Multi-shot SENSE DWI at 7T

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INTRODUCTION: Diffusion weighted images (DWI) are commonly acquired using single-shot methods combined with parallel imaging (1) to reduce acquisition time and artifacts related to susceptibility and T2* blurring (2). For high-resolution DWI, however, multi-shot sequences are necessary and shot-to-shot phase variations must be corrected using an additional navigator-echo (3,4) or self-navigated acquisitions (5) to measure erroneous phase terms due to subject motion during diffusion gradients. Recently, reconstruction schemes have been proposed that combine multi-shot (6) and parallel imaging (7) using iterative conjugate gradient phase correction or using variable density EPI for self-calibration and navigation (8). In this study we propose a simplified method for multi-shot SENSE DW images using a conventional interleaved EPI sequence. A preliminary DWI study at 7 Tesla is presented.

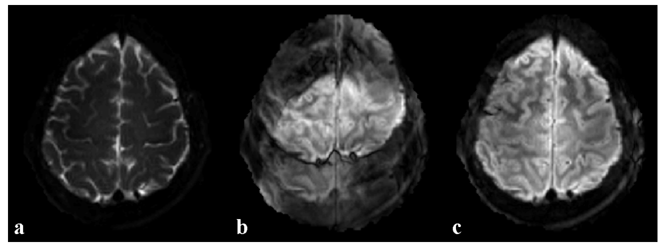

Figure 1. Multi-shot SENSE reconstruction images for *b*=0 (a) and 700 s/mm^2 without (b) and with (c) phase correction.

METHODS: The aliased image, **g**, due to undersampling of *k*-space can be expressed as,

$$\mathbf{g} = \mathbf{E} \cdot \mathbf{f}, \qquad [1]$$

where **E** is an encoding matrix and **f** is the ideal unaliased image. For the reconstruction of phased-array coil data, including the effects of aliasing, coil-sensitivity and extra-phase due to subject motion, Eq.[1] can be expanded as,

$$\mathbf{g}(j, s, c) = \mathbf{A}(s) \cdot \mathbf{S}(j, c) \cdot \mathbf{P}(j, s) \cdot \mathbf{f}(j) \qquad [2]$$

where, **A**(*s*) is a folding matrix, **S**(*j*, *c*) is a diagonal matrix of the c^{th} coil-sensitivity and **P**(*j*, *s*) is a diagonal matrix of the s^{th} extra-phase due to subject motion, both for the j^{th} image column. Then **E** is a matrix combining **A**, **S** and **P** for all coils and interleaves. Finally, each column of the SENSE reconstruction image, **f**(*j*)**'**, with phase correction can be expressed as,

$$\mathbf{f}(j)' = (\mathbf{E}^H \mathbf{E})^{-1} \mathbf{E}^H \mathbf{g}(j) \qquad [3]$$

where H denotes the conjugate transpose and a whole image can be reconstructed using Eq.[3] repeated separately for each image column.

Spin-echo multi-shot SENSE DW EPI brain images were acquired for a healthy volunteer on a 7 Tesla Philips Achieva whole body scanner (Philips Healthcare, Cleveland, USA) using a 16 channel receiver head coil. An image-echo acquisition is immediately followed by a 2-D navigator-echo acquisition with 180° refocusing RF pulse between the two echoes. Both echoes were acquired with SENSE reduction factor = 3, FOV = 240×240mm, slice thickness = 4mm, *b*-value = 0 and 700 s/mm^2, 7 slices with no interslice gap, TR/(TE_1,TE_2) = 5500/(69.1,99.9)ms for image (TE_1) and navigator-echo (TE_2), respectively. Coil sensitivity maps were acquired separately and processed for each coil (1). A B0 field map was also acquired to compensate for the differences of bandwidth between the two echo acquisitions (9).

RESULTS: Figure 1 shows *b*-value = 0 (a) and 700 s/mm^2 without (b) and with (c) phase correction. Diffusion encoding is in the through-plane direction. In-plane acquisition voxel size is 1.5×1.65mm, reconstructed at 0.75mm. Compared to the image (b), the ghost artifacts are removed in (c) after reconstruction using the proposed method.

DISCUSSION: A simple reconstruction method was successfully used to reconstruct DW images acquired with multi-shot and SENSE accelerated EPI. Because the susceptibility-induced distortion is severe at higher magnetic field strength, there is a significant mismatch in the susceptibility-induced distortions in the image- and navigator-echo data, due to the difference of acquisition bandwidths. To compensate for this, reconstructed navigator-echo images must be deformed into the image-echo image space using an acquired field map for accurate phase correction.

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