Noninvasive Measurement of TBI Using High Resolution Multiecho Susceptibility Weighted MRI at 3T

H. Tang[1], P. Sati[2], P. Yeh[3], B. Wang[3], H. Pan[3], J. Smirniotopoulos[1], R. Selwyn[1], T. Oakes[3], and G. Riedy[3]

[1]Center for Neuroscience and Regenerative Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD, United States, [2]NINDS, National Institute of Health, Bethesda, MD, United States, [3]Walter Reed Army Medical Center, Washington DC, United States

Introduction Susceptibility weighted imaging (SWI) [1-2] is sensitive for detecting neurovascular abnormalities, iron deposition, calcifications, and hemorrhages in neurodegenerative diseases and trauma. The objective of this study was to develop and evaluate a sensitive neuroimaging technique for Traumatic Brain Injury (TBI). The proposed SWI technique was implemented using a 3D multiecho gradient echo method to improve the visibility of the veins and lesions in various brain regions, and to provide a quantitative tool for brain lesion characterization based on R_2* and phase mapping analysis.

Methods Healthy volunteers (4 females, 8 males) and male TBI patients (6 mild, 3 moderate; 7 blast injury, 2 non-blast trauma; 3 weeks to 9 months post injury) were examined under an Institutional Review Board approved protocol. The MR measurements including volumetric T_1, T_2, SWI, and contrast enhanced FLAIR MRI were performed at Walter Reed Army Medical Center, using a 3T GE750 Systems (GE Healthcare, Milwaukee, WI) equipped with a 32-channel phased array head coil.

SWI was implemented using a 3D flow-compensated multiecho gradient-echo sequence, with TR=45ms, 5 echoes, TE0=13ms (recent images were acquired with TE0=5ms), echo-spacing 6ms, flip-angle=20°, BW=62.5 kHz, and asset-factor=2. Ninety slice images were acquired with a 512×256 matrix, 24×24 cm^2 FOV, and 1.5mm slice thickness. This produced sufficient cross sections to cover an entire brain within a clinically acceptable scan time (5'30'').

Image Analysis SWI images were processed based on the magnitude and phase information [1] obtained at each individual echo time, using the SPIN software (HUH-MR Research Radiology, Wayne State Univ., Detroit, MI). Minimum intensity projections (mIPs) were performed over 7 slices. Magnitude, high-pass filtered phase images, SWI at each echo time, and the combination of SWI at multiple echo times can be used during the review process.

Multiecho datasets were used to quantify the R_2* maps of the entire brain. Apparent R_2* maps were obtained using mono-exponential fit over the 5-echo magnitude images. In addition, phase maps were obtained from the 5-echo phase images by correcting for phase wrap and performing a linear fit of the phase variation in the temporal domain. The generated phase maps were finally high-pass filtered by applying a Gaussian filter and subtracting from the original phase maps.

Finally, an image processing and non-uniformity correction software incorporating various image filtering methods was developed in-house. The software was used to correct for the brain image intensity non-uniformity caused by the 32-channel phased array coil at 3T and, consequently, to improve the visibility of venous and traumatic lesions at the brain surface. Comparisons were made between the SWI and conventional T_1/T_2 weighted images.

Results Figure 1 shows typical R_2* map (top) and phase map (bottom) for a healthy subject derived using the multiecho approach. Figure 2 demonstrates the brain images of a TBI subject, which were acquired using various MRI methods. R_2* maps were calculated using the multiecho 3D GRE dataset. The TBI lesions (indicated by arrows) are clearly visible in the SWI. The Sub-Dural hematoma at the left frontal lobe was highlighted in the FLAIR image acquired post Gd injection. Figure 3(a) demonstrates the right temporal encephalomalacia in a TBI subject. The square summation of SWI from the 1st and 2nd echoes was applied to the temporal regions with moderate TBI, and the SWI derived from the longer echo images were used to identify nearby small lesions and micro-hemorrhages (TE=25ms, Fig. 3a, image on the right) that are not detectable by conventional T_1/T_2 weighted images. Figure 3(b) shows the cerebral encephalomalacia in another TBI subject. R_2* was increased around the injured region. R_2* is intrinsically greater in the Globus Pallidus region (40 s^{-1}). Figure 3(c) demonstrates a cavernous malformation in brain. The venous drainage was clearly depicted in the SWI, calcification (shown as positive phase) can be differentiated from hemorrhages in the phage map (Fig. 3c, image on the right).

Conclusions and Discussions MRI techniques with multi-contrast capability may help detection and classification of types and patterns of TBI. The proposed multiecho gradient echo method which provides with R_2*, phase map, and SWI contrast is a sensitive technique to image TBI. SWI at longer TE has stronger susceptibility effect yielding greater venous contrast, whereas SWI at shorter TE provides higher SNR and less off-resonance artifact. Heterogeneity of TBI lesions will benefit from the multiecho SWI acquisition and analysis.

