Towards compressed sensing accelerated geometrically undistorted Single Point Images under 10 seconds

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Introduction:
When frequency encoding is used, MR images suffer from geometric distortions due to chemical shift and susceptibility effects, which hamper accurate localization. Single Point Imaging (SPI) [1] does not suffer from these effects in the phase encoding directions and provides geometrically undistorted images and field maps, which is important in radiotherapy treatment planning [2]. In areas where strong field disturbances are present such as close to iron and prostheses [3,4] significant geometric distortions are present in conventional sequences and SPI could improve the measurement of the surrounding tissue. The major disadvantage of SPI is the excessive scanning time, which has limited the use of SPI for clinical purposes.
In this work a 2D Free Induction Decay (FID) spectroscopic imaging (SI) sequence is adapted to produce a series of undistorted single point images in plane, within a reasonable time frame. The acquisition time is decreased through the use of a small number of data points, which can be further decreased (or be used to allow for higher spatial resolution) in the future using undersampling schemes or parallel imaging. To show the potential of recently developed reconstruction methods the data is retrospectively undersampled and reconstructed with a compressed sensing algorithm [5]. As multiple single point images are acquired in a single data set, these images can be used to study T2* dephasing effects or averaged to increase the SNR. In this work data from a transversal slice through the nasal cavities is presented as a known problem area due to the presence of susceptibility effects and is of particular interest in radiotherapy treatment planning.

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. Data from a conventional Gradient Echo (GE) and a FID-SI sequence was acquired with an acquisition matrix of 91x91, voxel size 2.81x2.81x10mm, FOV 256mm and 10° flip angle. The GE acquisition with TR/TE=5.0/2.3ms and a bandwidth of 285Hz/pix was acquired in 0.93 seconds (Fig 2a). The FID-SI acquisition with TR/TE=5.4/1.5ms, a spectral width of 8000Hz and 16 data points was acquired in 35 seconds, resulting in 16 single point images with different T_2* weightings corresponding to'echo times' of t0+(n-1)dt, met t0=1.5ms for a 10mm slice and 1.82ms for a 5mm slice and dt=0.125ms. A second FID-SI acquisition with a 5mm slice thickness to minimize partial volume effects and TR/TE=6.7/1.82ms was performed in 45 seconds (Fig 1a-e). The GE and the 7th FID-SI image with 10mm slice thickness corresponding to an equal point in time (TE=2.3ms, t0+6*dt)) were divided by their mean intensity to equalize the signal intensity level (Fig2a-b). The FID-SI image was subtracted from the GE image to highlight the differences (Fig 2c). The geometrically undistorted phase data from the total signal was used to produce an undistorted field map (Fig 2d). To demonstrate the possibility to further 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 4 and 5 (25% and 20% of k-space data) using total variation minimalization as the sparsifying transform and 40 iterations (Fig 1d-e).

Results:
In Fig 1a-c the effect of complex summation of 1,4 and 13 images in the time domain can be observed. The summation of 4 images does not result in additional dephasing effects and can be used to increase the SNR in the current situation, while loss of signal surrounding the nasal cavities can be seen when 13 images are averaged. In Fig 1d-e the retrospectively undersampled and reconstructed images using a compressed sensing algorithm can be seen. The geometric detail is preserved using either a factor 4 or 5 undersampling, while more detail remains when a factor 4 is used. In Fig2a-b, a GE image is shown along the corresponding SPI and both images were divided by their mean for comparison. The difference between the GE and FID-SI image are highlighted in Fig 2c where the arrows indicate hyperintensities in the GE images that can be attributed to chemical shifts or susceptibility effects. Fig 2d shows an undistorted field map derived from the FID-SI phase data. The field map confirms that differences between the GE and SI images in Fig 2c are located in the areas where significant field inhomogeneities are present.

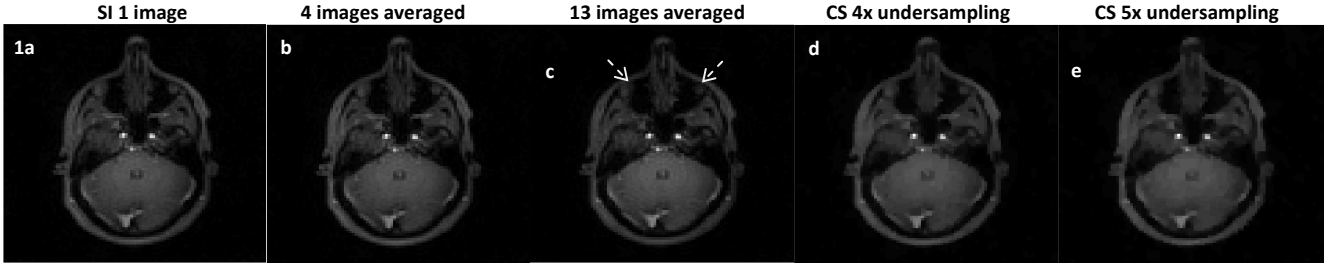

Fig 1a-c FID-SI images from a 5mm slice where the arrows indicate additional loss of signal due to averaging over time, d-e Retrospectively undersampled data reconstruction of 1a with compressed sensing using 25% and 20% of k-space data.

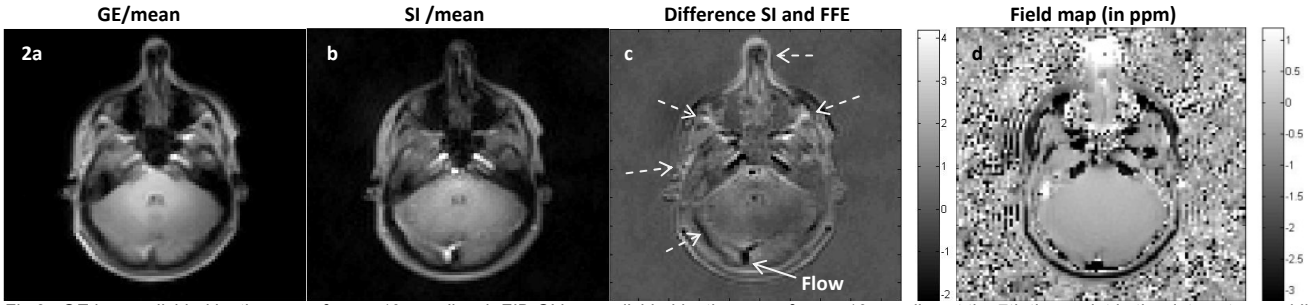

Fig 2a GE image divided by the mean from a 10mm slice, b FID-SI image divided by the mean from a 10mm slice at the 7th time point in the data set resembling TE=2.3ms, c Difference image of a and b where the arrows indicate significant differences between the two images, d Field map derived from the FID-SE data set.

Conclusion:
The 2D-FID-SPI sequence provides geometrically undistorted results in plane and is superior in this respect to low resolution GE images with normal bandwidth settings. The observed differences will increase when larger magnetic field perturbations are present such as in iron rich environments or near prostheses. Complex averaging of a number of these undistorted images from a single data set can be used to increase SNR as long as T_2* effects do not cause significant dephasing of the signal. Other averaging methods can be explored to make more efficient use of the data. The implementation of undersampled data acquisition on the MR system is expected to bring the current acquisition under 10 seconds or to increase the spatial resolution by a factor of 2. An accelerated acquisition in combination with implementation of ultra short echo times offer perspectives for the use of FID based SPI techniques in clinical areas.

References:
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