Conjugate Gradient Correction And Reconstruction Of Multishot Diffusion Weighted Variable Density EPI

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Introduction: Diffusion weighted imaging (DWI) can produce images with severe phase variations due to motion sensitivity induced by strong diffusion encoding gradients. Single shot EPI methods avoid the problem by acquiring all lines of k-space with a single set of gradients, but suffer from limited resolution. Parallel imaging methods have been shown to improve the resolution of DWI and reduce distortion from susceptibility by reducing the echo train length required for EPI [1]. A multishot EPI approach could potentially reduce echo train length even further, but such methods are susceptible to ghosting artifacts due to intershot phase variations. A self-calibrated, variable density EPI (VD-EPI) trajectory fully samples the center portion of k-space with each shot, which could be used to measure both the phase error from motion [2] and the coil sensitivity for parallel imaging. However, conventional multishot phase correction techniques do not adequately correct undersampled regions of k-space [3,4]. Recently, an iterative conjugate gradient (CG) reconstruction algorithm was demonstrated for undersampled VD multishot non-Cartesian acquisitions [4]. The CG technique enables self-calibrated reconstruction of accelerated acquisitions while simultaneously correcting for intershot phase variations. This study extends the iterative CG algorithm to a multi-shot accelerated VD-EPI trajectory to minimize ghosting artifacts in DW EPI.

Methods: A multishot DW EPI pulse sequence was designed to fully sample the center 1/8 of k-space at the Nyquist rate for each shot. Echo train shifting of the undersampled outer portions was applied to reduce discontinuities from T2* magnitude scaling and phase evolution during each readout. For accelerated imaging, the outer portions were undersampled further by a reduction factor of 2 to reduce ETL. Phantom and in-vivo images were acquired with this sequence and with diffusion weighted single shot spin echo EPI on a clinical 1.5T whole body scanner (GE Signa Excite, GE Healthcare Technologies, Waukesha, WI). Imaging parameters for the multishot sequence were: TR = 3000 ms, TE = 120 ms, BW = +/- 100 kHz, FOV = 24 cm, matrix = 128x128, slice thickness = 5 mm, b = 0 and 500, diffusion weighting directions = 3, number of shots = 3, peripheral cardiac gating active. For all acquisitions, sampling was restricted to the flat portions of the readout gradients to simplify reconstruction for this experiment.

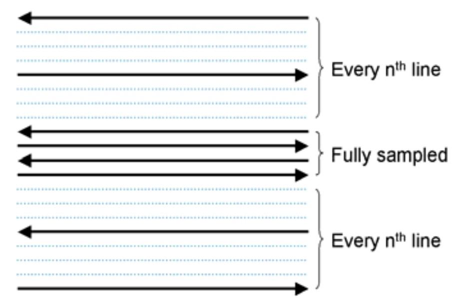

Figure 1. VD-EPI trajectory for n shots. Every n^{th} line in the outer parts of k-space is acquired while the center is fully sampled. Outer regions are spaced further by an acceleration factor for parallel imaging.

All multishot image reconstructions were performed offline (Sun Microsystems, Santa Clara, CA) using Matlab (Version 7, The Mathworks, Inc., Natick, MA). Using the central portions of k-space, data acquired without diffusion weighting gradients was used to generate sensitivity maps for parallel imaging, and phase error maps for each shot were generated by multicoil combination of phase differences between data acquired with and without diffusion weighting gradients. The resulting sensitivity and phase error maps were utilized in the iterative conjugate gradient phase correction algorithm. The same raw data was also reconstructed using a simple density corrected summation of the shots, with a refocusing reconstruction algorithm [3], and with generalized SENSE [5] applied to the data corrected by the refocusing algorithm.

Results: Images are shown in figure 2. Ghosting artifacts were noticeably reduced in images produced by the iterative CG algorithm compared to those of the other reconstructions. Applying SENSE reconstruction after refocusing phase correction still produced some observed residual artifacts.

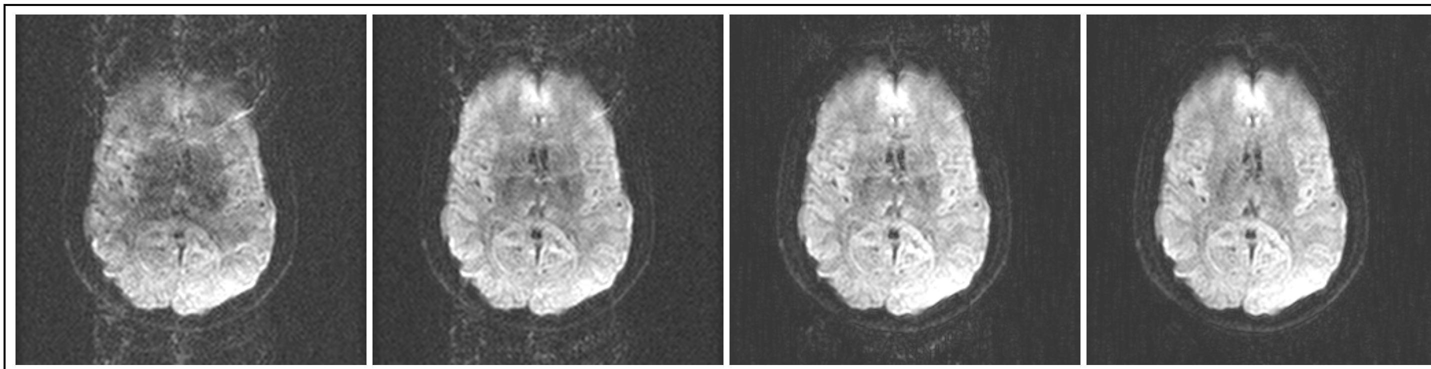

Figure 2. Diffusion weighted volunteer brain images acquired with acceleratedDW multishot variable density EPI. The same data was reconstructed with a) density corrected summation, b) refocusing phase correction c) refocusing phase correction followed by SENSE, and d) the CG algorithm.

Discussion: We have shown that iterative CG phase correction and parallel imaging reconstruction can be applied to self-calibrated mutlishot EPI while reducing artifacts seen with other reconstruction techniques. The refocusing algorithm is effective in correcting phase errors for fully sampled data, but undersampling has an aliasing effect on phase errors in the image; hence performing SENSE reconstruction on data corrected with the refocusing algorithm leads to imperfect unwrapping of aliased signal. The CG algorithm effectively performs both the refocusing phase correction and SENSE reconstruction simultaneously by taking both the measured phase error and coil sensitivity information into account.

References: 1. Bammer R et al, MRM 46:548-554. 2. Nunes RG et al, MRM 53:1474-1478. 3. Miller KL and Pauly JM, MRM 50:343-353. 4. Liu C et al, MRM 54:1412-1422. 5. Pruessmann KP et al, MRM 46:638-651.