Accelerated free breathing MRI with continously moving table using compressed sensing

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Introduction

In MRI with continuously moving table (CMT) breathing motion is an important issue. Recently motion compensation techniques for CMT-MRI during free breathing have been introduced [1, 2]. They apply parallel imaging to reconstruct multiple snapshots of the breathing motion from a fully sampled k-space and combine these snapshots subsequently. In this study the compressed sensing (CS) technique [3] is evaluated for the reconstruction of snapshots in free breathing CMT-MRI. One snapshot per slice position without significant motion or reconstruction artifacts was reconstructed from a k-space randomly undersampled in phase encoding direction with a reduction factor of R = 2. Compared to other free breathing acquisitions, image details could be well resolved.

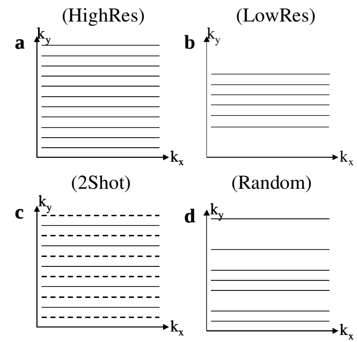

Fig. 1: Different sampling schemes.

Methods

A T2 weighted CMT turbo-spin-echo sequence with the TRAPS technique for RF power reduction [4] was used to acquire 32 axial slices (Slice thickness = 5mm, slice gap = 1mm, FOV = 225x360mm^2) from one volunteer during free breathing. The following acquisition schemes were used: (HighRes) The complete k-space was acquired with one echo train (Fig. 1a). (LowRes) Only the lower spatial frequencies were acquired with a shorter echo train (Fig. 1b). (2Shot) The complete k-space was acquired with two echo trains, one for the even lines and one for the odd lines (Fig. 1c). (Random) Phase encoding lines were randomly sampled with the sampling density decreasing from the inner to the outer k-space (reduction factor R = 2) using one echo train (Fig. 1d). The sequence parameters for the different acquisitions are given in table 1. For the (HighRes) and the (LowRes) acquisitions a larger TE was chosen compared to the other acquisitions to avoid artifacts, i.e. the center echo was placed later in the echo train. Artifacts occur if contiguous parts of the central k-space are acquired at echo train positions where the signal differs significantly due to the T2 decay. This happens if the center echo is placed too early in the echo train and linear k-space reordering is used.

Dataset	TR	TE	Echo train length	Acquisition time	In plane resolution
(HighRes)	5485ms	160.64ms	129	33s	1.8x1.4mm^2
(LowRes)	3150ms	100.4ms	81	19s	3.0x1.4mm^2
(2Shot)	2750ms	85.34ms	67	33s	1.8x1.4mm^2
(Random)	2750ms	85.34ms	67	16.5s	1.8x1.4mm^2

Table 1: Parameters of the different acquisitions.

For the (HighRes) and (LowRes) acquisitions conventional reconstructions were applied, for the (2Shot) acquisition the reconstruction proposed in [1] was used, which applies parallel imaging to reconstruct snapshots from either even or odd lines and averages them subsequently. A CS reconstruction according to [3] and a conventional reconstruction where the missing lines were filled with zeros were applied to the (Random) acquisition. For the CS reconstruction the following function was minimized [3]:

$$\Phi(i) = \left\| F \cdot W^{-1} \cdot i - y \right\| + \lambda_w \cdot \left\| i \right\|_1 + \lambda_{tv} \cdot TV\left(W^{-1} \cdot i\right)$$

Here F denotes the Fourier transform, W the wavelet transform, TV the total variation, i the image in the wavelet domain and y the measured data. The parameters λ_w and λ_{tv} were determined as follows. Data acquired from another volunteer according to the (HighRes) acquisition scheme was randomly undersampled. Four randomly selected slices were reconstructed using CS with parameters of λ_w and λ_{tv} varying between 0 and 0.02 in steps of 0.0005. The reconstruction with the best parameter combination was finally found by determining the minimum artifact power between the conventional reconstructions from the fully sampled data and the CS reconstructions for the selected slices.

