Phase-Labeled Reference EPI for Frequency-Segmented Inhomogeneity Corrections (PREFICS)

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Introduction: In echo-planar imaging (EPI), magnetic field (B_0) inhomogeneities result in geometric distortions in the image [1]. In brain imaging these occur mainly adjacent to air-tissue or bone-tissue boundaries and introduce an additional phase in the affected voxels which accrues during the EPI echo train. In Cartesian imaging this phase modulation in k-space leads to a displacement of the respective voxels in image space [2] (see Figure 1a). There exist various techniques to correct for those B_0 inhomogeneities. Acquiring a phase-labeled reference EPI scan allows creating a displacement map in a very short amount of time [3]. In Cartesian imaging this map can be used to correct distortions using pixel-shifting methods. Artifacts arising in non-Cartesian acquisitions, however, cannot be reverted by simple pixel-shifting. Instead, conjugate phase reconstruction methods can be used [4,5]. For that, the acquisition of an undistorted gradient echo-based field map is required. This is time-consuming due to the use of multiple radiofrequency (RF) pulses. In this work, we demonstrate a new technique, termed **p**hase-labeled **r**eference **E**PI for **f**requency-segmented **i**nhomogeneity **c**orrection**s** (PREFICS). With this technique an undistorted field map can be obtained in very short time. This is achieved by deriving the field map from a rapidly acquired displacement map using a phase-labeled reference EPI scan. With this map it is then possible to correct for field inhomogeneities in non-Cartesian EPI.

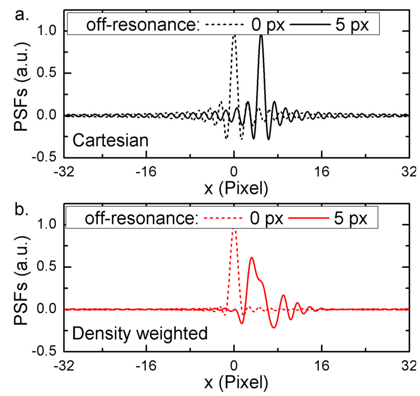

Figure 1: Simulation of the effect of a field inhomogeneity on a single voxel. a. In Cartesian EPI, the PSF is shifted. b. In density weighted EPI, the shape of the PSF is altered.

Materials and methods: Measurements were performed on a 3 T scanner equipped with a 12-channel head coil. K-space density weighted images [6] were acquired using an EPI sequence (128x128 matrix, slice thickness 3.0 mm, echo spacing ES=0.76 ms, readout bandwidth 1502 Hz/Px). With density weighting it is possible to acquire images with a prospectively chosen modulation transfer function (MTF) while ensuring optimal signal-to-noise ratio (SNR). If the approximate signal decay $S_n=\exp(-ES\cdot n/T_2^*)$ is known (n are the respective echoes of the acquired echo train: n=0…127), this is achieved by varying the k-space density ρ_n during acquisition according to [7]: $\rho_n = 1/\Delta k_n = MTF_n/S_n^2$. Here, the sampling was chosen to result in a Kaiser function MTF for ringing artifact reduction assuming T_2^*= 50 ms. In contrast to Cartesian EPI, there is no linear dependence between phase accrual and k-space position. Thus, field inhomogeneities do not only lead to a displacement but to an alteration of the point spread function (PSF) shape, resulting in side-lobe ringing (Figure 1b). Thus, a conjugate phase method needs to be applied for correction [5]. In addition to the density weighted EPI, a phase-labeled reference scan comprising of two single-shot EPIs with the second one shifted by one blip in phase encoding direction was acquired. As described in [3], a displacement map in distorted coordinates was derived from this reference scan. This displacement map was subsequently applied to itself using b-spline interpolation. Thus, after sign inversion a field map in undistorted coordinates was obtained. Based on this map, multi-frequency interpolation [5] was applied to correct the density weighted data. A multi-reference gradient-echo field map scan comprising of 128 echo trains was acquired to obtain an accurate reference field map [8].

Results: Figure 2a shows an uncorrected density weighted EPI acquisition of the human brain. Ringing artifacts arising from field inhomogeneities are clearly visible (indicated by the red arrows). Images corrected using multi-frequency interpolation based on field maps derived with the rapid PREFICS method and from the multi-reference gradient echo field map scan are shown in b. and c., respectively. A corresponding gradient-echo image of the same slice is depicted in d. With both field maps it is possible to correct the ringing artifacts and to restore the correct geometric shape of the brain. In contrast to the multi-reference gradient-echo field map scan, the PREFICS scan comprises of only two EPI acquisitions and can thus be acquired 64 times faster.

Discussion and Conclusions: The PREFICS method allows deriving a field map from a phase-labeled reference EPI scan, which can be acquired using only two EPI shots. Thus, the field map can be acquired faster than with any gradient echo based sequence, where multiple time-consuming RF pulses are always mandatory. With the derived field map it is possible to successfully correct for inhomogeneity effects in non-Cartesian EPI acquisitions using a conjugate phase method. The method was demonstrated for density weighted acquisitions, but can in principle also be applied to other non-Cartesian trajectories such as spiral or PROPELLER EPI.

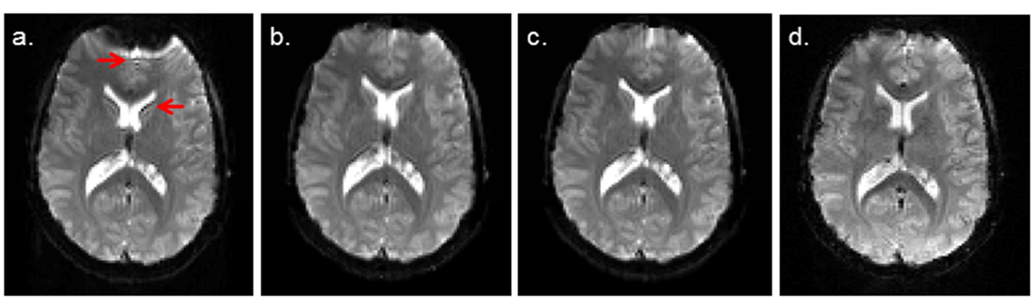

Figure 2: a. Uncorrected density weighted EPI acquisition. The ringing artifacts which originate from field inhomogeneities are clearly visible (red arrows). b. Corrected image based on the PREFICS method. c. Corrected image based on multi-reference gradient-echo field map. d. Reference gradient-echo image.

References: [1] Jezzard MRM 2004; 34:65-73 [2] Reber MRM 1998; 39:328-30 [3] Xiang MRM 2007; 57:731-41 [4] Macovski, MRM 1985; 2:29-40 [5] Man MRM 1997; 37:785-92 [6] Greiser MRM 2003; 50:1266-75 [7] Zeller JMRI 2012; in press [8] Schmithorst IEEE MI 2001; 20:535-539