Optimization of 3D EPI technique for radio frequency (B1) field mapping at 3T

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Introduction Spatial inhomogeneities in the radio-frequency (RF) field (B_1) increase with field strength as the RF wavelength approaches the dimensions of the human head. B_1 inhomogeneities pose various problems such as spurious signal and contrast changes in MRI, leading to bias in quantitative imaging and difficulties in tissue segmentation. Here, we optimize the 3D EPI B_1 mapping method introduced by Jiru and Klose [1] that determines the local flip angle from the signal intensity of spin-echo (SE) and stimulated-echo (STE) images. With this method, inhomogeneities in the main static field (B_0) lead to geometric distortions in the images and biased flip-angles due to off-resonance precession of the spins [2]. We present an extension of this approach using carefully chosen RF pulses and a post-processing procedure that corrects biased flip angles and image distortions along the phase direction.

Methods **Image acquisition:** All data were acquired using a 3T whole-body Tim Trio system (Siemens Medical Solutions, Germany), operated with a body transmit coil and a 12-channel head-only receive coil. Distributions of B_1 fields were determined on human subjects from 3D EPI acquisitions of SE (varied between 160^o and 200^o) and STE pulses [1]. The resolution was 4x4x4 mm^3 for an acquisition time of 2min 20s. Flip angle maps were normalized to the nominal flip angle (= 100%). An additional B_0 map was also acquired for correction of image distortions and off-resonance spin precession effects (acquisition time of 2 min). **Thresholding of the flip angle maps:** High local B_0 values lead to off-resonance precession of the spins and therefore to biased flip angle values in the B_1 maps [2]. To determine the maximally tolerable local B_0 value we acquired B_1 maps on a gel phantom. Rectangular RF pulses were used with the shortest achievable duration (700us) to generate the SE and STE. An offset was added to the frequency of the RF pulses and varied within a range [-100 200] Hz, which corresponds to local B_0 values present in the human head at 3T. At a voxel position where B_0=0Hz, the maximum tolerable B_0 value is the frequency at which the flip angle deviates by more than 5% error from the unbiased value (obtained with no offset frequency). We use this value in our post-processing procedure for thresholding of the B_1 maps. **Image post-processing:** Artefactual voxel displacements along the phase encode direction (R->L) were corrected by *unwarping* the images based on the local B_0 value [3]. Brain regions where the local B_0 field was beyond our threshold value were masked out of the images and the missing flip angle values were estimated by averaging those of the remaining neighbouring voxels (*padding*).

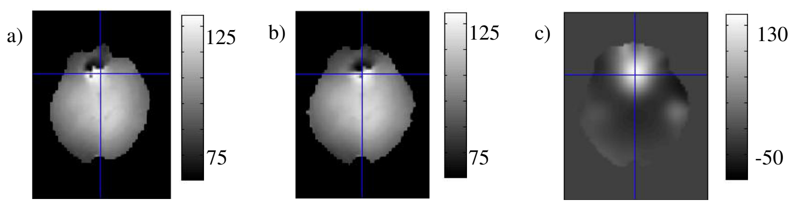

Figure 1: a) Original flip angle map obtained using the 3D EPI method. b) Unwarped flip angle map. c) Corresponding B_0-field map (in Hz). While unwarping of the images clearly improves image distortions, the flip angle biases remain. These occur where local B_0-field values are high suggesting off-resonance effects as the source of these artefacts.

Results Figure 1 shows axial views of unsmoothed B_1 maps. For demonstration purposes, the duration of the rectangular SE and STE RF pulses was set to 1400us. However, for all data presented in the following we used the shortest achievable RF duration (700us). Figure 1 a) shows a B_1 map before post-processing. Figure 1b) shows the same flip angle map after unwarping along the R->L direction: the symmetry of the image is restored. However, strong artefactual B_1 discontinuities remain in the Orbital Frontal Cortex (OFC) corresponding to high local B_0-field values (see figure 1c)). The maximum tolerable local B_0 values can be seen in figure 2. In the human B_1 maps, voxels where the local B_0 value is beyond 110Hz were replaced using our padding procedure. The results are displayed in figure 3a), smoothed with an 8mm kernel. Discontinuities in the OFC region are no longer visible. For comparison, we show flip angle maps obtained using a reference 'DAM' method (figure 3c)) [4]. Results using both methods are within a 5% margin for all central regions of the brain. Repetitive acquisitions of 3D EPI B_1 maps show instabilities below 3% across the brain volume (unshown).

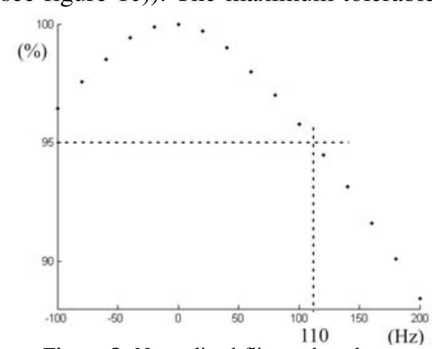

Figure 2: Normalized flip angle values vs RF pulse frequency offset, obtained on a gel phantom.

Conclusion Susceptibility gradients are shown to induce significant bias into flip angle maps due to off-resonance effects. However, we have shown that appropriate choice of RF pulses, unwarping of the images and interpolation of the affected voxels can correct for these artefacts. We were able to obtain reliable flip angle maps at 3T over the entire brain volume with a sufficient resolution and in an achievable experimental time.

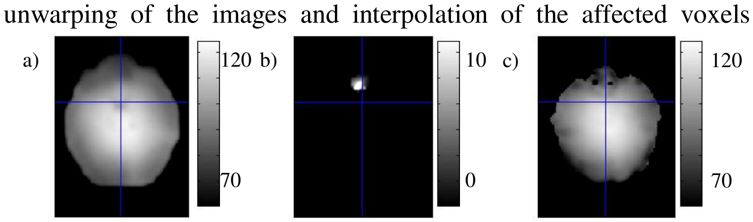

Figure 3: a) Flip angle map after complete post-processing. Bias is no longer visible in the OFC. b) Difference image of padded and unpadded images. c) Flip angle map obtained using a reference 'DAM' method.

[1] F. Jiru and U. Klose, MRM **56**:1375-1379 (2006). [2] J. Wang *et al*, MRM **56**:463-468 (2006). [3] C. Hutton *et al*, NeuroImage **16**:217-240 (2002). [4] J. Sled and G. Pike, MRM **43**:589-593 (2000).