A new Approach Predicting Optimal Imaging Gradient Orientation for EPI

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Introduction

Echo planar imaging (EPI) is one of the fastest and increasingly used magnetic resonance imaging (MRI) sequences. Due to its sensitivity to microscopic susceptibility gradients, EPI is commonly used for functional MRI (fMRI), to measure the susceptibility changes to the blood oxygen level dependent effect (BOLD). However, this sensitivity also implies image artefacts due to macroscopic susceptibility gradients caused by field inhomogeneities. The latter lead to geometric distortions caused by phase errors and lead to signal loss due to intravoxel dephasing. These effects depend on the orientation of the susceptibility gradients relative to the spatial encoding gradients of EPI. Deichman et al (1) optimized the orientation of the imaging gradients experimentally. The goal of this work was to develop a numerical solution, which predicts the optimal orientation and polarity of the imaging gradients by simulation of the EPI MR-signal.

Materials and methods

For the EPI signal simulation, a B_0 map was acquired with a three dimensional (3D) two echo, fast low angle shot (FLASH) sequence. The corresponding measurement was performed with an isotropic spatial resolution of 4mm. Measurements were performed on a 3T whole body system (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany). From this data, a field gradient map was derived, which was used for the simulation. In the simulation procedure a modified *k*-space trajectory for each voxel was calculated. This trajectory is the superposition of the k-space trajectory, $\mathbf{k}_{img}$, of the imaging gradients and, $\mathbf{k}_{grad}$, the k-space trajectory of the susceptibility gradients. The simulation is performed in that way, that the total *k*-space vector, **k**, of a voxel describes a state of intravoxel dephasing. The corresponding signal $S_{vox}(t)$ at a time point t of $\mathbf{k}_{img}$ is derived from the signal equation of a homogeneous object with a constant spin density, ρ_{hom},: $S_{vox}(t)=\iiint_{dV} \rho_{hom} \exp(-i\mathbf{kx})dxdydz$. dV is the volume of a voxel defined by its extensions Δx, Δy, and Δz. **k** is the *k*-space vector given by: $\mathbf{k}= \mathbf{k}_{img}(t) + \mathbf{k}_{grad}$. **x** is the spatial vector with the coordinates x,y,z. The homogeneous spin density, ρ_{hom}, is defined by the normalization condition, i.e. the integral over one voxel yields 1 and, therefore, $\rho_{hom}= 1/(\Delta x\ \Delta y\ \Delta z)$. The integration of the signal equation then yields: $S_{vox}(t)=\mathrm{sinc}(k_x*\Delta x/2)*\mathrm{sinc}(k_y*\Delta y/2)*\mathrm{sinc}(k_z*\Delta z/2)$. k_x, k_y, k_z are the spatial components of the total *k*-space vector, **k**. Its imaging part is a blipped EPI encoding scheme with an acquisition bandwidth of 130 kHz. A voxel signal S^i_{vox} is finally calculated by the integration of $S_{vox}(t)$ over the acquisition duration of the simulated EPI scan. For the simulation, the imaging orientation was rotated in steps of 5° starting from -90° to +90° relative to a pure axial orientation. Additionally, the phase encoding direction was swapped between the two in plane axes. The rotation was performed around the left-right axis (pitch). To measure the degree of distortion, the voxel signal is normalized to the signal of an undistorted voxel, i.e. $\mathbf{k}_{grad}$ is zero. Hence, an undistorted voxel has a value of 1. A distortion due to $\mathbf{k}_{grad}$ leads to a deviation from 1. Therefore, a measure 'distortion' was defined by the square root of $(S^i_{vox}-1)^2$.

Results and Discussion

The Figure 1 shows the distortion derived from the simulation results and its dependency on the pitch rotation angles for the four different in-plane orientations. The distortion parameter in these figures were determined from a local region of interest in the orbito frontal lobe, where the strongest susceptibility gradients are expected. In Figure 2, the simulated image with the worst distortions is shown. This image corresponds to the maximum in the red curve (inverted phase encode direction). In contrast, Figure3 shows the image with minimal distortion. It corresponds to the minimum of the green curve in

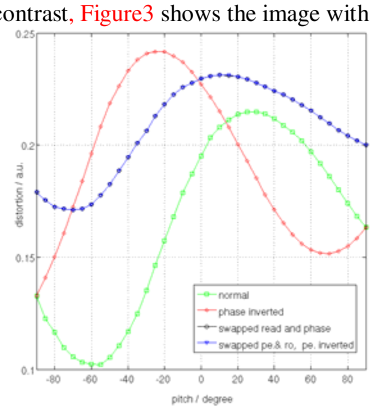

Figure1: distortion over pitch

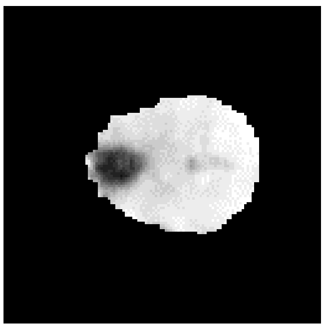

Figure2: image with largest distortion

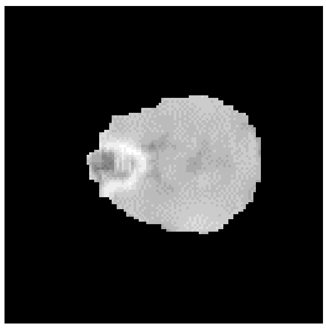

Figure3: image with smallest distortion

Figure 1. Hence, the lowest distortion is predicted for an image orientation of a coronar orientation and a pitch angle of 35°. The correspondence of image quality and distortion parameter indicates that the defined distortion parameter is a good measure for the signal loss in the simulation results. The simulated images itself, show signal voids, which are in good correspondence to well known artefacts in EPI-images. Hence, this kind of signal distortion simulation is a promising approach to predict the optimal gradient orientation for EPI acquisition. The dependence of this best orientation on the experimental conditions and on different subjects as well as its variability needs to be examined.

References:

(1) R. Deichmann, et al. NeuroImage 19, 430-441, 2003.