# Fast Single Breath-hold 3D Abdominal Spiral Imaging with Water / Fat Separation and Off-resonance Correction

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## Introduction

Large volume coverage, short total scan time and robust water/fat separation are important issues in abdominal MRI. Breath-hold approaches are often used to avoid respiratory motion artifacts, which demands for efficient sampling schemes. Spiral imaging is one of them [1], but shows high sensitivity to off-resonance [2]. Image blurring resulting from spatially varying $B_o$ inhomogeneities and chemical shift composition can degrade image quality seriously. If both effects are separable, correction can potentially be done. Three-point chemical-shift imaging, in particular IDEAL [3], was found to achieve high quality water/fat separation, delivering a $\Delta B_o$ map as a byproduct. Recently, Brodsky et al. [4] proposed to use this additional information for non-Cartesian water/fat imaging.

In this work this concept was applied to 3D single breath-hold water/fat resolved, off-resonance corrected spiral imaging using the stack of spirals approach. Parallel imaging was employed to improve SNR, sampling efficiency and to achieve an up-front data compression during image reconstruction reducing IDEAL reconstruction time, opening new applications for self-referenced non-Cartesian MRI.

## Theory

For a chemical shift encoded spiral gradient echo scan using a fixed k-space trajectory, the sampled receiver signal $s_n(t)$ of the n different echoes centered at $TE_n$, can be given as:

$$s_n(t) = \sum_j \left[ \int \rho_j(\boldsymbol{r}) \ \exp(i\boldsymbol{k}(t)\boldsymbol{r}) \ \exp(i\gamma\Delta B_o(\boldsymbol{r})t) \ \exp(i\gamma\Delta B_o(\boldsymbol{r})TE_n) \ \exp(i\omega_j t) \ d\boldsymbol{r} \right] \exp(i\omega_j TE_n)$$

In this equation the index *j* denotes the different species (like water and fat) having the chemical shifts $\omega_j$. The term $\Delta B_o(\boldsymbol{r})$ denotes the spatial off-resonance and *t* the time during signal sampling. Coil sensitivities and relaxation effects are neglected. After gridding and SENSE reconstruction chemical shift decomposition can be performed in the spatial domain via IDEAL, but off-resonance correction using $\Delta B_o(\boldsymbol{r})$ and appropriate $\omega_j$ demodulation for the corresponding species has to be done in k-space using Conjugate Phase Reconstruction (CPR) [2]. Two approaches are conceivable: a simple single step approach as outlined in Fig.1(a) and a more sophisticated one proposed by Bodsky [4] (Fig.1(b)). Both start from the images obtained at different TEs which represent appropriate superposition of individually gridded and un-folded single coil images received.

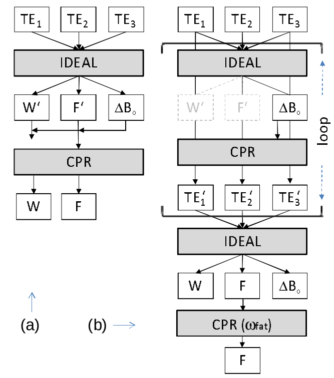


Fig.1 Spiral water/fat separation and correction algorithms. (a): simple approach, (b) more accurate one using three iterations in a loop.

## Methods

Data were acquired in five healthy volunteers (23-27 years) on a 1.5T clinical scanner (Achieva, Philips Healthcare) using a 32-element cardiac coil with sufficient feet-head (FH) coverage. Informed consent was obtained. 3D interleaved spiral gradient echo imaging was performed, using the stack-of-spirals approach (spiral matrix size: 256², FOV: 360×360mm², interleaves: 14, AQ window: 15ms, α: 10º, TR: 23ms). Chemical shift encoding was achieved by sampling for each interleaf ($i_n$,$k_z$) successively in time three gradient echoes at different TE's (1.0/2.5/4.0 ms) while keeping TR fixed for the entire scan. In this way motion and flow related data inconsistencies are minimized. One-dimensional SENSE (R: 1.6 – 2.0) was applied for acceleration, only in the stack direction allowing increased volume coverage. Thus, data for 28 to 38 slices are acquired (thickness: 5mm) plus a 25% extra oversampling in the slab direction to compensate for RF pulse imperfections. Image reconstruction was performed on the system using conventional regridding combined with SENSE [5] unfolding. This already resulted in a massive data reduction from 32 channels into one. The resulting three 3D data sets ($TE_1$, $TE_2$, $TE_3$) were subjected to spiral water/fat separation using the two approaches outlined above.

## Results and Discussion

All volunteer scans were successful and yielded good and reproducible image quality. Excellent water fat separation and off-resonance deblurring was achieved using both approaches. The experiments confirmed that high resolution water/fat resolved spiral imaging is feasible in the abdominal region without the need for extra information. The appealing aspect of the IDEAL approach is "the field map for free" that facilitates image based deblurring which shows remarkable improvements as demonstrated in the example shown in Fig. 2. Due to the SENSE reconstruction based channel compression the numerical effort for the w/f separation and the deblurring is manageable. Both reconstruction approaches showed slight differences in areas of strong local $B_o$ gradients. Further studies on the interplay of the applied $B_o$-map smoothing in IDEAL and the consequences for the CPR accuracy are needed. In the future IDEAL has to be modified to improve $B_o$ estimation after having water and fat sufficiently separated. Spiral SENSE should be employed to further boost scan time or volume coverage. The combination of IDEAL, SENSE and spiral signal sampling could pave the way for interesting future water / fat resolved clinical applications.

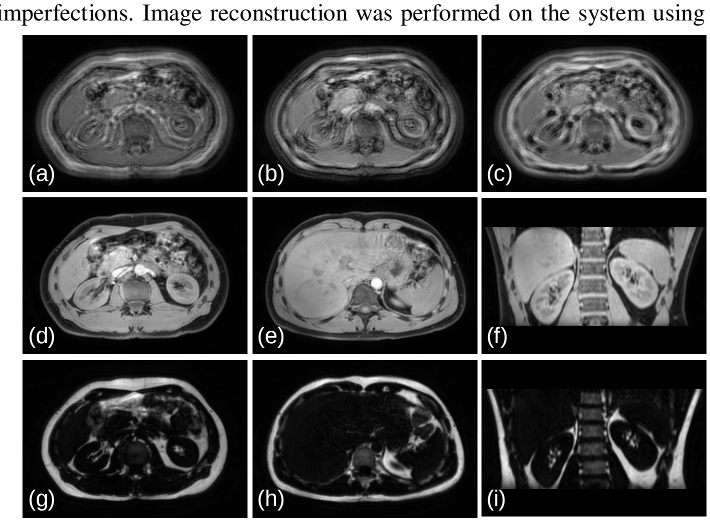


Fig.2. Single breath-hold water/fat resolved abdominal 3D spiral imaging. (FOV: 360×360×190mm$^3$, measured voxel: 1.4×1.4×5mm$^3$). Top row single slice at different TEs (a-c) - strong artifacts. (d, g) corresponding water/fat images, (e, h) same for a different slice, (f, i) and appropriate 3D coronal water/fat reformats after correction and separation. A single acquisition was sufficient to support off-resonance correction and water/fat separation.

## References

[1] Ahn B, et al. IEEE TMI 1986; 5:2-12. [2] Man LC, et al. MRM 1997;37:785-92. [3] Reeder SB, et al. MRM 2005;54:636–644. [4] Brodsky EK, et al. MRM 2008; 59: 1151-64. [5] Pruessmann K. et al., MRM 1999; 42: 952-962.