Single Breath-hold Abdominal T1 Mapping using 3-D Cartesian Sampling and Spatiotemporally Constrained Reconstruction

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Synopsis

Volumetric T\textsubscript{1} mapping in the abdomen is desirable for whole liver assessment of hepatic diseases. In case of breath-hold imaging, accurate but time-consuming methods that sample the relaxation curve (IR or Look-Locker) are restricted to few slices only. To address these limitations, sparse Cartesian sampling with spatiotemporal incoherence is utilized to render 3-D Look-Locker within a single breath-hold possible. We demonstrate feasibility in both phantom and in-vivo measurements. The proposed method shows high agreement with a 2-D reference acquisition and enables an accurate mapping for a wide T\textsubscript{1} range, including very low values due to its high temporal resolution.

Introduction

Abdominal T\textsubscript{1} mapping can help diagnosing and staging hepatic diseases such as liver cirrhosis\textsuperscript{1}. Yet, accurate methods that are based on sampling the relaxation curve are usually limited to a few slices in case of breath-hold imaging. Common 3-D techniques are often based on a variable-flip-angle approach, which is B\textsubscript{1} sensitive, even when complemented with an additional B\textsubscript{1} mapping acquisition and correction\textsuperscript{2}. Look-Locker sequences are considered more accurate albeit time-consuming, restricting volumetric Look-Locker to static imaging only\textsuperscript{3}. Sparse sampling with incoherence in both space and time can alleviate this problem. To this end, an existing 3-D CINE sequence prototype\textsuperscript{4,5} was extended to support inversion pulses and FLASH contrast.

We investigate whether the increased signal of 3-D acquisitions in combination with a sparse spatiotemporally incoherent sampling of the relaxation curve in high temporal resolution can yield T\textsubscript{1} values in a wide range with high accuracy. To our knowledge, this is the first application of whole-liver T\textsubscript{1} mapping and 3-D Cartesian Look-Locker within a breath-hold. Experiments include both phantom and in-vivo measurements.

Materials and Methods

A Look-Locker T\textsubscript{1}-mapping scheme with continuous sampling after an initial inversion pulse was used. We utilized a multi-TI CINE protocol with an IR-FLASH sequence featuring adiabatic inversion\textsuperscript{4}. Time points in the reconstruction were assigned to contrasts after inversion pulses. For sufficiently high spatiotemporal sampling density, k-space segmentation with multiple inversions and therebetween a wait-time for free relaxation was introduced.

A variable-density spiral spokes pattern ensured Cartesian sampling with a high temporal resolution\textsuperscript{5} (~100ms), which allows to determine very low T\textsubscript{1} values. For improved k-space coverage, multiple spiral arms were sampled in each shot and the set of spokes was rotated successively by the golden angle per shot and TI (Figure 1). Time-resolved reconstructions were performed using a FISTA algorithm\textsuperscript{6}, which incorporates wavelet regularization in both space and time domain. 40 iterations with spatial/temporal regularization weights of 0.0006/0.007 were used. T\textsubscript{1} maps were obtained using a phase-corrected multi-step parameter fitting utilizing a smoothed flip angle map.

A 3 T MR scanner (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) was used for all experiments. An 18-channel body coil was used for volunteers, a 20-channel head coil for phantom experiments. Reconstructions were compared against 2-D multi-slice reference measurements of a prototypical LL sequence by means of ROI mean and standard deviation:

**In-vivo:** axial slices from a 6-slice 2-D acquisition were compared against corresponding slices in 3-D

**Phantom:** assessment based on the T1-array of the NIST phantom\textsuperscript{7}

3-D imaging parameters: FoV = 365x255x150mm\textsuperscript{3}, matrix = 160x94x30, TR = 2.4ms, TE = 1ms, flip-angle = 6°, bandwidth = 1563Hz/Px, 19 TIs, ΔTI = 102ms, net acceleration = 15.4, acquisition window = 2s, wait time = 3.8s, 4 inversions.

2-D imaging parameters: FoV = 380x308mm\textsuperscript{2}, matrix size = 192x125 (1mm\textsuperscript{2} interpolated), slice thickness = 5mm, TR = 3ms, TE = 1.3ms, flip-angle = 8°, bandwidth = 1530 Hz/px, 16 TIs, ΔTI = 225ms (2x acceleration), scan time = 22.8s (6 slices).
Results and Discussion

The 3-D+t image reconstructions took less than a minute using the scanner graphics hardware while T1 mapping on the CPU (not parallelized) required 5–10s per slice. In-vivo results in Figure 2 show axial slices and a coronal reformation from the 3-D acquisition (A-C) in comparison to the 2-D reference (D,E). Figure 3 illustrates the signal recovery of the 3-D and 2-D acquisition in comparison. Labeled ROIs used for the in-vivo quantitative evaluation, which is presented in Table 1, are shown. Table 2 summarizes the results of the phantom evaluation.

Average hepatic T1 values of 799±32 and 810±44ms between the 2-D reference and 3-D show very high agreement in vivo. The phantom comparison shows excellent agreement with reference values for both methods in a wide range. Yet, only the 3-D acquisition with its short ΔTI allowed determining phantom tubes with T1 values as low as 60ms accurately. While the visual appearance between 2-D and 3-D is quite different due to image resolution, the 3-D acquisition, despite high acceleration, is hardly affected by artifacts and allows delineating most vessels and anatomical structures.

Conclusion

The feasibility of a 3-D Look-Locker acquisition for abdominal T1 mapping within a single breath-hold was demonstrated. Utilizing an efficient reconstruction framework for spatiotemporal sparsity, our method enables whole-liver mapping with a 2.3x2.3x5mm³ resolution in 23s. Excellent agreement with a 2-D reference was shown for volunteer and phantom data for a wide T1 range of 60–2000 ms. Additionally, the spatiotemporal sparsity enables the usage of very short ΔTIs making an accurate mapping of very low T1 values feasible. Future works aims at improving scan efficiency.

Acknowledgements

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References


Figures
Figure 1: Incoherent sampling in space and time was implemented by a Cartesian spiral spokes pattern with variable density. A golden angle rotation of subsequently generated spiral arms as well as jittering of oversampled positions targets good k-space coverage.

Figure 2: In-vivo comparison of a 3-D whole liver acquisition (2.3x2.3x5 mm\(^3\) resolution) against two 2-D reference acquisitions (1 mm\(^2\) interpolated resolution) in two selected slices (A,B vs. D,E). The 3-D acquisition enables volumetric processing such as coronal reformation (C). Further shown are labeled ROIs, which are used for the quantitative evaluation.

Figure 3: Exemplary recovery curves (effective T1) for the 3-D Look-Locker acquisition (left) and the 2-D reference acquisition (right) for the phantom tubes\(^7\) T1-3 and T1-10. Unfilled markers mark the signal over time for a flip angle of 8° while filled markers correspond to a flip angle of 6° (3-D only). Dashed lines denote fits to the data. Note how the recovery plateaus earlier for the volumetric case, dependent on flip angle and TR. Further, the short ΔTI of the 3-D acquisitions is advantageous to capture the high dynamics in case of rapid relaxation.

Table 1: In-vivo quantitative comparison based on ROI mean and standard deviation (SD) between the 2-D reference and 3-D Look-Locker acquisition.

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Table 2: NIST phantom\(^7\) quantitative ROI comparison of the “T1 array” between the 2-D reference and 3-D acquisition.