

The Reproducibility and Correlation of Phase Errors in Diffusion Weighted Imaging with the Cardiac Cycle

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INTRODUCTION – One of the fundamental problems with multi-shot diffusion weighted (DW) MRI is phase mismatch between shots. The ultimate source of these errors is motion, however, one component of it is reproducible and correlated with the cardiac cycle. This assumption is central to correction techniques that combine shots that occur in similar portions of the cardiac phase and uses the combined data set for phase navigation [1, 2]. It is however unknown to what extent this assumption is true. In this work we examine the reproducibility of phase using a rapid time-resolved single shot DW GRE EPI sequence.

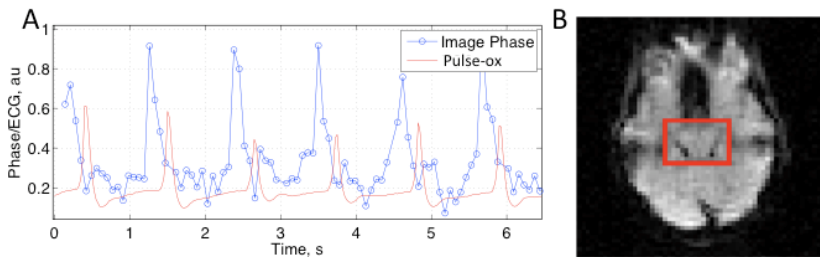


Fig. 1 – (a) The average phase in an ROI versus time (blue) and the pulse oximeter signal (red) are highly correlated. (b) a magnitude image for one of the 400 time-points and the approximate location of the ROI (red box).

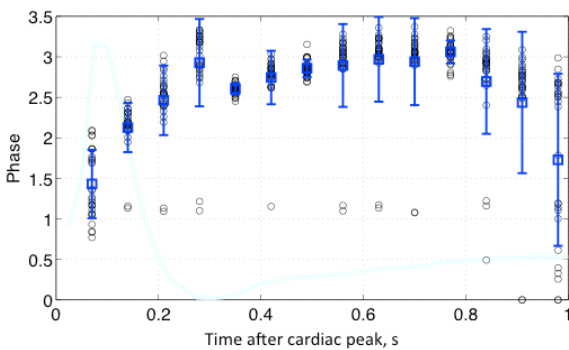


Fig. 3 – The mean phase in an ROI versus time after the cardiac peak (black, circles) plotted with the mean phase (blue squares) and standard deviation (blue error bars) taken over all 30 cardiac cycles observed. A scaled pulse-oximeter waveform is shown for reference (light blue).

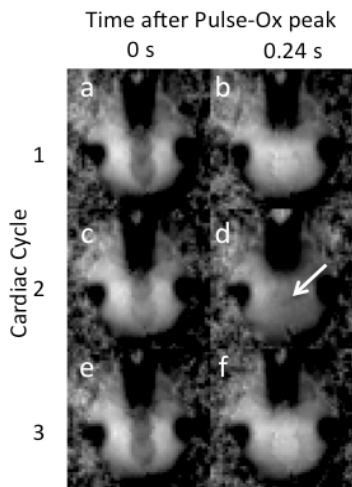


Fig. 2 – Unwrapped phase images from 2 time points in the cardiac cycle (columns) shown for the first 3 cardiac cycles observed.

METHODS – • **MRI:** Single-shot time resolved DW GRE EPI was performed on a healthy volunteer using a 1.5T scanner (Signa HDX, GE Healthcare) with 8-channel head coil. A dynamic series of 400 images were acquired on a single slice with a TR of 70 ms and a b-value of 250 s/mm². Other sequence parameters were: 64² matrix, FOV 26 cm, S/I diffusion direction. A pulse-oximeter was fitted to the right hand of the volunteer to measure cardiac waveforms.

• **Data processing:** Dynamic time-resolved images were reconstructed by Fourier transformation. Phase maps were computed from the complex image, and were then phase-unwrapped. To examine the reproducibility of the cardiac induced phase, the unwrapped phase maps were grouped into cardiac cycles, corresponding to individual heartbeats found from the measured pulse-oximeter waveforms. For this volunteer 30 heartbeats occurred during the scan. The mean value of the phase for each time-point image was calculated in a central ROI (Fig 1b, red square). The mean and standard deviation of the mean phase in the ROI was also computed across images acquired at similar time in the cardiac cycle. This standard deviation indicates how reproducible the phase is over multiple cardiac cycles.

RESULTS AND DISCUSSION – The phase was found to be highly correlated with the cardiac cycle (Fig 1a) in agreement with previous work [1], however, residual difference were observed in the phase maps corresponding to similar locations in the cardiac cycle (Fig 2). Phase maps from 2 places in the cardiac cycle for the first three heartbeats are shown in Figure 2.

The first point after the peak has a marked drop in the phase in the central part of the image for all three heartbeats (Fig 2a,c,e) while the phase maps from .25 second later in the cycle all show a phase in this region that is more similar to the rest of the image (Fig 2b,d,f). In the second heartbeat (Fig 2c,d), however there are some differences (Fig 2d, arrow), most notably the lower phase in the 2nd time point (Fig 2d) as compared with the others (Fig 2b,f). In Figure 3, the mean phase in an ROI for all 30 heartbeats and all time points is plotted versus the time after the pulse-oximeter peak (Fig 3 black circles). The mean and standard deviation of the means (Fig 3 black circles) is also shown (Fig 3 blue squares, errorbars) with a pulse-oximeter wave form for reference (Fig 3, light blue). In general the phase is fairly reproducible between different heartbeats and follow the same trend, however there are a significant variations over this short scan and several out-lying points.

CONCLUSION – The phase errors accrued during diffusion weighting are highly correlated with the cardiac cycle and fairly reproducible between different heartbeats with some variability. Future work will focus on using this information to guide efforts in phase correction for multi-shot DWI.

REFERENCES – [1] Miller and Pauly. MRM 2003. [2] McNab et al. MRM 2010.

FUNDING – 1 R01 EB008706, 1 R01 EB008706 S1, 5 R01 EB002711, 1 R01 EB006526, 1 R21 EB006860, Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation, Oak Foundation. GE Healthcare