Fast Parallel Spiral Chemical Shift Imaging at 3 Tesla Using Iterative SENSE Reconstruction

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Introduction

Spiral chemical shift imaging (CSI) [1] reduces the scan time of a CSI experiment by acquiring the time domain data while playing out spiral gradient waveforms along two spatial dimensions. This achieves the simultaneous encoding of both spatial and spectral information and theoretically permits the acquisition of a complete 2D CSI data set with a single excitation. However, for most applications, limitations on maximum gradient strength and slew rate usually make multiple excitations necessary in which either the start of the data acquisition is shifted (spectral interleaves) or the spiral k-space trajectories are rotated (spatial interleaves). Gradient limitations are even more a problem at higher field strength because of the increased dispersion of the chemical shift. While parallel imaging techniques are commonly used even in non-Cartesian imaging to speed up the acquisition, so far, they have been only applied to CSI using conventional phase encoding [2] and echo planar spectroscopic imaging [3]. Therefore, the aim of this work was to reduce the minimum total measurement time (T_{min}) of spiral CSI by using an iterative sensitivity encoding (SENSE) reconstruction algorithm [4].

Methods

All measurements were performed on a GE 3 T MR scanner equipped with self-shielded gradients (40 mT/m, 150 mT/m/ms). A quadrature birdcage body coil was used for RF excitation and an 8-channel head coil for signal reception. The body coil was also used for signal reception to estimate the coil sensitivities of the phased array using a fast gradient recalled echo imaging sequence. The sequence was tested on a spherical phantom filled with a solution of various brain metabolites at physiological concentration levels.

A spiral CSI sequence with point resolved spectroscopy (PRESS) volume pre-selection [5] was used with TE = 144 ms. The spiral gradient waveforms were designed for 4 spatial interleaves with a FOV of 24×24 cm^2 for a 16×16 matrix and a spectral width of 1202 Hz. Due to hardware restrictions the number of data points acquired continuously at the readout bandwidth of 250 kHz was 16K. The gaps between consecutive readouts were synchronized with the rewinder part of the spiral gradient waveforms. For a TR of 2 s, the total measurement time was 16 s including 4 excitations without data acquisition to establish a steady state. To simulate accelerated data acquisition, the data set was subsampled by using only every R^{th} interleaf (R = 1, 2, and 4).

Apodization in the time dimension of the data set comprised 3-Hz Gaussian line broadening and zero-filling up to 1K points. After performing a 1D Fourier transform along the time dimension, the chemical shift artifact along the readout was removed by a frequency-dependent linear phase correction. Reconstruction in the spatial dimensions was accomplished by a variant of iterative SENSE reconstruction using the conjugate gradient method and a transfer function approach [6]. Depending on R, different numbers of iterations (n_{it}) were used (R = 1: n_{it} = 5; R = 2: n_{it} = 30; R = 4: n_{it} = 80). Alternatively, a sum of squares (SoS) reconstruction was accomplished by setting all coil sensitivity information to "1". Using n_{it} = 1, this is similar to gridding reconstruction without correcting for coil sensitivity variation.

Each data set was then Fourier-interpolated in both spatial dimensions by a factor 2. After 0^{th} order phase correction, metabolic images were calculated by integrating the resonances in absorption mode and subtracting the baseline contributions from the residual water.

Results and Discussion

Using the PRESS volume pre-selection, an approximately 2(z)×11(x)×11(y)-cm^3 box selected the top, right sector of the sphere (Fig. 1). Metabolic images of NAA reconstructed with R=1 and R=2 for both SoS and SENSE are shown in Fig. 2. Subtle differences in relative image intensities between Fig. 2a and 2b are due to normalization with coil sensitivities. Due to insufficient k-space sampling, the image reconstructed with R=2 and SoS (Fig. 2c) is severely aliased. Considering that only half of the data were used for the image reconstructed with R=2 and SENSE (Fig. 2d), the image is comparable to the one reconstructed with R=1 and SoS (2b). Minimum spatial aliasing artifacts for observed. In contrast, even the image reconstructed with SENSE showed severe artifacts for R=4 (data not shown). Figure 3 depicts spectra from two different voxels for each of the four data sets. While the spectra from a voxel inside the PRESS box agree very well for all four different reconstruction variants, the spectra reconstructed with R=2 and SoS displays substantial aliasing artifacts in the voxel outside the pre-selected volume. The different baseline levels are due to residual water also affected by the reconstruction.

Conclusion

The presented data demonstrate the feasibility of reducing T_{min} of fast spiral CSI by using iterative SENSE reconstruction. Phased array coils generally suffer from intensity modulation from varying B_1 field. The conjugate gradient SENSE algorithm inherently removes these modulations. The reduction in the number of spatial interleaves is beneficial when extending CSI to incorporate multiple frequency dimensions.

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References

[1] Adalsteinsson E, Spielman DM, *MRM* 41, 8-12, (1999). [2] Dydak U et al., *MRM* 46, 713-722 (2001).
[3] Otazo R et al., *Proc. ISMRM 2006*, 69. [4] Pruessmann KP et al., *MRM* 46, 638-651 (2001).
[5] Kim, DH et al., *Proc. ISMRM 2002*, 2493. [6] Wajer FTA, Pruessmann KP, *Proc. ISMRM 2001*, 767.

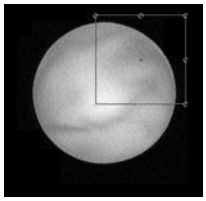

Fig. 1: MRI of the phantom (position of the PRESS box indicated).

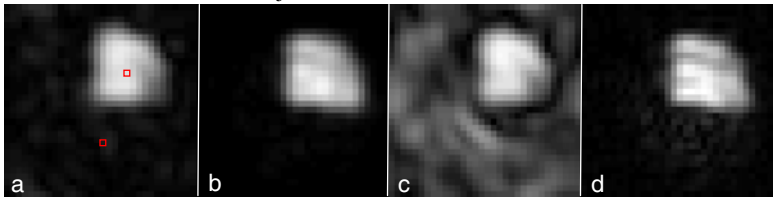

Fig. 2: Metabolic images of NAA: (a) R = 1, SoS (b) R = 1, SENSE, (c) R = 2, SoS, and (d) R = 2, SENSE.

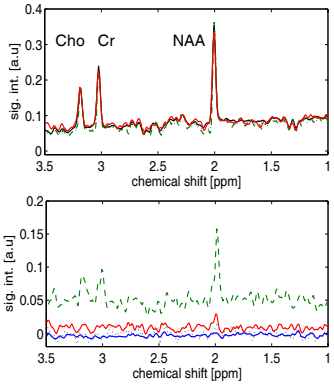

Fig. 3: Spectra from a voxel inside (top) and outside (b) of the PRESS box (locations indicated in Fig. 2a) for R=1, SoS (dotted black), R=1, SENSE (solid blue), R=2, SoS (dashed green), and R=2, SENSE (solid red)