First, SWI generated at different echo times are complementary in depicting venous structures and traumatic lesions. Larger veins are clearly shown at shorter TE, and smaller venous structures are better visualized at longer TE. Second, for frontal regions with TBI, and for regions with severe field inhomogeneity, square sum of SWI derived from shorter echoes provides reasonable lesion contrast with less off-resonance artifact and signal drop out, which can be complementary to the SWI derived from the longer echoes for depicting micro-hemorrhages and mild TBI lesions. The multiecho approach can help interpreting the TBI data in areas with severe off-resonance effects. Last, R_2* map generated by the multiecho imaging scheme may provide a measure of iron deposition in brain. The phase maps generated by the multiecho data are quantitative, which can be used to help characterize TBI lesions and calcifications. The field map generated by the multiecho approach can be used to reduce the artifacts and distortions in SWI, and to correct for the R_2* maps. Further analysis and development in this area are undergoing, to improve the brain lesion detection in regions suffering from air/tissue field inhomogeneity effects.

The preliminary imaging data - from healthy subjects and TBI patients - shows improved visibility of brain vasculature and traumatic lesions with the multiecho SWI technique. SWI complements conventional T_1/T_2 weighted and FLAIR MRI. Longitudinal studies will help define the relationship between these imaging markers and clinical outcomes. In turn, this may allow more sensitive identification of mild TBI, and optimize therapy and match patients with the most appropriate intervention.

Reference
1. Haacke EM, Mittal S, Wu Z, et al. AJNR Am J Neuroradiol 30: 19-30, 2009.
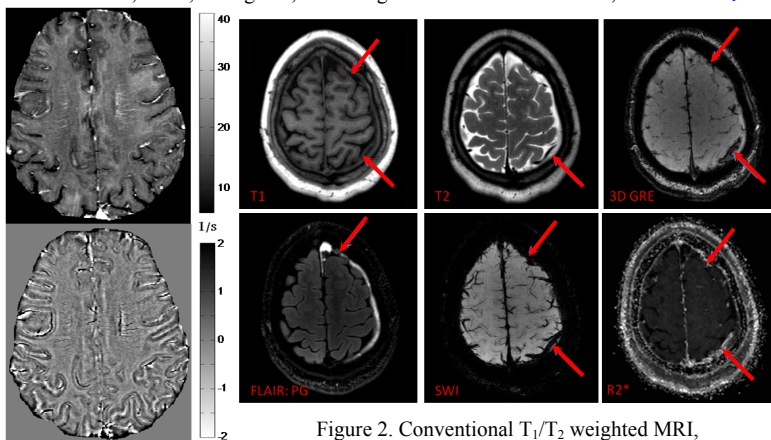2. Haacke EM, Xu Y, Cheng YN, et al. Magn. Reso. Med. 52:612-618, 2004.

Figure 1. R_2* map (top) and phase map (bottom) derived from the multiecho acquisition

Figure 2. Conventional T_1/T_2 weighted MRI, contrast enhanced FLAIR, SWI, and R_2* map for a TBI subject.
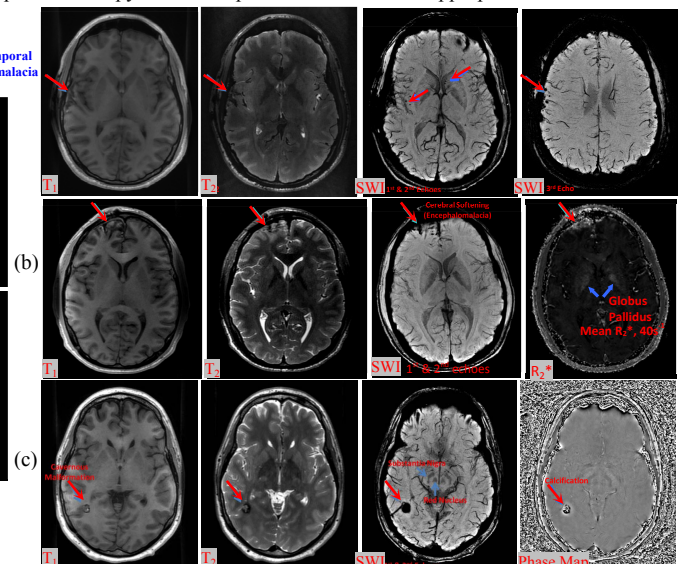

Figure 3. Multi-echo SWI complements conventional T1/T2 weighted MRI.