Reconstruction and frequency mapping with phase-cycled bSSFP

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Introduction. Balanced steady-state free precession (bSSFP) imaging is a fast acquisition technique giving high signal with very short repetition times. However, its steady-state is very sensitive to off-resonances (and therefore B_0 inhomogeneity), leading to non-uniform intensity and signal voids across the image. Adding a linear increase in the phase to the RF pulses moves the signal voids to different values of off-resonance, therefore the acquisition of multiple images with different phase cycling schemes, and their subsequent combination (by means of maximum intensity projection [1], sum of squares [2], etc.) is an effective way to reduce the impact of these artifacts. In this abstract, we propose the non-linear pixelwise fit of the different phase cycles to the Freeman-Hill formula [3] that describes the bSSFP signal, in order to obtain the corrected signal amplitude together with a B_0 map.

Materials and methods. Three-dimensional bSSFP acquisitions with four phase cycles (0°, 90°, 180° and 270°) where performed on the head of a healthy volunteer with a 1.5T MR Scanner (Espree, Siemens Healthcare, Erlangen, Germany). Scanning parameters were the following: TR/TE 6.74/3.37ms, flip angle 35°, Matrix size 128x88x64, voxel size 2.2x2.2x2.2mm^3. The acquisitions provided a sampling of the bSSFP signal intensity with respect to off-resonance (see fig. 1). These samples were inserted in a Levenberg-Marquardt non-linear fitting algorithm (Matlab, Natick, MA) and the Freeman-Hill formula was used as a function model, where only the dependency on off-resonance and an additional multiplication factor were retained. Fixed values for T_1 and T_2 were assumed, and TR and flip angle were adapted from the scanning parameters.

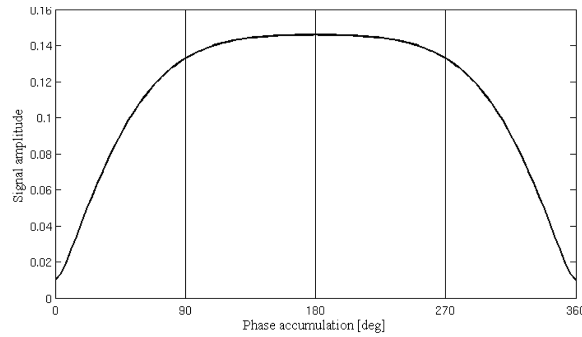

Fig. 1: bSSFP signal at different phase cycles/off resonances.

Results. Fixed values of T_1 and T_2 set to 800 and 300 were empirically found to give the minimum amount of fitting errors in the considered image of the head. The reconstructed image is shown in figure 2, and the off-resonance (B_0) map is shown in figure 3.

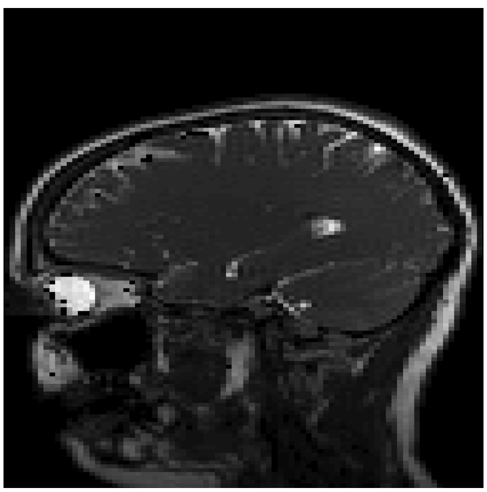

Fig. 2:Reconstructed (banding-free) signal amplitude

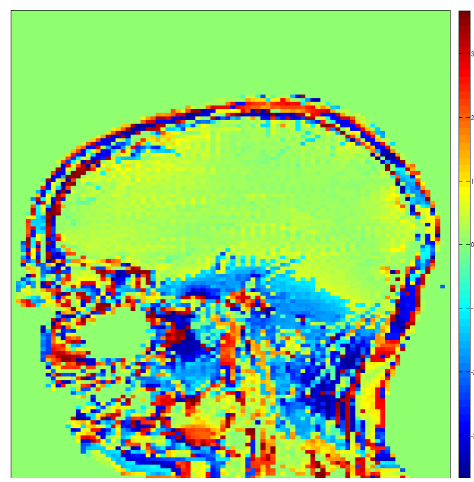

Fig.3:Off-resonance map

Discussion. While more time-consuming in the reconstruction, this method allows the reconstruction of the ideal bSSFP signal at every voxel in the image, without the residual fluctuations that can happen with other reconstruction methods. The availability of an accurate B_0/frequency map is also a benefit, and can be used for inhomogeneity correction, temperature mapping, etc. The fitting might fail in some voxels where the actual T_1 and T_2 values are very far from the assumed ones (mostly cerebrospinal fluid or vitreous humor), resulting in black pixels in our reconstructions. The observed errors are however minimal and in locations generally of less clinical importance for diagnosis. In case that accurate reconstruction of these areas is needed, the values can be changed in order to avoid fitting errors in these tissues.

References. [1] Haacke EM, *et al*, Radiology 1990; 175: 545-552. [2] Bangerter NK, *et al*, Magn Reson Med 51 (2004), pp. 1038–1047. [3] Freeman R, Hill H, J Magn Reson 1971; 4: 366-383.