Age Dependence in Phase Images of Human Brain at 3T and 7T: Implications for High Field Contrast Mechanisms

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Introduction: Gradient echo sequences with moderately long echo times (TE≈T2*) allow for phase imaging of the brain with contrast based on tissue susceptibility differences. Phase images provide excellent delineation of veins due to deoxyhemoglobin [1,2], and high gray matter (GM) and white matter (WM) contrasts thought to be due to parenchymal iron concentration [3,4]. Imaging at higher field is expected to increase the sensitivity in these susceptibility weighted images [4]. The objective of this study was to quantify the phase shift in different brain regions of normal subjects of different ages at 3T and at 7T, and to correlate phase shifts to the brain tissue iron content computed from published biochemical data [5].

Materials and Methods: We imaged 6 human subjects (age 18-54 years) at 3T and 7T (Philips Achieva) using a 2D gradient echo sequence. Acquisition parameters correspond to Ogg's work [3] but were adjusted to the larger T1 at higher fields, i.e. TR/TE/flip angle=1300/25ms/60° at 3T and TR/TE/flip angle=1600/12ms/50° at 7T. Image sets were acquired at each field with both low resolution (0.9x0.9x5mm, identical to Ogg [3]) and high resolution (0.45x0.45x2.5mm). Additional data were acquired in 3/6 subjects to further assess effects of SNR, resolution and TE. Magnitude and phase images were reconstructed off-line from the time domain data, using IDL with high pass filtering to remove slowly varying field inhomogeneities [1,2]. Different brain regions, including frontal and motor GM and WM, putamen, globus pallidus, caudate, thalamus and ventricle, were manually traced on the magnitude and phase images. For the globus pallidus, putamen, caudate and thalamus, three sets for ROIs were drawn and compared: 1) the whole anatomic structure, 2) including only the darkest part [3] and 3) including only a homogenous, bright region with no evident vasculature.

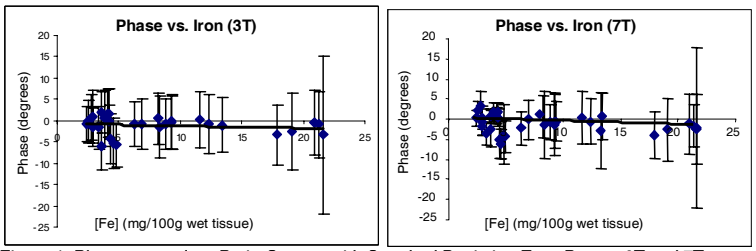

Figure 1. Phase versus Iron Brain Content with Standard Deviation Error Bars at 3T and 7T

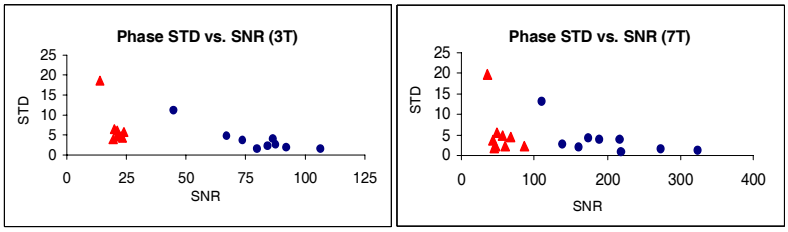

Figure 2. Phase STD versus SNR for one representative subject at 3T and 7T. Graphs display results for both image resolutions (red triangles-0.45x0.45x2.5mm,and blue stars-0.9x0.9x5mm)

Results: Plots of phase shifts versus iron content for different brain region computed from the high resolution images using the subject's age and Hallgren's equations [5] are shown in Figure 1, for 3T and 7T. No phase change with iron concentration or magnetic field was observed. The overall behavior of the phase with iron content was not significantly changed by the inclusion of the whole, darkest or the most homogenous region of the caudate, putamen or globus pallidus. To address the question if the large standard deviation (STD) in the phase shift measurements are simply due to the overall signal to noise ratio (SNR), or are reflective of true anatomy at the resolution limit, we compared magnitude image SNR with phase STD. Figure 2 shows the relation between SNR and phase STD, however, high resolution data (red triangles) have a steeper behavior than low resolution data (blue stars) indicating that at least some of the variability of phase shifts on the high resolution images is reflecting true anatomy. Note that overall SNR at 7T is 2 to 3 times higher than at 3T.

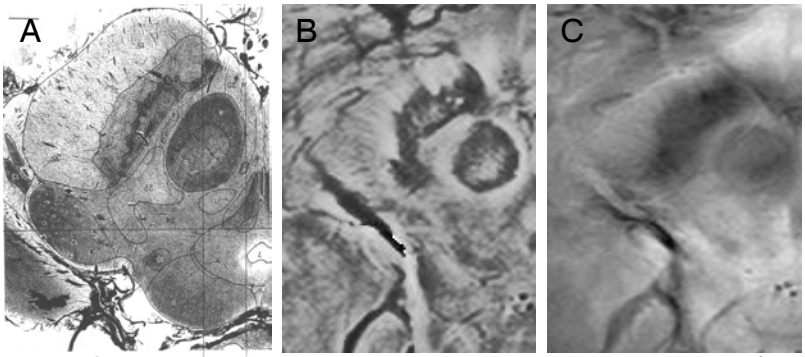

Figure 3. Comparison between india ink stained vasculature* (A), equalized histogram of the phase (B) and magnitude image at the level of red nuclei and substantia nigra in a subject at 7T. Note the correspondence between high vessel area on india ink stained tissue (A) and low phase signal on phase equalization image (B). * Adapted from Duvernoy et al.[6]

Discussion: Since we could not reproduce at 3T and 7T the dependence of phase versus brain iron content reported by Ogg et al. at 1.5T, this leaves open the question regarding the contrast mechanism in high field susceptibility weighted phase images. Venous structures appear very prominently on phase images suggesting that susceptibility weighted images may predominantly reflect venous microvascular density. Comparison of published india ink stained section of brain stem [6] with phase images may support this hypothesis as shown in Figure 3. This assumption may also be consistent with theoretical models indicating that dephasing due to diffusion in the susceptibility field of perturbers in the micrometer size range, such as capillaries may be more prominent than diffusion in the field of nano-meter sized perturbers such as ferritin. The later may explain why R2 measurements correlate more robustly to parenchymal brain iron content [7]. As suggested by Haacke et al. [4], further experiments including changing of blood oxygenation level and/or vascular contrast agents are required to separate non-heme and heme iron effects in phase and T2* images.

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