Compressed sensing-accelerated spectroscopic imaging to obtain geometrically accurate water & fat images and field maps for use in MR-guided interventions

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Introduction:

In MR-guided interventions it is often crucial to minimize geometric distortions due to chemical shift and susceptibility effects, which are present in the image domain when frequency encoding is used for spatial localization. These distortions hamper geometrically accurate T_2* mapping, localization of the water-fat distribution and the field distribution, which can have detrimental effects in e.g. radiotherapy planning [1], MR guided HIFU ablation, MR thermometry and attenuation correction in MR/PET [2,3,4].

In this work a spin-echo (SE) spectroscopic imaging (SI) sequence is investigated for its ability to enable geometrically accurate water-fat decomposition and field map calculation. Since only phase encoding is used in the SE-SI sequence, off-resonance effects do not interfere with spatial encoding. Therefore, each sample can be used to produce an undistorted image, resulting in a series of so-called single point images, each with a different T_2* weighting. Depending on the goal of the study these images can be used in many ways, for example to increase SNR by (complex) averaging or to map T_2*. Here the aim is to obtain geometrically undistorted water & fat images and field maps, which can be accomplished by combining the spectroscopic information and the phase evolution of the SE-SI signal. To decrease the inherently longer acquisition times of phase encoded images we propose to make use of compressed sensing [5] and provide an example of the reconstruction of the data with retrospectively undersampled data.

Methods:

A healthy volunteer was scanned on a 3T MR system (Philips Achieva) with an 8 channel head coil. A transversal slice including the nasal cavities and sinuses close to the ears was selected assuring the presence of susceptibility induced signal dephasing and image distortions in the frequency encoding directions. Accurate visualization of these problematic areas is of particular interest for radiotherapy treatment planning for head-and-neck cancer. Data from the conventional SE and the SE-SI sequence was acquired with an acquisition matrix of 92x92, voxel size 2.78x2.78x10mm, FOV 256mm and TR/TE of 100/30ms. A 2D-SE was acquired in 20 seconds with NSA=2 and the bandwidth at 118.5 Hz/pix (Fig 1a). A 2D-SE-SI dataset was acquired in 11 minutes and 4 seconds with a 2D spin echo spectroscopic imaging sequence using a spectral width of 4000Hz and 64 data points symmetrically sampled with respect to the echo. In addition to the 64 undistorted images in the time domain, 64 spectroscopic images with a spectral bandwidth of 62.5Hz each were obtained by Fourier transforming the time domain signal. The spectra were retrospectively corrected for B_0 inhomogeneities by matching a theoretical spectrum containing two peaks with a 3.35 ppm difference with the measured spectra to improve the water fat separation. To obtain a water only image the signal in three adjacent frequency bins was summed (corresponding to 0Hz – 125Hz with respect to f_0, Fig 1f) as shown in Fig 1h. Similarly a fat only image was obtained by summing three frequency points (corresponding to -437Hz – -312.5Hz with respect to f_0, Fig 1g) as shown in fig 1j. The geometrically undistorted phase data from the total signal was used to produce a field map (Fig 1e), which was separated in field maps with voxels containing predominantly significant water or fat signal (Fig 1i,k) by multiplication of the field map with a mask from the water or fat frequency derived from Fig 1h,j. To demonstrate the possibility to dramatically reduce scan time of the SE-SI sequence an undistorted image was retrospectively undersampled and reconstructed using a compressed sensing algorithm [5]. The image was reconstructed with undersampling factors of 5 and 8 (20% and 12.5% of k-space data) using total variation minimization as the sparsifying transform and 20 iterations (Fig 1c-d). It has been shown that the reconstruction algorithm can be used on the total spectroscopic imaging data set and retain the spectroscopic information [6].

Results:

Geometric inaccuracies can be observed when comparing the SE-image in Fig 1a to the undistorted single point image in Fig 1b due to both chemical shift differences of water and fat (wfs) and susceptibility effects (sus1&2). The effect of reconstruction of retrospectively undersampled data from Fig 1b can be seen in figure 1c-d where no significant loss of geometric accuracy is visible up to 5x undersampling. Loss of geometric accuracy surrounding the nasal cavities can be observed for an undersampling factor of 8. In the field map in Fig 1e significant gradients near the nasal cavities can be observed, which could hamper accurate separation of water and fat. Fig 1i shows the field map from voxels containing predominantly water signal and B_0 deviations can be seen close to the border with air or fat. Fig 1k shows a field map for voxels containing predominantly fat signal, which shows B_0 deviations at the hyperintense structures at the center of the image.

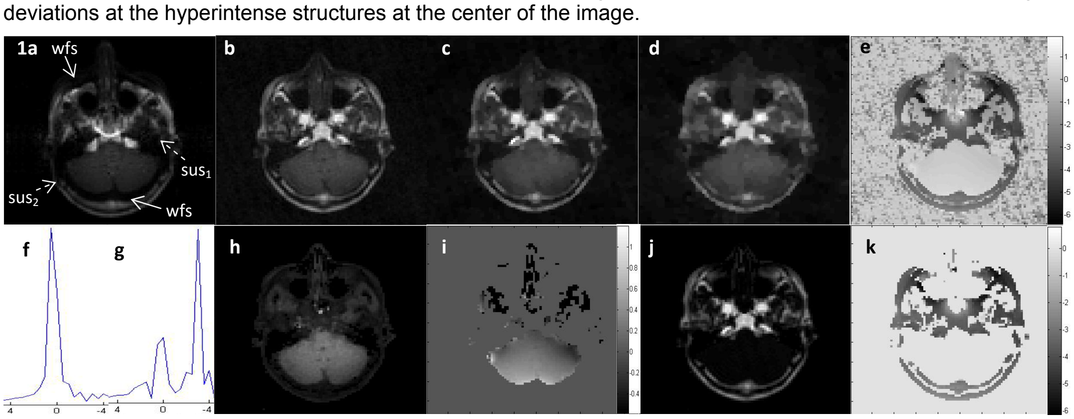

Fig 1a SE image, **b** single point SE-SI image, **c-d** image reconstructions from 20% (c) and 12.5% (d) k-space data of Fig 1b, **e** SE-SI field map (in ppm), **f** spectrum of water signal in gray matter (in ppm), **g** spectrum of fat signal at the border of the skull (in ppm), **h** spatial distribution of the water frequency, **i** field map of voxels containing mainly water (in ppm), **j** spatial distribution of the fat frequency, **k** field map of voxels containing mainly fat (in ppm)

Discussion and conclusion:

Single-point images derived from a SE-SI data set produce geometrically accurate images in the presence of magnetic field perturbations. In this respect the results are superior over the conventional SE acquisition with similar parameters, which is of importance for radiotherapy treatment planning. In addition geometrically accurate images of the water and frequency distribution and water and fat field maps are shown, which is useful for MR thermometry in water or fat intense environments and MR/PET attenuation models. Shortening of the TR in combination with implementation of optimized undersampling schemes on the MR system could result in an acquisition time around 1 minute for a similar 2D SE-SI data set as presented in this work.

References:
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