On The Role of Physiological Fluctuations in Quantitative Gradient Echo MRI

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Purpose: Physiological fluctuations in biological tissues adversely affect MR images if present during signal acquisition. This problem is especially important for quantitative MRI. The goal of this study is to reduce the contributions of physiological fluctuations in quantitative MRI based on T2* tissue relaxation properties. Specifically, we deal with GEPCI (1, 2), QSM (3) and SWI (4) techniques and propose methods allowing for substantial improvement of their results.

Methods: ***Image acquisition***: All studies were approved by the local IRB. Images were collected using a 3T Trio MRI scanner (Siemens, Erlangen, Germany) equipped with a 12-channel phased-array head coil. Two datasets were collected for each subject: a high resolution data (voxel size 1×1×3 mm3), and a low resolution data (voxel size 1×2×6 mm3). Both datasets used three dimensional (3D) multi-gradient-echo sequences with a flip angle of 30°, TR = 50 ms and the total acquisition times of 6 min 30 sec and 1 min 30 sec, respectively. For each acquisition, 11 echoes were collected with first echo time TE1 = 4ms and echo spacing ΔTE = 4ms. The last echo was used as a navigator echo by applying additional magnetic field gradients to unwind the spatial encoding gradients before it.

B_0 fluctuation correction: We use navigator echoes (5) to monitor and correct the signal fluctuations due to the fluctuations of the magnetic field B_0. First Inverse Fourier Transform is applied to the navigator signal (kx-space) along the readout direction (x) to produce images projected on this direction. Then for each spatial point x of this image and each phase encoding step, the phase difference between the N-th ($\varphi_N(x)$) and the first ($\varphi_1(x)$) spatial encoding step is calculated. Finally, the correction is applied to each phase encoding step with gradient echo time TE, according to the equation: $S_N^c(x,TE) = S_N(x,TE) \cdot e^{-i(\varphi_N(x)-\varphi_1(x))\cdot TE/(11\cdot\Delta TE)}$, where $S_N^c(x,TE)$ and $S_N(x,TE)$ are the signals in k-space after and before correction, respectively.

Keyhole-type k-space center averaging: A keyhole (6) -based technique was also used to further reduce physiologically-induced artifacts. New k-space data are generated after applying the B_0 fluctuation correction using the same reference phase to both high-resolution and low-resolution datasets. The central part (which has the same size as low-resolution data) of the k-space of high-resolution data is combined with low-resolution data by taking the average of these two.

Results: Fig. 1 shows that physiological fluctuations completely mask two hypointense multiple sclerosis (MS) lesions (indicated by red arrows in Fig. 1) in the centrum semiovale that become clearly visible after corrections. In addition, corrections also improve visualization of blood vessels, as indicated by blue arrows in Fig. 1. Importantly, physiologically induced artifacts can dramatically affect the global R2* distribution of the whole brain (red line in Fig. 1c). The corrections applied greatly changed the R2* distribution, not only by shifting the distribution to the left (smaller R2*), but also making the distribution much tighter. Fig. 2 shows that the applied corrections greatly improve the quality of R2* (Fig. 2a and e), frequency shift (Fig. 2b and f), QSM (Fig. 2c and g) and SWI (Fig. 2d and h) measurements.

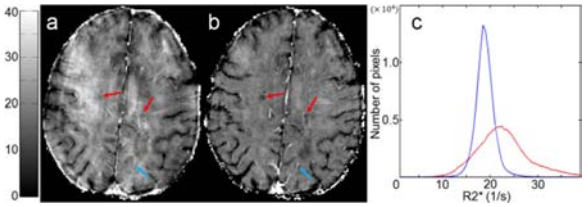

Fig. 1 R2* maps from MS patient before (a) and after (b) correction; c. R2* distribution of the normal appearing white matter of whole MS brain before (red line) and after (blue line) corrections.

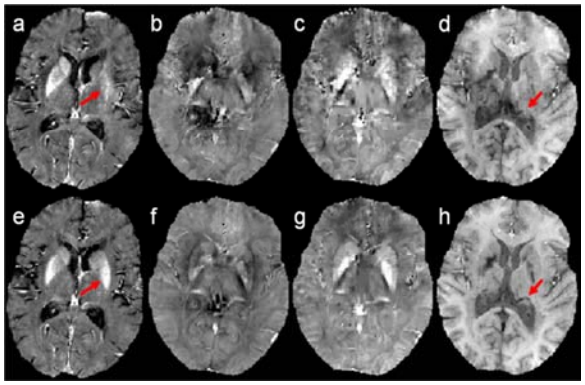

Fig. 2 Comparison of R2* (a & e), frequency shifts (b & f), QSM (c & g) and SWI (d & h) measurements before (upper row) and after (bottom row) corrections.

Conclusion: We evaluated the role of physiological fluctuations in quantitative MRI based on T2* tissue relaxation properties and MR signal frequency shifts. Specifically, we addressed the effects of such artifacts on GEPCI, QSM and SWI techniques, and proposed methods to overcome these artifacts. We demonstrated that the employed strategies substantially reduce the width of the R2*=1/T2* distribution within a human brain, indicating that significant improvement in tissue damage measurement, as shown here in images from a MS patient, would be expected. We also showed improvement in the visual quality of SWI and QSM images. We conclude that the use of the correcting strategies employed here has potential to greatly reduce physiologically-induced artifacts in GEPCI, QSM and SWI, making the quantitative value of these techniques more accurate and reliable.

References: (1) Yablonskiy, Proc. ISMRM (2000), 8: 431; (2) Luo et al., NeuroImage (2012), 60: 1073-1082; (3) de Rochefort et al., MRM (2008), 60: 1003-1009; (4) Reichenbach et al., Radiology (1997), 204: 272-277; (5) Ehman et al., MRI (1989), 173: 255-263; (6) van Vaals et al., JMRI (1993), 3: 671-675.