Characterization of local field disturbances through phase derivative mapping

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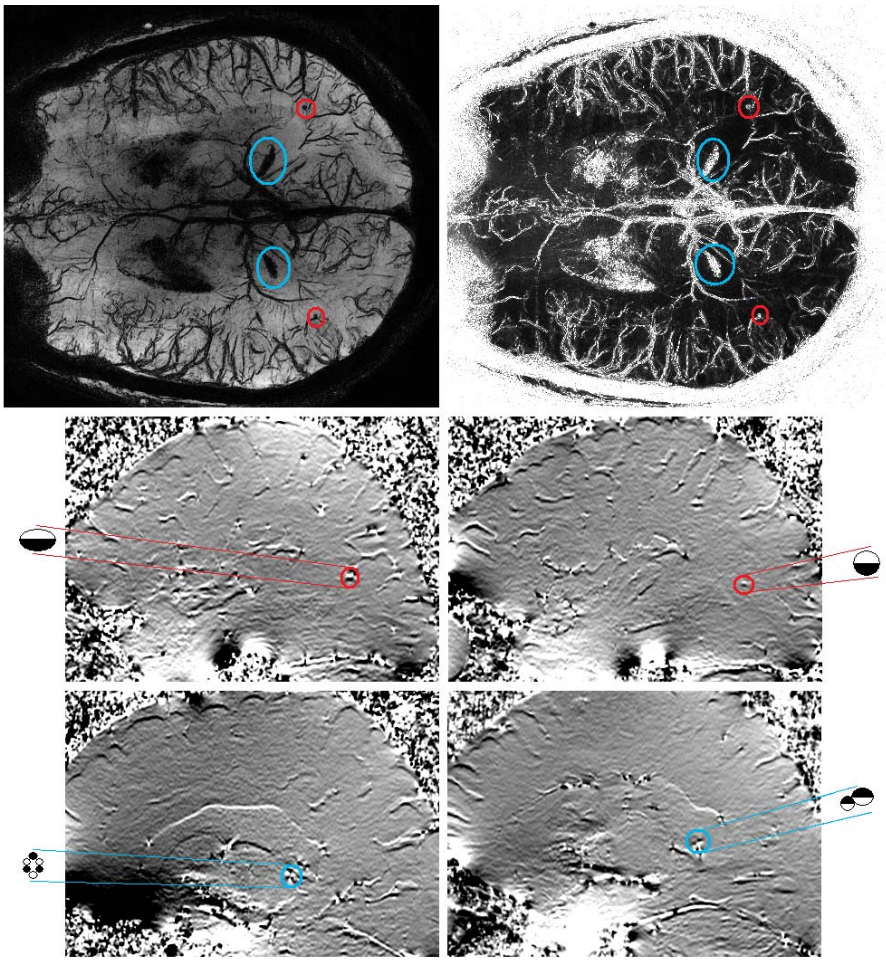
Introduction: In most (clinical) MRI studies, magnitude images are used as the only source of information. Especially in the presence of local field distortions, this may be considered as a suboptimal usage of available data, since information on the local magnetic field is primarily encoded in the signal phase. Utilizing the full MR signal, i.e., the signal magnitude as well as the signal phase, would in principle allow for a more complete characterization of structures and lesions. Unfortunately, the signal phase is often difficult to interpret due to phase wraps and poor discrimination in areas with low signal to noise. Due to these difficulties the full complex signal most often not used in clinical practice. In this work we want to explore an extension of the usage of the phase, by using the phase derivative. We demonstrate that, for microbleeds and calcifications in the brain, by using the phase derivative, local field disturbances can be detected and analyzed in terms of positive or negative susceptibility deviations.



