Real-Time Quantification of Brain Motion Using Gradient-Echo Phase

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Introduction: Characterization of sub-millimeter pulsatile brain motion can be important for accurate functional and diffusion brain studies. Phase-contrast methods are difficult to apply in real time because of the long flow-encoding pulses required to accrue sufficient phase[1]. In gated scans, small head movements can contribute significant errors if not carefully removed. Furthermore, it is difficult to achieve adequate phase SNR over the entire head in a single image because of the wide dynamic range of motions present. If VENC is chosen large enough to encode the higher velocities without aliasing, then phase SNR in other areas is inadequate.

We have used a recently introduced method for phase-based velocity imaging[2] in which phase accrues over many TR intervals. This allows for significantly shorter encoding gradients in each TR. Using this approach, we can acquire real-time motion-encoded movies of the brain.

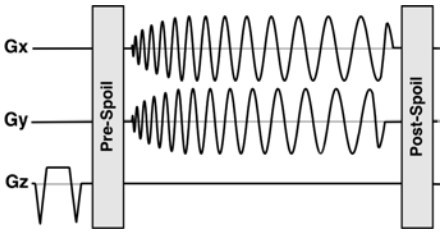

Figure 1: *Pulse sequence for velocity imaging. Pre-spoiler and post-spoiler lobes are used to encode flow over multiple TRs.*

Methods: The motion-encoding technique (Fig.1) consists of a gradient-echo pulse sequence with pre-spoiler and post-spoiler gradients added to select one of 3 different gradient echoes per TR interval, corresponding to the FISP, CE-FAST, and T2-FFE echoes[3,4]. Total spoiler gradient area is kept constant from TR to TR in order to maintain the gradient echo condition. No RF spoiling is used. Phase in each of the resulting echoes (of order m={-1,0,1}) arises from 3 sources: velocity along the spoiler direction (θ_V), time-varying sources such as off-resonant precession (θ_{P1} and θ_{P2}, before and after TE), and stationary sources such as coil phase and excitation-pulse phase (θ_C):

$$\angle M_m = \theta_{P1} - m(\theta_{P1} + \theta_{P2}) + \theta_C + a_m\theta_V$$

A linear combination of the three echoes can be used to isolate the velocity contribution, θ_V. If a reliable field map were pre-acquired, then θ_{P1} and θ_{P2} are fixed and only two echoes would be required. The spoiler axis dictates velocity directional sensitivity, which increases with spoiler area.

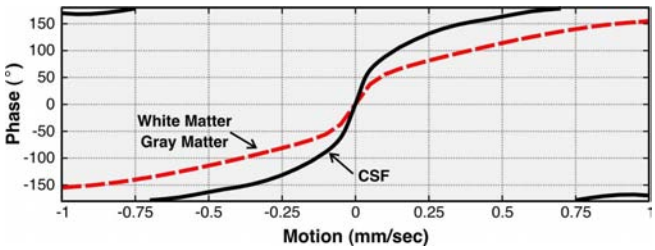

Figure 2: *Phase accrual as a function of motion is nonlinear and sigmoidal. This allows higher phase SNR for low-velocity spins while reducing aliasing of higher velocities.*

Phase as a function of velocity for this sequence is shown in Fig. 2 for CSF, white matter, and gray matter. The nonlinear sigmoidal phase response provides adequate SNR for visualization of motion in low-velocity areas while preventing unwanted phase aliasing in higher-velocity areas. Although phase in CSF is larger than that in brain tissue because of its extremely long T2, θ_V is insensitive to moderate variations in tip angle or relaxation. As a result, the nonlinearity can be accurately removed by inversion.

We employed an 8-interleave spiral pulse sequence with 1.75-mm in-plane resolution, 5-mm slice thickness, tip angle 60°, 2.3-ms pre-spoilers, TR=23ms, and TE=3.1ms. This resulted in 1.9 true frames per second, reconstructed with a sliding window at up to 17 frames per second. The technique was tested on 3 healthy male volunteers in mid-sagittal and axial slices.

Results: Figure 3 shows single image frames acquired at peak post-systolic velocity (a and c) and during diastole (b and d). Slow velocities (~ 0.1mm/sec) in the frontal lobe are well visualized with significant phase signal. Relatively high velocities are simultaneously visualized without phase aliasing and with minimal signal loss due to velocity dispersion. Figure 4 shows velocity signal versus time for two regions at corresponding locations in each hemisphere, derived from axial image data.

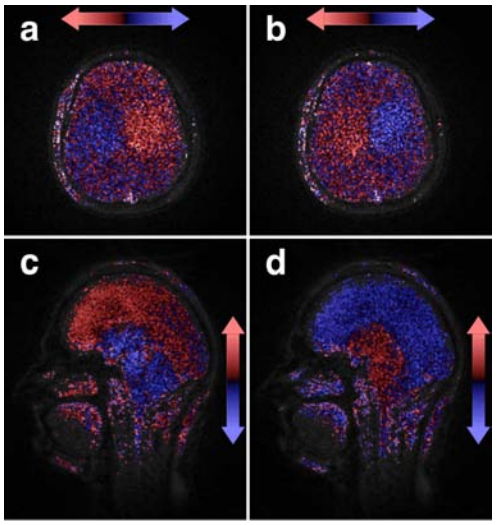

Figure 3: *Velocity maps captured at peak systole (a,c) and during diastole (b,d). Axial images (a,b) depict medial pulsation of the hemispheres. Sagittal images (c,d) show high SNR for slowly moving tissues with minimal aliasing in higher velocity regions.*

Discussion: We have implemented real-time imaging of brain motion using a unique gradient echo pulse sequence. Images acquired with this technique correlate well with known motion patterns. The technique does not require the large bipolar gradients typical of phase contrast studies, thereby permitting rapid image acquisition. Because of the steady-state nature of the phase signal, a nonlinear relationship arises between velocity and accrued phase. This nonlinearity may be removed through post-processing and may be of benefit in maximizing phase SNR. This approach might be combined with other techniques such as diffusion imaging in order to acquire simultaneous displacement maps for correction.

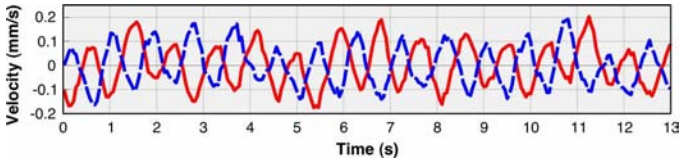

Figure 4: *Velocity vs. time for ROIs chosen from each hemisphere of the axial data in Fig. 3. The expected counterpulsating motion is observed.*

References:

1. Feinberg DA, *et al.* Radiology 163: 793-799, 1987.
2. Overall WR, *et al.* Proc. 13th ISMRM: 597, 2005.
3. Vlaardingerbroek MT, *et al.* Magnetic resonance imaging. 2nd ed., 1999.
4. Kim DJ, *et al.* MRM 19(1): 20-30, 1991.