Direct SENSE imaging for fast, multi-echo fMRI over a restricted field of view

Mark Chiew[1,2], and Simon J Graham[1,3]

[1]Medical Biophysics, University of Toronto, Toronto, Ontario, Canada, [2]Rotman Research Institute, Toronto, Ontario, Canada, [3]Imaging Research, Sunnybrook Research Institute, Toronto, Ontario, Canada

Introduction: Functional magnetic resonance imaging (fMRI) data acquisition can suffer from lack of sensitivity, and in the case of whole-brain imaging, lack of temporal resolution. Multi-echo fMRI methods have been developed to increase contrast-to-noise ratio (CNR) by acquiring and strategically combining multiple images at varied echo times during a single RF excitation [1]. Parallel imaging techniques such as SENSE have emerged as useful tools for reducing acquisition time [2], and restricted field-of-view (FOV) methods have been developed to provide improved temporal sampling over selected regions of interest (ROIs). Here, a new method is proposed for collecting densely sampled data across a set of distinct ROIs at very low repetition times (TR as low as 50 ms), using coil sensitivity encoding. This new method, called "DSI" (Direct SENSE Imaging), uses a modified STEAM [3] localization technique for selective ROI excitation and direct encoding of spatial information using coil sensitivity profiles, with a readout containing both T2 and T2* contrast acquired in the absence of imaging gradients. Here, we initially demonstrate the DSI technique using a prototype implementation for acquiring fast multi-echo fMRI data in a 4-voxel experiment.

Theory: In general, parallel imaging methods reduce the spatial encoding required from imaging gradients for full image reconstruction. When spatial encoding is viewed as a simple linear system [4], parallel imaging amounts to removing rows from the encoding matrix due to the fact that each receive coil in a multi-channel array applies its own encoding as well. The full encoding matrix is achieved by multiplying the gradient encoding steps by the number of coils. In standard Fourier encoded imaging, each encoding matrix row represents a particular combination of read and phase gradients which take time to apply, and significant time savings are gained by skipping steps using parallel imaging. In practice, entire phase encoding lines are typically dropped, and the overall reduction factor in encoding time is related to the number of receive coils available. Ideally, with N independent coils, a factor of N reduction would be achievable - in practice however, often much smaller acceleration factors are used as the coils are not fully independent. In the encoding matrix, the number of required rows or encoding steps is at least the number of voxels in the output image. Using a reduced FOV approach however, greatly limits the number of voxels M, and if M << N, spatial encoding can be performed directly by coil sensitivity encoding, without requiring any Fourier encoding at all. Recovery of the signals in each of the M ROIs or voxels becomes a matter of simply inverting the encoding matrix, which is comprised entirely of coil sensitivity data. One major underlying assumption in the inversion of the linear system is that the coil sensitivities are approximately constant over the ROI, which constrains the size and possibly the placement of the ROI locations.

Methods: Sequence development and testing were performed using a Siemens 3T TIM Trio (VB15). We used a modified STEAM localization scheme (Fig. 1) to achieve a 4-voxel reduced FOV. The primary differences here from a standard STEAM sequence are that the 1st and 3rd radiofrequency (RF) pulses are dual-band, and excite or refocus spins in 2 planes with user-controlled widths and separation. The intersection points of these orthogonal pairs of planes define the ROI locations, along with the 2nd RF pulse which dictates the plane of the 4 voxels. Additionally, the flip angle α of the 3rd RF pulse can be set < 90º, to accommodate faster imaging [5]. Standard imaging gradients can be inserted easily for standard 2DFT readouts, which are used for validation of the ROI placement. In the prototype implementation, TM = 9 ms, TE = 25 ms and TR = 100 ms, were chosen to minimize T1 contrast, while optimizing T2 contrast and imaging time. Because data acquisition begins at TE/2 after the 3rd RF pulse, the amplitude of the free induction decay (FID) is T2 weighted, whereas the FID itself is a densely sampled T2* decay. Coil sensitivity profiles were generated using a pair of 3D T1 MPRAGE acquisitions, one using the body coil, and one using a 32 channel soccer ball geometry head coil [6]. The encoding matrix was generated using the coil sensitivity maps and the known voxel coordinates, and the raw data were kept in complex form throughout the reconstruction. Here, data were acquired with α = 90º, and 1024 spectral points at 16.4 kHz acquisition bandwidth on a cylindrical bottle phantom. ROIs were 5 mm^3 cubic voxels placed in the centre of the phantom, and 256 measurements (25.6 s total imaging time) were acquired.

