A Fully Flow Compensated Dual Echo Sequence:The Role of Acceleration and Background Gradient Effects on Flow Compensation

Dongmei Wu[1], Sagar Buch[2], Saifeng Liu[2], and E. Mark Haacke[1,3]
[1]*Shanghai Key Laboratory of Magnetic Resonance, East China Normal University, Shanghai, China,* [2]*School for Biomedical Engineering, McMaster University, Hamilton, Ontario, Canada,* [3]*Department of Radiology, Wayne State University School of Medicine, Detroit, MI, United States*

Introduction: Recently, a variety of multi-echo gradient echo sequences (GRE) have been presented for simultaneous MR angiography and venography (1-5), as well as susceptibility weighted imaging (SWI). The drawbacks of these sequences are their high sensitivity to flow artifacts, especially at the longer echo times. The presence of flow induced phase will hamper the quality of SWI images and create artifacts in quantitative susceptibility mapping (QSM). Therefore, it is critical to understand these potential sources of error and then eventually remove them if viable. In this study, we present a fully flow compensated dual echo GRE sequence with alternating positive/negative readout gradients as a means to determine both acceleration effects and flow dephasing resulting from the presence of background field inhomogeneities. This unique approach suggests that the MR angiogram from the first echo can be used as a means to remove spurious phase for both SWI and QSM calculations.

Materials and methods: The specially designed fully flow compensated double echo sequence was built with both positive and negative polarity readout gradients. The sequence was run twice with different polarities and complex divided phase data were obtained. Since the background field effects are the same in both scans, the only remnant phase in the complex divided phase will be from either uncompensated velocity or acceleration effects. The data were then evaluated in straight segments of vessels in the head and neck to determine the quality of flow compensation. Similarly, areas of high acceleration were evaluated to determine the magnitude of acceleration effects. Once the acceleration term is found, it can be subtracted from each of the different polarity phase images and the remaining phase will be purely induced by the background gradient (G'). The next step is to determine the predicted values for both the acceleration induced phase (φ_a) and the G' induced phase (φ_{bf}). This can be done for φ_a by using the second moment calculation from the sequence diagram and the known geometry of the vessels (making it possible to calculate radius of curvature and hence acceleration). To predict φ_{bf}, we collected a short echo GRE sequence with TE = 2.5ms and used the 3D geometry of the brain itself to both predict the background fields and hence G' and to remove the background field phase effect to study the phase induced by G' itself. Once G' is known φ_{bf} can be calculated. Hence, we can measure and predict both φ_a and φ_{bf} in this approach.

Results: Phase maps for φ_a and φ_{bf} were successfully generated for both short and long echoes. As expected, straight segments showed no remnant phase indicating the sequence was indeed well velocity compensated as expected. However, areas of rapid curvature such as in the middle cerebral arteries (MCA) showed significant non-zero phase effects from acceleration that agreed with the theoretical predictions based on the sequence design. For this sequence, the second moment was 1.72 x 10^{-10} T/m*sec^3 for TE = 22.5ms. With an acceleration of 100m/sec^2, as can be the case in the MCA, the resulting phase is predicted to be $\varphi_a = \gamma a M_2/3 = \pi/2$. This is close to the measured values in the acceleration phase maps which range from zero to π/2. Similarly, the predicted G' effects from the background field predict $\varphi_{bf} = \gamma G' v TE^2/2 = \pi/6$ which also matched well with the measured G' terms.

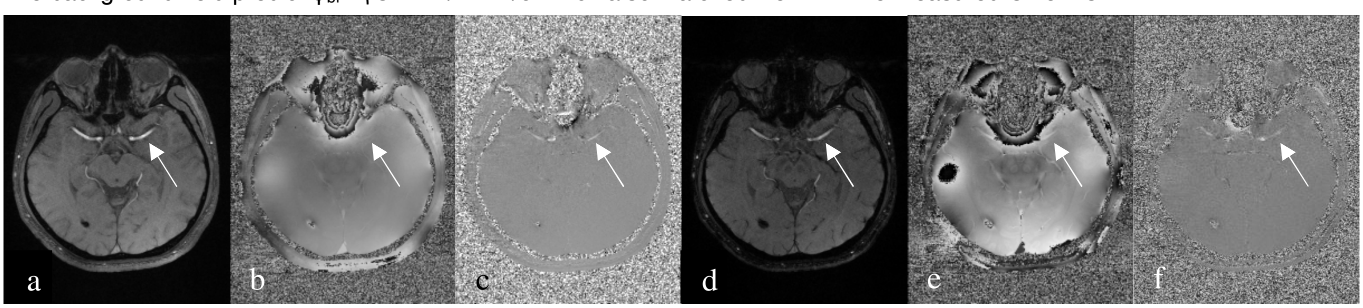

Figure 1. Short echo images (TE = 10ms): a) magnitude; b) phase from background field at TE= 10ms; and c) phase from acceleration effects. Long echo images (TE = 22.5ms): d) magnitude; e) phase from background field; and f) phase from acceleration effects. Note that the MCA G' induced phase effects are much greater at TE = 22.5ms (see arrow in e) because of the dependence of phase on TE^2.

Discussion and Conclusions: Although it is possible today to do an excellent job in designing a fully velocity flow compensated dual echo sequence, nature plays a confounding role in destroying the compensation due to background field gradients and adding to the confusion by superimposing onto the phase acceleration effects as well. In this study, we demonstrate the importance of each term, especially at longer echo times on the order of 20ms. We also suggest that for SWI and QSM processing that one might use the bright signal from the inflow effect in the first echo as a means to detect arteries (which appear to be the main culprits in both errors) and then automatically set the phase to zero for both SWI and QSM calculations. This would avoid the deleterious effects of both errors.

References:
1) Y. Du et al. J MagnReson Imaging. 2009;30(2):449-54.
2) A. Desitung et al. J MagnReson Imaging. 2009 Jun;29(6):1478-84.
3) B. Xu et al. MagnReson Med 72:438–445 (2014).
4) KT Bae et al, J MagnReson Imaging2010 Jan;31(1):255-61.
5) SS Oh et al. MagnReson Med 2014 Aug;72(2):452-8.