Methods: 3D multiple gradient echo (2 echoes) imaging was performed on a 7.0-T whole body system (Philips Healthcare, Cleveland, OH, USA), using a 16-channel receive coil (Nova Medical, Wilmington, MA, USA). Scan parameters included: TE_1=2.5ms, TE_2=15 ms, TR=20 ms, FOV 200×200×100 mm^3, matrix: 508×399×167, reconstruction matrix 576×576×333 and NEX=3, Excitation pulses consisted of non-saturated excitation pulses with nominal flip angle variation of 16° to 24° in the feet-head direction over the slab. Written informed consent was obtained from all participants of the study.
The phase gradient was calculated as described previously [1]. The derivative images were corrected for B_1 inhomogeneities by subtraction of the derivative images at two echo times. For the slices covering the ventricles a maximum intensity projection of the phase gradient magnitude was calculated. A minimal intensity projection was made of the corresponding signal magnitude images. For further analysis the derivatives in each direction were studied slice-wise for some structures. For display purposes the derivative in the direction of B_0 was averaged using a Gaussian filter of width 2 pixels.

Results: Figure 1 shows a minimal intensity projection of the magnitude and a maximum intensity projection of the phase gradient magnitude of 51 slices covering the ventricles. The middle and bottom rows show the phase derivative along B_0. The middle row shows two slices corresponding to the position of two micro-bleedings (red circles), the bottom row shows the same for two structures in the ventricles (blue circles). In the inserts in figure 1, a schematic representation of the pattern of the derivative is given. The phase gradient magnitude and the magnitude, as shown in figure 1, clearly depict the field disturbances by negative and positive contrast respectively. The pattern of the phase derivative, for the field disturbances in the middle row of figure 1, shows from bottom to top, a decrease followed by an increase in the phase, in other words an increase of the local field for the disturbance. As expected this corresponds to a paramagnetic field disturbance, for example a (micro)bleeding. For the structures depicted on the bottom row, the pattern is similar up to a minus sign. In other words, these field disturbances on the bottom row are diamagnetic, for instance a calcification.

Discussion: In the past few years many publications concerning local field disturbances have appeared [2, 3]. Often these publications aimed at detection or depiction of field disturbances using the signal magnitude. Since signal dephasing in the magnitude image is independent of the sign of the field of the disturbances, these studies did not allow discrimination between paramagnetic and diamagnetic disturbances. Techniques need to be sign dependent to enable characterization of field disturbances. SWI, as presented in [2], is able to detect calcifications, but for the characterization prior knowledge or more information is needed. The phase gradient magnitude might be used to detect field disturbances in a similar way as the signal magnitude. Note, however, that the signal magnitude and the phase gradient magnitude can be used simultaneously, since both are available with the acquired data. The phase gradient magnitude highlights field disturbing structures only, while absence of signal in the signal magnitude images can have multiple sources (low spin density, T_1-effects, short T_2).
The contrast in the magnitude image is determined by the effective flip angle, while the contrast in the phase gradient magnitude is independent of B_1 inhomogeneities. The B_1 influences the phase derivative through the signal to noise in the signal magnitude, which determines the noise in the phase image. Only at low signal to noise, the influence of B_1 on the phase derivative will be apparent. At higher field strengths, such as the 7T system used in this study, where B_1 tends to be more inhomogeneous, this is a significant benefit of the phase derivative. The patterns, as shown in the bottom two rows of figure 1, are quite clear, but not in all slices. For example, if multiple small structures, such as in the right bottom image of figure 1, are grouped closely, a more difficult interpretable pattern is formed. Although these more difficult patterns possibly hamper characterization of structures, still some characterization might be possible using the multiple directions of the derivative and the shape of the disturbance. Phase gradient mapping therefore might be expected to constitute a valuable tool to detect and characterize for example microbleedings or calcifications at unexpected locations. Further research needs to be conducted to assess the possibilities and limitations of the phase derivative for its usage as an additional source of information on field disturbances.

Conclusion: Signal magnitude analysis only allows for detection of local field disturbances. By using phase gradient mapping, detection and characterization of local field disturbances is shown to be possible.

References: [1] De Leeuw, H et al. *Proc. ISMRM* 2009; 261 [2] Wu, Z et al. *JMRI* 2009:29:177-182 [3] Jeong, S.W. et al *Archives of Neurology* 2004;61:905-909