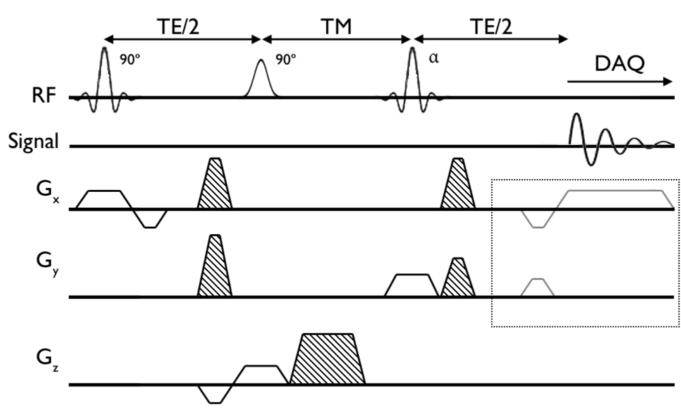

Figure 1 – Schematic of the modified STEAM localization. The shaded regions represent gradient spoiler pulses, and the light grey pulses inside the dashed box represent optional 2DFT imaging gradients.

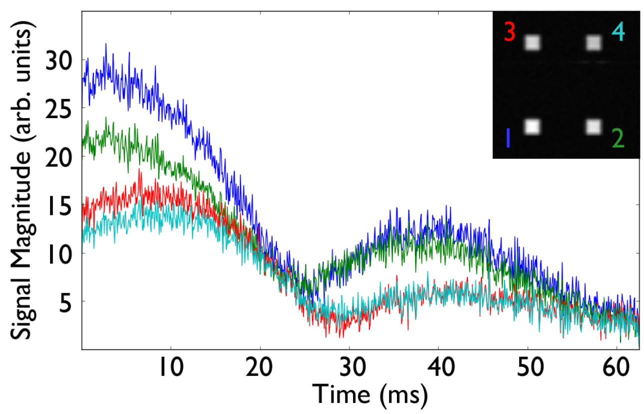

Figure 2 – Reconstructed FIDs from the 4 ROIs showing off-resonance modulation, taken from measurement #100 out of 256. Inset shows a 1x1 mm^2 2DFT image taken with the modified STEAM localization. Relative signal amplitudes between the ROIs are preserved when comparing the FIDs and the image amplitudes.

Discussion: The DSI technique builds on both the MR encephalography [7] and inverse imaging [8] techniques for fast brain imaging. Simulations (not shown) and experimental data indicate that DSI is capable of collecting finely sampled FIDs at high temporal resolutions. These 1024 point FIDs collected at 100 ms intervals can be interpreted as very densely sampled multi-echo fMRI data, which can be processed to produce very robust BOLD time-series data [9]. The reduced FOV approach has number of applications, including targeted investigations of BOLD signal latencies between ROIs, where both signal robustness and temporal resolution are desirable. When combined with water and fat suppression, this technique can theoretically be used to acquire spectroscopy data across multiple ROIs in exactly the same amount of time as a traditional single voxel spectroscopy acquisition. This can be applied to investigations in temporally resolved spectroscopy as well as MR thermometry, where DISSI can provide absolute temperature estimates in various ROIs. While the current prototype implementation demonstrates 4 cuboid ROIs, in principle more can be localized as long as the ROI number is significantly less than the number of receive coils. With better shimming procedures to reduce spurious off-resonance effects, this technique shows promise as an alternative to whole-brain fMRI for fast imaging in targeted, ROI-based investigations.

References: [1] Posse, S., et al., *Magn Reson Med* 1999; 42(1): 87-97 [2] Pruessmann, K.P., et al., *Magn Reson Med* 1999; 42(5): 952–62 [3] Frahm, J., et al., *J Magn Reson* 1985; 64(1): 81-93 [4] Sodickson, D.K., et al., *Medical Physics* 2001; 28(8): 1629-43 [5] Frahm, J., et al., *Magn Reson Med* 1991; 22(1): 133-42 [6] Wiggins, G.C., et al., Magn Reson Med 2006; 56(1): 216-23 [7] Hennig, J. et al., *Neuroimage* 2007; 34(1): 212-9 [8] Lin, F.H., et al., *Magn Reson Med* 2006; 56(4): 787-802 [9] Chiew, M., et al., *IEEE Trans Med Imaging* 2011; 30(9): 1691-1703