Prospective Correction Rigid-Body Motion-Induced Phase for Diffusion-Weighted SSFP Imaging

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TARGET AUDIENCE – Researchers interested in high-resolution diffusion-weighted imaging, Diffusion-weighted SSFP (DW-SSFP) and real-time phase correction.

PURPOSE – In DW-SSFP motion-induced signal loss varies with diffusion direction causing artifacts in DTI metrics. Signal loss can be global (Fig 1, A vs B) as well as focal, such as in regions with higher motion (Fig 1b, red arrow), leading to errors on various spatial scales. This signal loss arises from 2 mechanisms:

(1) Phase cancelation of multiple shots (Retrospective problem)
(2) Loss of steady state phase coherence (Prospective Problem)

The first problem has been addressed with phase navigation and reconstruction [1,2,3] while the second problem remains open since it cannot be solved retrospectively. In this work a navigator-based, prospective correction is proposed to preserve the steady state phase coherence.

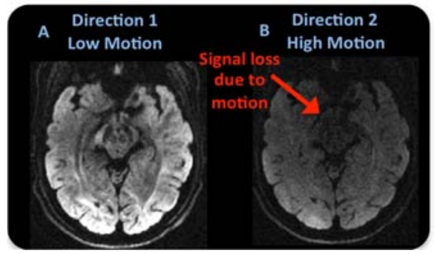

Fig. 1 *– The effect of motion on DW-SSFP images. Diffusion directions with low motion (A) experience less signal loss than directions with more motion (B).* ***This causes bias in DTI metrics.***

METHODS – *MRI:* Figure 2 explains the DW-SSFP pulse sequence used for prospective correction. Parameters were: Flip angle: 40°, Resolution 1.37x1.37x1.37 mm, FOV: 220x220x220 mm, TR: 42 ms, Diffusion gradient 0.4 G/cm x 6 ms. The readout was a spiral projection trajectory with 4000 interleaves [3]. Motion-induced phase error was simulated in the phantom by playing blip gradients on each axis (Fig 2c) at various TRs in a pseudo random pattern. The pattern was the same for all experiments to ensure repeatability. An agar phantom was scanned on a 3T magnet (GE Healthcare). Scans were performed with the test blips (Fig 2c) both on and off and with the prospective correction turned on and off.

Prospective correction: Navigator data was sent in real-time to the manufacturer's built-in real-time server and was processed via an in-house routine to determine the shift and phase of the center of k-space. For speed an approximate centroid-based method was used. The shifts were used to determine the amplitudes of the blips (Fig 2,f) that would correct the linear component of the phase while the phase of the center of k-space was used to set the next RF pulse phase (Fig 2,g). **Together these two corrections prevent linear and constant phase terms from affecting future phase coherences thus preserving the steady state.**

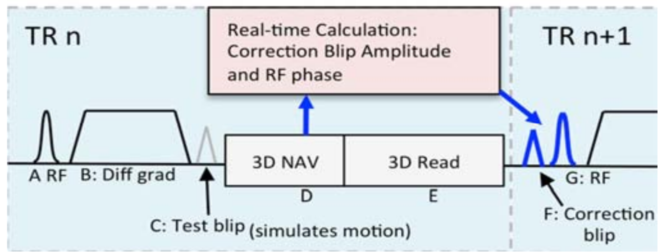

Fig. 2 *– Schematic of the DW-SSFP sequence, prospective correction and test mechanism. The RF pulse (A) and diffusion gradient (B) provide the steady state spin preparation while the readout is performed in 2 parts: a 3D stack-of-spiral navigator (D) and 3D spiral projection readout interleaf (E). Data from the Navigator is sent to the real-time processer as soon as it is collected and processed to determine the rigid-body motion parameters (pink box). Blip amplitudes (F) and the RF phase (G) are determined to correct Rigid-body motion. A test blip is inserted at various times to simulate motion in a phantom (C).*

Image reconstruction: Because the corrections (Fig 2,fg) occur after the readout, motion-induced phase will still shift the k-space and modulate the phase of the acquired data. This can be corrected retrospectively [4]. Reconstructions with and without this correction are performed for each data set.

RESULTS– Figure 3 demonstrates the principle result of this work. When motion is simulated by turning on the blips (Fig 3 b,c,e,f), the best result is achieved with both prospective and retrospective correction (Fig 3f). It has a signal magnitude most similar to the reference image with no motion and no prospective correction (Fig a,d). Because there is no motion in the reference images, the retrospective correction has no significant effect (Fig 3d). Note that the signal level in the image with both prospective corrections and retrospective corrections (Fig 3f) is the closest to the reference (Fig 3a).

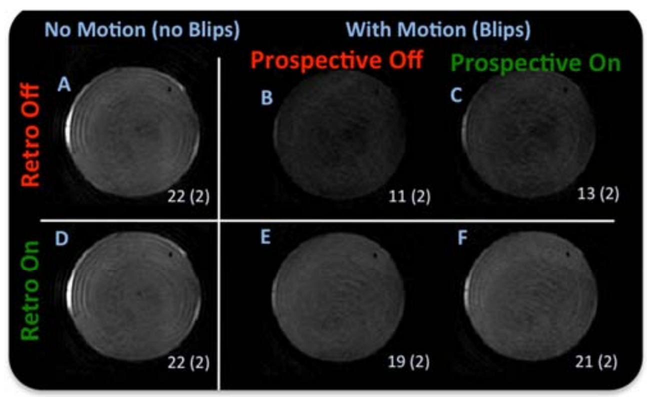

Fig. 3 *– Axial reformats from the prospective motion correction in a phantom. The reference images with no motion (A,D) are compared to images with motion (B,C,E,F). Prospective correction restores signal lost to motion (C) compared to the same experiment without (B). The addition of retrospective correction increases the signal in both (E,F) however the best result is achieved with the combination of Prospective and Retrospective corrections. Window and level is the same in all images. Mean and standard deviation of the signal in the phantom appears below each image in arbitrary units.*

DISCUSSION and CONCLUSIONS – This work demonstrates clearly the feasibility of mitigating motion-induced loss of signal in DW-SSFP using prospective phase correction. This is the first time such a correction has been successfully demonstrated and represents progress in overcoming a major challenge in DW-SSFP.

REFERENCES – [1] Jung et al. JMRI 2009; 29:1175–1184. **[2]** McNab et al. MRM 2010; 63:235–242. **[3]** O'Halloran et al. MRM 2012 Oct 5. doi: 10.1002/mrm.24489. [Epub ahead of print] **[4]** Van et al., IEEE Transactions on 2011; pp. 1933–1940.

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