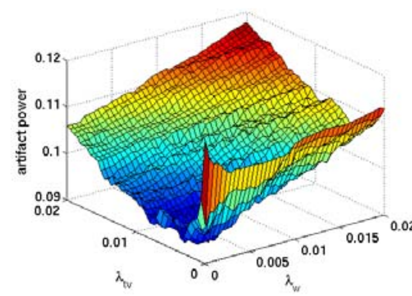

Fig. 2: Artifact power over λ_w and λ_{tv}.

Results

Fig. 2 shows the artifact power obtained for the different values of λ_w and λ_{tv}. The values λ_w^{opt} = 0.0065 and λ_{tv}^{opt} = 0.0035 obtained at the minimum artifact power were used for the reconstruction of the real undersampled data set (Random). Fig. 3 shows one slice reconstructed as described above for the different data sets. The (HighRes) and the (LowRes) reconstructions (Fig. 3a and 3b) show no motion artifacts but low signal (in particular the (HighRes) reconstruction) due to the high values of TE. In the reconstruction from the (2Shot) data the signal quality is improved, but misregistrations can be seen in the image. This is because the data was acquired with two shorter echo trains, each at a different breathing state. Hence snapshots from different breathing states are superimposed in the image. The CS reconstruction of the (Random) data set (Fig. 3d) shows finally good signal quality and no motion artifacts. Most reconstruction artifacts are successfully suppressed as well. In contrast to that the conventional reconstruction of the (Random) data where missing lines were filled with zeros contains artifacts all over the image due to the zero lines (Fig. 3e).

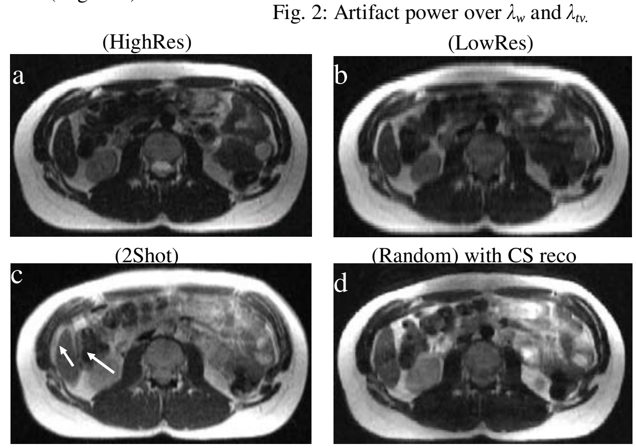

Fig. 3: Images reconstructed from the different data sets. The arrows in Fig. 3c indicate motion artifacts, the arrow in Fig. 3e reconstruction artifacts.

Discussion

The compressed sensing technique was shown to be a fast method for the reconstruction of snapshot images from a CMT acquisition performed during free breathing. Motion artifacts were successfully avoided – in contrast to the images reconstructed from the (2Shot) data – and good signal quality was obtained since the echo train was shorter than for the (HighRes) and the (LowRes) acquisition. Furthermore a fully automatic method for the estimation of the reconstruction parameters λ_w^{opt} and λ_{tv}^{opt} was proposed which could be used independently of the imaged subject for the studied data. In future studies the stability of the CS method for free breathing CMT-MRI and its applicability to patient data has to be evaluated. In particular it must be shown whether the prior knowledge used about the data (smoothness, sparsity in the transform domain) has an impact on the ability to identify lesions of interest. The robustness and the generality of the parameter estimation method have to be proven as well. A further speedup or an improvement of the image quality could be achieved by performing the random sampling and CS reconstruction in the hybrid k_y-z space [3] instead of separately for each slice.

References

[1] H. P. Fautz, et al.: Magn. Reson. Med., 2007. **57**(1): p. 226-232. **[2]** M. Honal, et al.: Proc. of SPIE Medical Imaging, 2008: p. 69130G **[3]** M. Lustig, et al.: Magn Reson Med, 2007. **58**: p. 1182-1195. **[4]** J. Hennig, et al.: Magn. Reson. Med., 2003. **49**: p. 527-535.