Robust Dual-Contrast 3D Abdominal Imaging within a Single Breath-hold

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Purpose: In MRI, several images with different contrasts are often advantageous for a precise diagnosis. In abdominal imaging these are usually performed during one or multiple breath-holds to avoid potential respiratory motion induced artifacts. Nevertheless, this approach can lead to spatial inconsistencies between data acquired in different breath-holds. It was proposed to perform multi-contrast MRI within the same breath-hold[1] using highly accelerated parallel imaging (PI). However, the disproportionately long delay between the two scans of approximately 1s increases the risk of a premature onset of breathing during the second scan, which can degrade the image quality substantially. To overcome this problem, dual-contrast imaging with fast sequence switching and flexible scan termination[2] that adapts automatically to the breath-hold capabilities of the patient is proposed in this work.

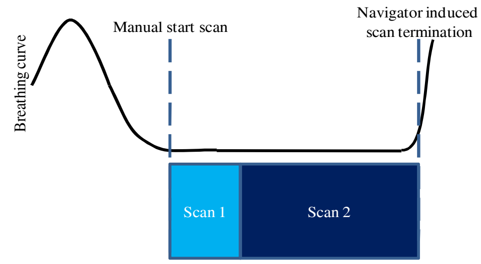

Fig.1: Scheme for dual contrast imaging in one breath-hold: The first scan is performed using a standard protocol. After fast sequence switching, the motion-robust scan is performed, causing scan termination at breathing onset, breathing curve indicated by black line.

Methods: The first scan is performed immediately after the breath-holding instructions [Fig.1] (both preparation phases before the breath-hold). During the first scan, which is chosen to last only a fraction of the breath-hold, it is likely that the patient is capable to hold the breath. Therefore, this scan can be fully sampled. Switching to the subsequent scan is performed using a spectrometer task swapping approach, pre-storing arbitrary MR sequences on the data acquisition system as parallel tasks, allowing switching sequences in less than a few micro-seconds. The second scan, which starts immediately after the first scan, has to be designed differently to be able to cope with sudden onset of breathing. In this work, an adapted profile order was chosen supporting temporally increasing spatial resolution[2] that enables flexible scan termination without motion artifacts. The k-space profile ordering is optimized to continuously perform a compromise between spatial resolution, SNR, and undersampling artifacts. Furthermore, it approximates a variable density Poisson Disk distribution at every point in time. This sampling ensures incoherent aliasing required for a combined compressed sensing (CS) and parallel imaging (PI) reconstruction of the undersampled data. An interleaved 1D pencil navigator is used to detect onset of respiratory motion for scan termination.

Abdominal imaging was performed on volunteers on a 1.5T scanner (Philips Healthcare, Best, The Netherlands), using a 16-element torso coil. For the first scan, a conventional 2D Look-Locker sequence, sampling 12 complete low-resolution single shot gradient-echo images after inversion (α: 10°, TE/TR: 2.8/6.4ms; voxel size $3\times2.6\times15$ mm³, total scan time: 3s), was chosen to estimate a central slice liver T_1 map, reconstructed using conventional reconstruction. For the second scan, a T_1-weighted spoiled gradient-echo sequence with a $TE_1/TE_2/TR$ of 1.29/2.34/3.67ms was employed to cover a typical FOV of $380\times280\times240$ mm^3 with an actual spatial resolution of $1.5\times1.5\times3.0$ mm^3. A combined PI and CS reconstruction (L1-SPIRiT[3]) was used for reconstruction of the two echo images, and water fat separation[4] was performed as a final step.

Results: The estimation of the T_1 map of the liver from the first scan is shown in Fig.2(a,b) with a measured T_1 value from ROI of 570ms, while the reconstructed images from the second scan are shown in Fig.2(c,d). This volunteer held the breath for 19s, with automatic scan termination at the onset of breathing. The effective scanning time of the second scan was 16s. For comparison, this data was further undersampled to simulate breath-hold durations of (3+13)s (Fig.3(d)) and (3+10)s (Fig.3(e)) to emphasize the automatically adapted resolution of the second scan.

Discussion: The protocol shown here was chosen as a feasibility study. It could be of interest as a building stone for future liver perfusion studies, delivering a coarse T_1 map to estimate relaxivity in every dynamic for high temporal correlation to improve perfusion analysis. However, the concept of combining multiple-contrast scans in a single breath-hold with ultra-fast sequence switching and the adaptive profile order to cope with early onset of breathing without compromising image quality can find many other applications.

Conclusion: With the proposed approach, multiple contrast images of the abdomen can be acquired quasi-simultaneously within a single breath-hold reducing the risk of misregistration. While the first scan is uncritical, the second scan is adapted to the breath-hold capabilities of the patient and is terminated automatically in case of the onset of breathing preventing motion artifacts at the cost of a potentially lower resolution.

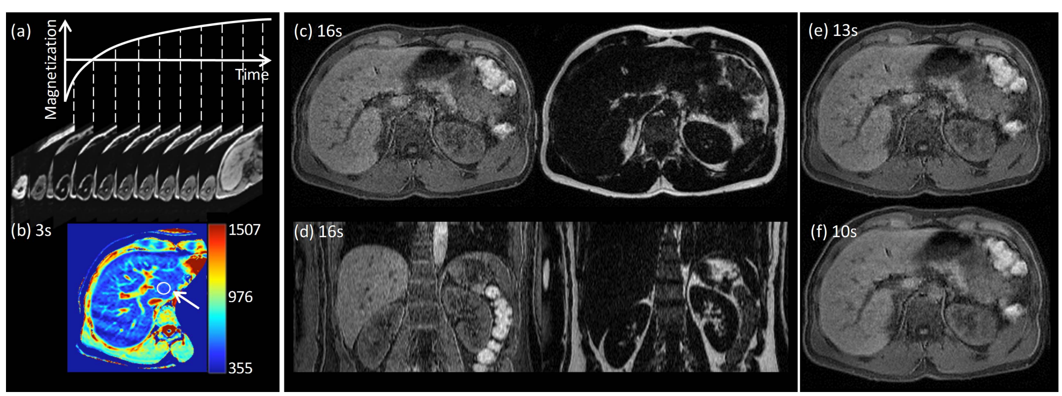

Fig.2: Results for dual-contrast single breath-hold abdominal MRI: In this example, a standard Look-locker T_1 mapping scan was combined with a second 3D water/fat resolved dual-echo Dixon. (a) Pixel-wise estimation of T_1 and (b) resulting T_1 map from the first scan (3s scan duration) during a breath-hold. (c,d) Selected water/fat images from the second scan acquired during the same breath-hold. From the total breath-hold duration of 19s, 16s were left for the second scan (c,d). Water images for simulated earlier breathing onsets resulting in scan duration of the second scan of 13s (e) and 10s (f), underlying the temporal resolution adaptation.

References: 1. Winkelmann R, et al. MAGMA (2006) 19:297-304. 2. Gdaniec N, et al. ISMRM 2012: 600. 3. Lustig M, et al. ISMRM 2009: 334.4. Eggers H, et al. MRM 2011, 65:96-107.