3D Diffusion-Weighted MRI with SSFP: Rigid- and non-Rigid-Body Phase Correction

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INTRODUCTION –

The diffusion-weighted (DW) SSFP sequence offers an efficient diffusion preparation that can be used for rapid 3D DW imaging of the whole brain [1,2,3]. The technique, however, is multi-shot and therefore susceptible to signal losses caused by shot-to-shot phase inconstancies that are ultimately due to motion. The goal in this work is to correct these phase errors using 2 types of 3D navigation:

1) True 3D navigation to correct **rigid-body** motion in every shot [4].
2) Batched 3D navigators to correct repeatable **non-rigid-body** motion over the cardiac cycle [2].

METHODS –

MRI: 3D DW SSFP imaging was performed on 4 healthy subjects at 3T with a 32-channel head coil using water-selective RF pulse, trapezoidal diffusion-encoding gradient, 3D navigator readout, then a spiral projection readout interleaf [5]. Sequence parameters: isotropic 1.4 mm^3 resolution, 280 mm^3 FOV, TR 23.4 ms, scan time 2 min per direction for 3 diffusion directions, 5000 spiral interleaves per volume, diffusion gradient width 6 ms with 1ms ramps, with amplitude 4 G/cm. For comparison 2D DW spin-echo EPI was performed on each subject.

Recon: Each interleaf was first corrected for rigid-body motion using the KICT algorithm [4]. Then to correct non-rigid-body motion due to cardiac pulsation, the interleaves were binned into 1 of 10 cardiac phases using pulse-oximeter waveforms. Corresponding 20^3 pixel navigators were reconstructed from each cardiac phase and used to reconstruct the images with a phase-corrected iterative SENSE algorithm [6]. "FA" maps were computed by taking the standard deviation across diffusion direction.

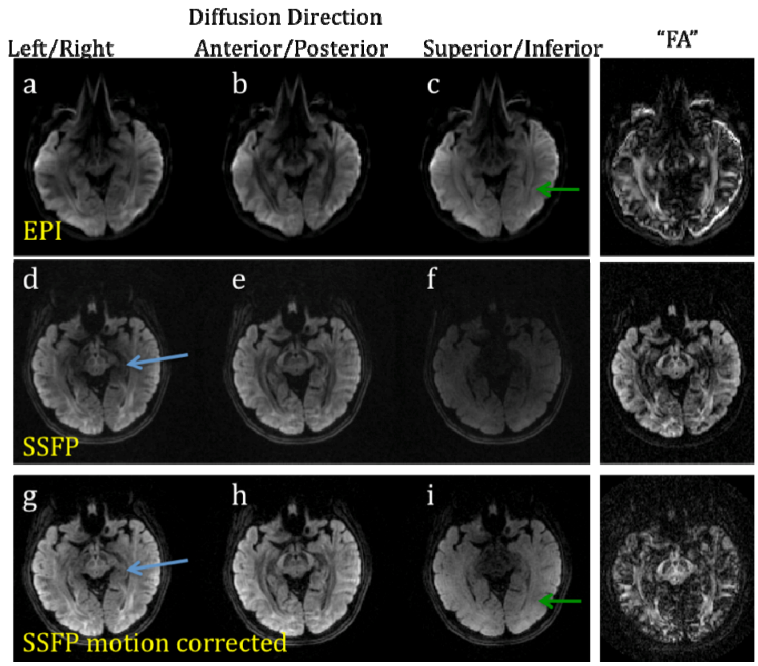

Fig. 1 - (a) Central axial slices of each 3D scan (a, columns) and each diffusion direction (a, rows). Scans were performed with a diffusion gradient strength of 0.5, 1, and 2.5 G/cm (from left-to-right); (b) axial, sagittal, and coronal views from the 5 G/cm scan with A/P diffusion encoding.

RESULTS–

1) Diffusion contrast in EPI images (Fig 1 a-c) is similar to SSFP (Fig d-i)
2) Motion correction restores signal loss (Fig 1 and 2, blue arrows)
3) S/I diffusion direction shows some loss of contrast (Fig 1, green arrows)
4) "FA" maps of motion corrected SSFP are similar to those of the EPI images (Fig right column)
5) The SSFP sequence provides high isotropic resolution. Slices can be reformatted in any orientation (Fig 2)
6) The whole brain is covered and shown by the surface renderings (Fig 2, g,h)

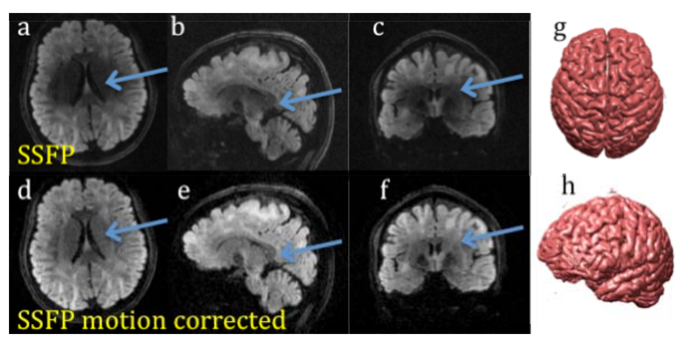

Fig. 2 – Motion Correction restores lost signal. An uncorrected volume (a,b,c) is compared to the corrected volume (d,e,f) in three perpendicular reformats. Signal lost to phase cancelation is restored (blue arrows). The Left/Right diffusion direction is shown. (g,h) surface rendering from the volume showing the 3D whole brain coverage.

CONCLUSIONS and DISSCUSSION –

The DW-SSFP sequence was shown to provide 3D whole brain coverage in 2 min per volume at 1.4 mm^3. The motion correction methods were shown to restore much of the signal loss caused by phase cancelation. The diffusion contrast was similar to the reference case of the EPI scan however the S/I diffusion direction exhibited some loss of contrast and signal magnitude due greater pulsitile brain motion in that direction. This will be addressed in future work by a prospective correction.

REFERENCES – [1] Jung et al JMRI 2009 [2] Mcnab et al. MRM 2010. [3] O'Halloran et al. ISMRM 2011. [4] Van et al IEEE. [5] Irarrazabal and Nishimura MRM1995. [6] Liu et at MRM 2005.

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