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

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Synopsis

Volumetric T_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_1 range, including very low values due to its high temporal resolution.

Introduction

Abdominal T_1 mapping can help diagnosing and staging hepatic diseases such as liver cirrhosis[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_1 sensitive, even when complemented with an additional B_1 mapping acquisition and correction[2]. Look-Locker sequences are considered more accurate albeit time-consuming, restricting volumetric Look-Locker to static imaging only[3]. Sparse sampling with incoherence in both space and time can alleviate this problem. To this end, an existing 3-D CINE sequence prototype[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_1 values in a wide range with high accuracy. To our knowledge, this is the first application of whole-liver T_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_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[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[5] (~100ms), which allows to determine very low T_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[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_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[7]

3-D imaging parameters: FoV = 365x255x150mm^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^2, matrix size = 192x125 (1mm^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 T_1 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 T_1 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 T_1 mapping within a single breath-hold was demonstrated. Utilizing an efficient reconstruction framework for spatiotemporal sparsity, our method enables whole-liver mapping with a $2.3x2.3x5mm^3$ resolution in 23s. Excellent agreement with a 2-D reference was shown for volunteer and phantom data for a wide T_1 range of 60–2000 ms. Additionally, the spatiotemporal sparsity enables the usage of very short ΔTIs making an accurate mapping of very low T_1 values feasible. Future works aims at improving scan efficiency.

Acknowledgements

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References

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Figures

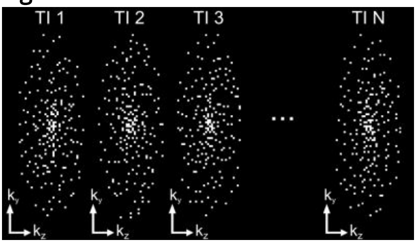

Figure 1: Incoherent sampling in space and time was implemented by a Cartesian spiral spokes pattern with variable density[5]. A golden angle rotation of subsequently generated spiral arms as well as jittering of oversampled positions targets good k-space coverage.

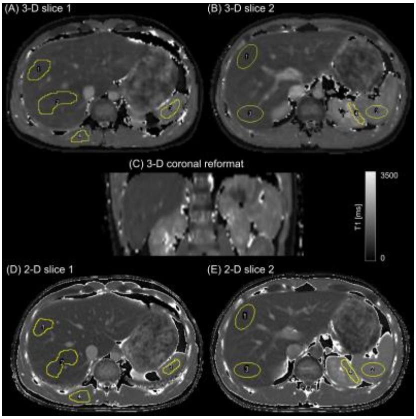

Figure 2: In-vivo comparison of a 3-D whole liver acqusition (2.3x2.3x5 mm^3 resolution) against two 2-D reference acquisitions (1 mm2 interpolated resolution) in two selected slices (A,B vs. D,E). The 3-D acquisition enables volumetric processing such as coronal reformation (C). Further shown are labeled ROIs, which are used for the quantitative evaluation.

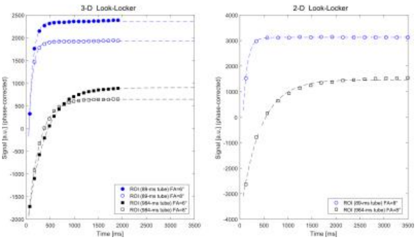

Figure 3: Exemplary recovery curves (effective T1) for the 3-D Look-Locker acquisition (left) and the 2-D reference acquisition (right) for the phantom tubes[7] *T1-3* and *T1-10*. Unfilled markers mark the signal over time for a flip angle of 8° while filled markers correspond to a flip angle of 6° (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.

Method	ROI 1 mean ± SD	ROI 2 mean ± SD	ROI 3 mean ± SD	ROI 4 mean ± SD
3-D slice1	812 ± 36	798 ± 54	1352 ± 80	1048 ± 49
3-D slice2	784 ± 25	1346 ± 83	846 ± 50	1516 ± 136
2-D slice1	784 ± 30	761 ± 37	1233 ± 58	1029 ± 40
2-D slice2	820 ± 23	1346 ± 51	831 ± 37	1489 ± 109

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.

Sample Name	Nominal values of "T1 array" at 3 T	LL 2-D: mean ± SD (rel. error)	LL 3-D : mean ± SD (rel. error)
T1-1	1989	2141 ± 18 (8 %)	2080 ± 85 (5 %)
T1-2	1454	1513 ± 17 (4 %)	1464 ± 18 (1 %)
T1-3	984	1007 ± 11 (2 %)	1029 ± 25 (5 %)
T1-4	706	728 ± 9 (3 %)	730 ± 14 (3 %)
T1-5	497	513 ± 8 (3 %)	500 ± 15 (1 %)
T1-6	352	360 ± 6 (2 %)	334 ± 9 (-5 %)
T1-7	247	259 ± 4 (5 %)	231 ± 8 (-6 %)
T1-8	175	180 ± 3 (3 %)	175 ± 8 (0 %)
T1-9	126	127 ± 3 (1 %)	127 ± 4 (0 %)
T1-10	89	93 ± 4 (4 %)	87 ± 3 (-3 %)
T1-11	63	98 ± 10 (56 %)	62 ± 4 (-2 %)
T1-12	45	413 ± 88 (820 %)	62 ± 7 (38 %)

Table 2: NIST phantom[7] quantitative ROI comparison of the *"T1 array"* between the 2-D reference and 3-D acquisition.