Self-calibrated and -navigated Parallel Imaging for Diffusion and Perfusion MRI

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INTRODUCTION:

Trajectory designs that oversample the origin of *k*-space are of particular interest for parallel imaging (PI) since they provide inherent self-calibration capabilities and allow one to extract important phase information for navigation purposes. These aspects are especially attractive when applied to multi-shot diffusion and perfusion imaging and/or in the presence of bulk physiologic motion where the correspondence between calibration and parallel imaging scan might be perturbed. In this work, we will discuss diffusion and perfusion methods based on variable-density spiral (VDS) waveform designs[1] that offer the aforementioned navigation and calibration properties.

METHODS:

For both, phase-navigation and coil sensitivity estimation, low-resolution images are generally sufficient. Therefore, the design parameters of our VDS can be adjusted so that for $k_r < k_{,rmin}$ the *k*-space trajectory obeys the Nyquist criterion for each interleave, whereas for $k_r > k_{r,min}$ the *k*-space is undersampled. The fully sampled center portion (~20x20) allows the reconstruction of low-resolution calibration images that can be utilized as coil sensitivity input for the PI reconstruction of the entire data set (Fig. 1). The VDS design can be either a bi-density spiral or a design with continuously varying spiral pitch. In case of diffusion imaging, a non-linear phase correction as outlined by Liu *et al*[2] has to be applied prior to the CG iteration of the SENSE recon. For the correction, the relevant phase information can be used from the low resolution images reconstructed from the VDS scan. All of our measurements were performed on 1.5T clinical scanners (GE Signa LX, Excite, 11.0) using an 8-channel neuroarray (MRDevices).

RESULTS:

For dynamic susceptibility-weighted perfusion imaging, the VDS was combined with a novel spiral-OUT-spiral-IN sequence that allows one much better measurements of the arterial input (ie, early echo, less distortions) without loosing T2* sensitivity at the second echo (Fig.2). Saturation effects and shape distortions of the arterial input function as well as geometric distortions could be significantly reduced with the self-calibrated, multi-shot scan. Moreover, the level of geometric distortions in the diffusion scans could be also reduced dramatically by the parallel imaging approach. Despite the use of an interleaved spiral approach, the information extracted from the low-res portion of the VDS suffices for phase-navigation and to compute reliable, high resolution images.

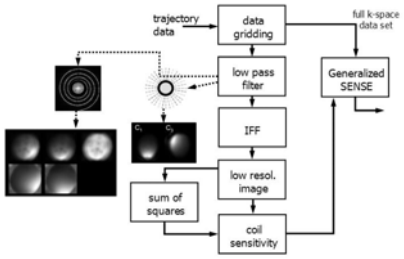

Figure 1: From the critically sampled data around the origin of k-space low resolution images can be computed. These images serve one to compute coil sensitivity and phase-navigation information that can be entered into the conventional CG SENSE reconstruction.

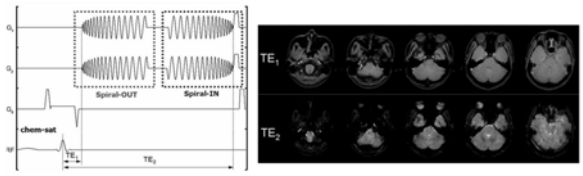

Figure 2: (left) Interleaved Spiral-OUT-spiral-IN VDS pulse sequence for improved dynamic susceptibility-weighted perfusion imaging (temporal resolution 2s). (right) The first (top) and second echo images are of remarkable quality and provide much better raw data for quantitative perfusion analysis than an EPI-based approach.

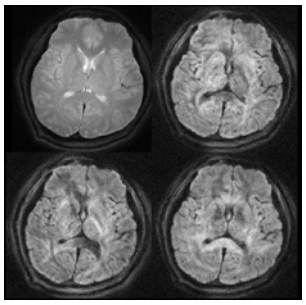

Figure 3: Phase-navigated multi-shot diffusion-weighted spin echo VDS imaging with diffusion encoding along 3 different directions. Top left unweighted image.

DISCUSSION:

The VDS approach allows us to compute coil sensitivity and phase navigation information without additional calibration scans or navigator echoes and reduces reconstruction errors. One major limitation of the current implementation (especially for the perfusion method) we encountered, thus far, is the reconstruction times of the iterative CG method and warrants further speed-up (parallel processing, spiral GRAPPA, …).

REFERENCES:

[1] Kim DH, Adalsteinsson E, *et al*. Simple analytic variable density spiral design. MRM 2003; 50:214-219.

[2] Liu C, Bammer R, *et al.* Self-navigated Interleaved Variable Density Spiral Diffusion Tensor Imaging. MRM 2004; in press.

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