Towards Clinical Robustness in 3D Abdominal Water/Fat Imaging

Nadine Gdaniec[1], Tim Nielsen[2], Peter Börnert[2], Holger Eggers[2], Mariya Doneva[2], and Alfred Mertins[1]
[1]*University of Lübeck, Lübeck, Germany,* [2]*Philips Research Laboratories, Hamburg, Germany*

Purpose: Image quality in abdominal imaging is often degraded by respiratory motion. Breath-holding is an efficient strategy to minimize the associated artifacts if the patient can hold his breath long and stable enough. Recently, a dedicated sampling pattern was proposed[1] to cope with a premature onset of breathing during scanning. It facilitates a continuous temporal changing compromise between undersampling artifacts, SNR, and spatial resolution allowing for scan termination at every point in time during the breath-hold. A combined parallel imaging (PI) and compressed sensing (CS) reconstruction approach[2] is employed to reconstruct the final images from the incomplete k-space data. However, optimal parameters have to be chosen for this sampling pattern. Therefore, it is one aim of this study to find the best compromise based on phantom experiments. In addition, dual-echo imaging was added to permit a water-fat separation. The scan was complemented with a fast motion detection navigator that does not disturb the steady state[3] allowing automatic scan termination. Furthermore, coil compression[4] was applied to reduce the reconstruction time.

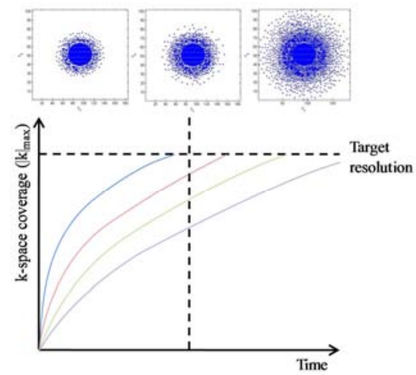

Fig.1: k-space coverage ($|k|_{max}$) over time: a compromise between SNR, sub-sampling, and resolution. Each line indicates the k-space coverage function for different values of the parameter R_{max}. For a given point in time, the achieved k-space coverage is different in all cases.

Methods: The sampling pattern copes with a premature onset of breathing by enabling flexible scan termination. A central area in k-space is fully sampled first, followed by the periphery. Elliptically shaped nested areas are partially sampled subsequently with samples approximating a variable density Poisson Disk distribution for incoherent aliasing enabling a CS reconstruction. The advance in k-space coverage, which is the radius of the nested areas here ($|k|_{max}$), becomes faster for a growing maximum reduction factor (R_{max}) [Fig. 1] (different R_{max} indicated by different colours). Nevertheless, the actually achieved resolution is also dependent on the success of the reconstruction. Simulations for different values of R_{max} were performed on phantom data. Imaging on volunteers was performed on a 1.5T scanner (Philips Healthcare, Best, The Netherlands), using a 16-element torso coil with an interleaved (k=0) navigator repeatedly measuring the k-space centre. Consistency of the navigator data is estimated based on the correlation between profiles from different time-points to monitor breath-holding. A T_1-weighted spoiled gradient-echo sequence with a $TE_1/TE_2/TR$ of 1.29/2.34/3.67 ms was employed to cover a typical FOV of $380 \times 280 \times 240 mm^3$ with an actual spatial resolution of $1.5 \times 1.5 \times 3.0 mm^3$. The 16 channel data was compressed using a coil compression technique[4] into 6 virtual coils for faster reconstruction. A combined PI and CS reconstruction, based on L1-SPIRiT[2], was used for reconstruction of the individual echo images. With a complex coil combination, the images from 6 virtual channels of two echoes are combined into one complex valued image for each echo, which enables efficient water-fat separation[5] for improved image contrast and high quality fat suppression.

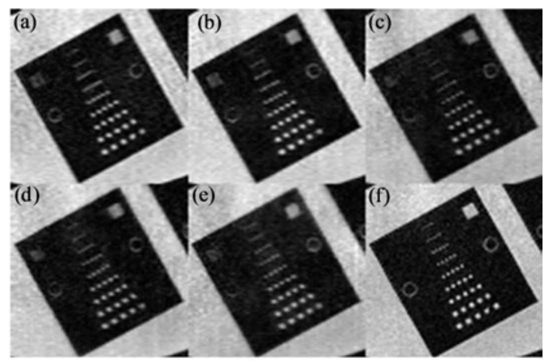

Fig.2: Simulation for different resolution approaching schemes using a fixed number of samples (images cropped). R_{max} are (a) 3; (b) 5; (c) 7; (d) 9, and (e) 12. (f) shows the fully sampled case. Improved resolution can be seen from (a) to (c) whereas noise increases for higher R_{max}.

Results: Sampling simulation results using a fixed number of samples and different maximum reduction factors are shown in Fig. 2. R_{max} was varied between 3 and 12. Fully sampled data is shown in Fig. 2(f). Fig. 2(a-c) shows an increase in the in-plane resolution with increasing R_{max}. This is also visible in the through-plane resolution (see upper left in the individual images). Neighboring slices become visible for lower resolution. The noise level becomes worse for even higher R_{max}, visible for R_{max} =12. For measurements on different volunteers, the value ranged from 5 to 8 with nearly unaffected image quality. From one of the acquisitions, a typical breathing curve based on the navigator signal is given in Fig. 3, which was for illustrative purposes not terminated. Detection of respiration onset is trustworthy with high efficiency. Water-Fat images with reliable and reproducible image quality (Fig. 3) were achieved from PI/CS reconstruction for all volunteers.

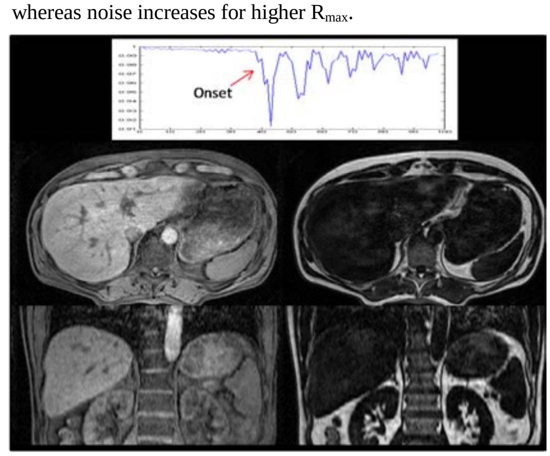

Fig.3: 3D water/fat resolved abdominal data (top). Typical navigator breathing curve terminate scanning at onset of breathing. Volunteer water-fat images and reformats obtained in an 18 second self-terminated breath-hold.

Discussion: Slow k-space coverage causes high resolution loss for short breath-hold duration, while faster k-space coverage takes lower note of the highest signal energy in the centre resulting in a higher noise level. A good indication is the overall reduction factor achievable with pure PI for 2D acceleration, whereas R_{max} can be chosen approximately up to a factor of two higher. Respiration controlled 3D water/fat resolved breath-hold abdominal imaging with coil compression for faster reconstruction is a promising building stone to pave the way towards clinical robustness in 3D abdominal imaging. This robust sampling approach can straightforwardly be extended to other sequences, and further applications can be found.

References: 1. Gdaniec N, et al. ISMRM 2012: 600. 2. Lustig M, et al. ISMRM 2009: 334. 3. Brau A, et al., MRM 2006,55:263-270. 4. Zhang T, MRM (2012), doi: 10.1002/mrm.24267. 5. Eggers H, et al. MRM 2011, 65:96-107.