Bloch simulation using the above acquisition parameters and stored in a dictionary. The range of T1 and T2 was chosen to lie in physiologically encountered ranges: T1 between 50 and 5000 ms, T2 between 20 and 2000 ms and off-resonance between -300 and 300 Hz with variable step sizes. A total of 296,904 dictionary entries were generated.

Results: The interaction of spatial and temporal incoherence greatly improves the acquisition efficiency of the MRF performance. A single-shot spiral acquisition allows quantification of four parameters simultaneously within 10 seconds per slice. Further improvements are expected through the combination of MRF and parallel imaging methods, which have not been included up to this point.

Conclusion: The interaction of spatial and temporal incoherence greatly improves the acquisition efficiency of the MRF performance. A single-shot spiral acquisition allows quantification of four parameters simultaneously within 10 seconds per slice. Further improvements are expected through the combination of MRF and parallel imaging methods, which have not been included up to this point.

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Figure 1: (a) One variable density spiral trajectory was used per TR of the MRF sequence. Flip angle (b) and TR(c) were also changed from one TR to the next.

Figure 2: In vivo results: (a) an image at the 5th TR out of 1000 was reconstructed from only one spiral readout demonstrating the errors from under-sampling. The T1 (b), T2 (c), M0 (d) and off-resonance (e) maps show a near perfect rejection of these errors.

Table 1: In vivo data: Comparison of MRF results and reference values on different brain regions.