Comparing Magnetic Susceptibility Mapping with SWI for Targeting Structures for Deep Brain Stimulation

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Introduction: Deep brain stimulation (DBS) is a stereotactic neurosurgical technique in which electrodes are inserted into deep-brain target structures such as the subthalamic nucleus (STN) and globus pallidus (GP). DBS is increasingly used to treat movement disorders such as Parkinson's disease and dystonia. Recently susceptibility-weighted imaging (SWI) [**1**], which utilizes the phase of the MRI signal, has been shown to offer improved visibility (contrast-to-noise) of the STN in pre-surgical MRI compared with standard T_2-weighted fast spin-echo (FSE) techniques [**2**]. However, because the phase contrast near the high-susceptibility iron-rich target structures is non-local and orientation-dependent, SWI may contain subtle artifacts which could lead to stereotactic targeting errors. It may be possible to assess and overcome these artifacts by calculating tissue magnetic susceptibility maps from the phase images acquired for SWI. Such maps have shown promise for overcoming the orientation-dependence and non-locality of the phase contrast at high-resolution and high field (7T) [**3,4**]. Here we investigated whether susceptibility maps can be calculated from standard clinical 1.5T MRI phase data and evaluated their potential for targeting the STN and GP for DBS by comparing the maps with SWI.

Methods: SWI images were acquired in 9 healthy adult volunteers, (4 male, ages 24-43) and also pre-operatively in a group of 10 patients (7 male, ages 43-74) referred for DBS surgery for movement disorders. Informed consent was obtained for all subjects. A 1.5T MRI scanner (GE Medical Systems, Milwaukee, WI, USA) with a transmit-receive quadrature head coil (compatible with the Leksell stereotactic frame) was used to acquire standard FSE as well as SWI. The SWI 2D gradient-echo sequence had TE = 40 ms, TR = 2.3 s and an in-plane resolution of 0.5 x 0.5 mm. To cover the brain, 48 axial slices of 2 mm thickness were acquired with no gaps. SWI were calculated using the method of Haacke et al. [**1**]. Magnetic susceptibility maps were calculated from the SWI phase images using newly developed methods [**3**] with a truncation value of 5. The susceptibility maps and standard SWI were compared and assessed visually to evaluate any superior-inferior shifts in the borders the STN, red nuclei, and GP in the SWI relative to the susceptibility maps. Custom image overlay software (RView, http://www.colin-studholme.net/software/software.html) was then used to compare the right-left and anterior-posterior extent of the red nuclei and DBS target structures between the SWI and susceptibility maps.

Results: Susceptibility maps were successfully calculated for all subjects, and were broadly similar to the SWI (and phase images) but showed important differences. In some subjects there were differences in the superior-inferior extent of the red nuclei and GP: the margins of the red nuclei and GP interna (GPi) sometimes appeared shifted by 2 mm in the SWI relative to the susceptibility maps (**Fig. 1**). Such through-plane shifts in the position of the superior margin of the GPi were observed in 5 patients and 2 volunteers and the superior margins of the red nuclei were shifted in 9 patients and 7 volunteers. No through-plane shifts were apparent for the STN. No differences in the right-left or anterior-posterior position of the GPi and STN were discernible on the image overlays (**Fig. 2**).

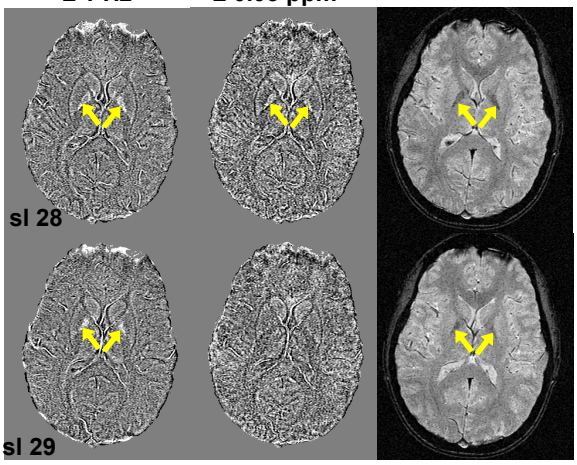

Figure 1 Through-slice error in GP position in a healthy volunteer: In the SWI and phase image the GP's superior margin is visible in slice 29 but in the susceptibility map it is visible in slice 28: there is a 2 mm shift in the superior margin of the GP in the SWI relative to the susceptibility map

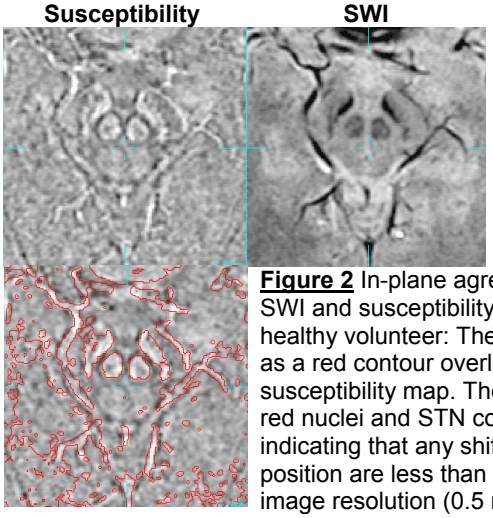

Figure 2 In-plane agreement between SWI and susceptibility maps in a healthy volunteer: The SWI is shown as a red contour overlaid on the susceptibility map. The margins of the red nuclei and STN correspond well, indicating that any shifts in R-L or A-P position are less than the in-plane image resolution (0.5 mm)

Discussion and Conclusions: Whole-brain tissue magnetic susceptibility maps were calculated from clinical 1.5T MR imaging data acquired at a single head orientation. Because susceptibility maps reduce the non-local contrast seen in phase images, they were compared with SWI and phase images to assess and attempt to overcome any potential errors in localizing the DBS target structures: the STN and GP. No relative shifts were observed for the STN showing that, at 1.5T, SWI improves the visibility of the STN without increasing targeting inaccuracy. Superior shifts in the borders of the red nuclei were seen in nearly all subjects. The borders of the GPi also appeared to shift by 2 mm in the inferior-superior direction on the SWI in several subjects. Susceptibility maps therefore show potential for overcoming position artifacts in SWI arising from non-local phase changes near iron-rich target structures. Susceptibility maps may therefore help reduce errors in pre-surgical localization of DBS target structures. Phase changes increase with magnetic field strength, suggesting that the targeting errors due to non-local phase contrast will be greater at high field strengths. Therefore, susceptibility mapping is likely to be increasingly important to reduce targeting inaccuracies at higher field strengths.

References:

1. Haacke EM et al. MRI 2005; 23: 1-25
2. R. O'Gorman et al. Proc. 17th ISMRM, 2009; 938
3. K. Shmueli et al. MRM 2009; In Press
4. K. Shmueli et al. Proc. 17th ISMRM, 2009; 466