Susceptibility Mapping of the Sinuses in the Brain by Preserving Phase Information in the Skull using Short Echo Times

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Introduction: Susceptibility mapping (SM) is a means by which to extract local tissue susceptibilities [1]. Usually the focus is on imaging tissues in the brain, and skull stripping is used to focus on phase unwrapping of the brain. Further, every effort is made to reduce background field effects [2] or remove sinus artifacts from forward modeling [3]. However, in this work, we focus on what is usually thrown away, the sinuses, using both simulated [4] and real data, to show that one can image these susceptibility objects when there is no signal from them (such as air in sinuses, teeth, bones, etc). Further, because the susceptibility effects between air and tissue are so large, we are able to use short echo times to extract the susceptibility.

Method: Two MRI data sets were acquired as fully velocity compensated, rf spoiled, high resolution, 3D gradient echo SWI-magnitude and phase images, with imaging parameters: TE_1=7.8msec and TE_2=5.2msec, TR=30ms, FA=20°, B_0=3T (Siemens Vario) and 0.5×0.5×1mm^3 resolution. The 5.2ms data are complex divided into the 7.8ms data to produce a new effective phase with effective TE of 2.6ms. Any aliasing is removed by shifting the baseline. The resulting phase image has minimal points with aliasing and any remnant wraps, around the ethmoid sinus in particular, are removed by using local thresholding. SMs ($\chi(r)$) are generated from the resultant phase images ($\varphi(r)$) by applying the regularized inverse filter (regularization threshold=0.2) given as: $\chi(r)=\{FT^{-1}[g^{-1}(k)\cdot\varphi(k)]\}/\gamma\cdot B_0\cdot TE$, where g-1(k) represents the inverse of the Green's function $g(k)= 1/3-k_z^2/k^2$, B_0=3T using TE=2.6ms [1]. In order to test our hypothesis, a 3D brain model, which includes the basal ganglia, midbrain structures, major veins, grey/white matter and cerebro-spinal fluid and air-tissue interfaces at the brain sinuses with $\Delta\chi_{air\text{-}tissue}$=9ppm, is utilized to simulate the phase images and simulate SMs [4]. One of the key advances in our approach is including the tissue outside the sinuses in the skull. Therefore we produce simulated SMs with and without the phase inside the skull. To reduce streaking artifacts an iterative algorithm [5] (three iterations) is used in the reconstruction of the SM.

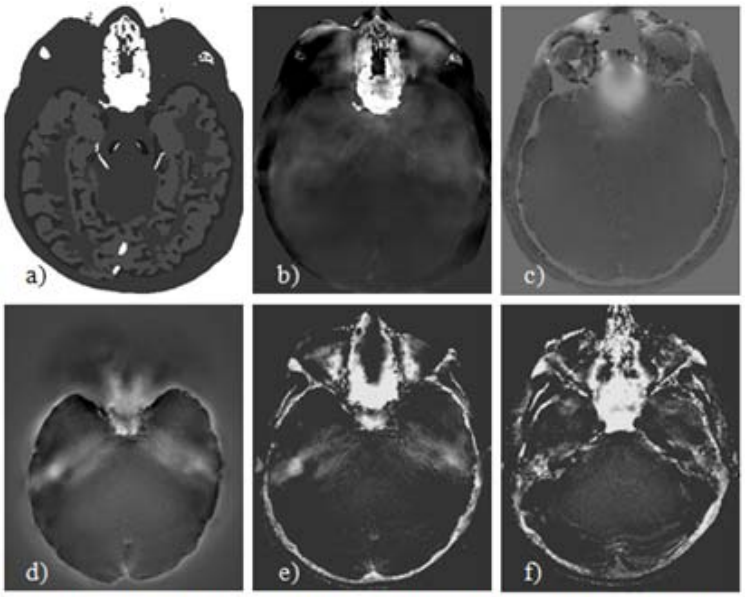

Fig 1: a) The 3D brain model used to test the proposed concept, b) Simulated SM resulting from the phase simulation after keeping the phase information both inside and outside the brain, c) The resultant phase (TE=2.6ms) after the complex division of phase data sets with echo times: TE_1=7.8ms and TE_2=5.2ms, d) SMs generated by not using the phase outside the brain for the real data, e) and f) SMs generated by preserving the phase inside the skull region (pericranium to scalp) for the real data.

Results: The simulated model (Fig. 1a) and its resulting SM (Fig. 1b) show the potential of this concept. The complex division result shows considerably less phase wraps around the air-tissue interfaces, allowing us to preserve the phase information even outside the brain (pericranium to scalp) (Fig. 1c). The results from the real data show poor delineation of the sinuses if the skull information is not kept (Fig. 1d) but much improved results when the skull information is kept (Fig. 1e). The mean susceptibility values, especially inside the ethmoid sinus, are much higher than other areas of the brain as we expected (Fig. 1e, f). The maps of brain sinuses can be generated from SMs by thresholding the regions with susceptibility values of greater 4ppm to remove any structures with lower susceptibility.

Discussions and Conclusions: The relevant local information about the brain is buried under the dominant phase effects caused by the high susceptibility difference at the air-tissue interfaces necessitating the application of filtering techniques like homodyne HPF or SHARP [2], which can alter the actual phase information. The sinus maps demonstrated in this abstract can be used to reduce this unwanted phase by generating the phase behavior using a forward calculation for any desired echo time. In order to extract the sinuses more accurately, the SM can be combined with the magnitude images to keep only those points that are clearly air and not tissue. Although higher resolution (0.5mm)^3 will possess lower SNR, it will provide us with better phase information (with less partial volume effects) around the sinuses. We also use two in-phase images of 5.2ms and 7.8ms to ensure that the fat in the skull shows the correct phase behavior and is not contaminated by water/fat phase shifts. The two key points that make this extraction of sinuses possible are the short effective echo time and the inclusion of the skull information which provides the necessary missing information to reconstruct the 3D shape of the sinuses. Another important structure on the edge of the brain, the superior sagittal sinus which is usually the region of interest for oxygen saturation studies, could be better reconstructed in SMs if the phase outside the SSS on the skull region was preserved. Eventually, this method could be used to image teeth, bone (making imaging the spine more interesting for SM), and other structures with variable susceptibility that are generally viewed as a problem; now these structures can be viewed as an important source of information.

References: [1] Haacke et al., JMRI(2010);32:663–676. [2] Schweser, F. et al. NeuroImage 54 (2011) 2789–2807; [3] Neelavalli, J. et al. JMRI (2009) 29:937-948. [4] Buch et al., ISMRM(2012):4462. [5] Tang et al. Magn Reson Med (2012).