Observation of Time Dependent Magnetic Field Correlation in the Human Brain

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Introduction: The Magnetic Field Correlation (MFC) is a quantitative MRI metric that characterizes magnetic field inhomogeneities (MFI) generated in the brain by iron-rich tissue structures. The MFC gives information beyond that provided by more commonly used parameters for brain iron quantification, such as R2 and R2* [1-5]. Prior work indicates that the MFC increases rapidly during adolescence, consistent with known age-related brain iron changes [6] and that Alzheimer's patients have elevated MFC values in the basal ganglia compared with age-matched controls [7]. The MFC may be decomposed into macroscopic (macroMFC) and microscopic (microMFC) components that reflect, respectively, MFI which vary on length scales large and small compared to the voxel dimensions [8, 9]. In previous phantom studies, we have shown that the microMFC decreases monotonically with time, as is the theoretically expected behavior in the presence of microscopic MFI [4]. The present work demonstrates the time-dependence of microMFC in vivo by estimating MFC at three different times for selected regions of interest within the brain of 21 normal human subjects.

Theory: As described previously by Jensen et al [4], the temporal dependence for microMFC can be approximately modeled by the equation:

$$\text{microMFC}(t) = \text{microMFC}(0) \cdot \left(1 + \frac{4Dt}{r_c^2}\right)^{-3/2}, \qquad (1)$$

where t is the time, D is the diffusion coefficient, and r_c is a characteristic length for the subvoxel MFI. By measuring microMFC at various times and using experimentally determined values for D, Eq. (1) can be applied to estimate the characteristic length r_c.

Methods: Imaging was performed on 21 healthy adult subjects (age 34.4 ± 10.0 yr; 11 male, 10 female) using a Siemens Trio 3T scanner. MFC data was acquired for three times (t = 23, 35, 45 ms) using a single-shot EPI asymmetric spin echo sequence with the 180° refocusing pulse shifted by times t_s = 0, -4, -8, -12, and -16 ms from its standard (i.e., spin echo) position and with three different echo times (TE = 46, 70, 90 ms). Both magnitude and phase images for each acquisition were saved. Other imaging parameters were: TR = 2000 ms, acquisition matrix = 128×128, FOV = 256×256 mm^2, bandwidth = 1346 Hz, slice thickness = 2 mm, interslice gap = 2 mm, number of slices = 9, averages = 10. Diffusion-weighted image (DWI) data was also acquired for each subject in order to estimate D. MFC and DWI data were processed offline on a PC using in-house MATLAB scripts (Mathworks, Natick, MA). The parametric maps for microMFC were derived from the magnitude and phase images following established methods [8, 9]. Regions of interest were chosen from within the globus pallidus (GP), putamen (Put), and thalamus (Th) for all subjects. The microMFC results for the three times were fit to Eq. (1) using LABfit [10] with microMFC(0) and D/r_c^2 as free parameters. The best fit values for were then combined with the measured values for D in order to estimate r_c.

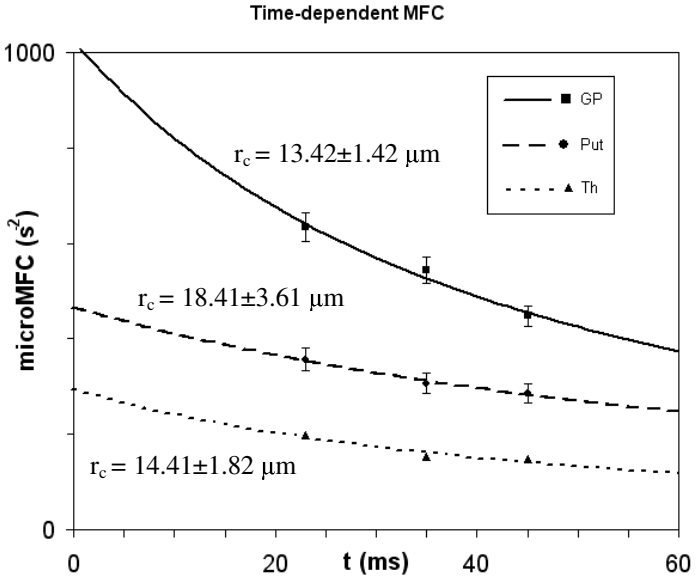

Figure 1. MFC values for specified ROI across subjects (avg. ± SEM), for t = 23, 35, 45 ms. The lines indicate the fits based on the functional form given by Eq. (1). The estimation for r_c in each ROI is indicated next to the appropriate line.

Results and Discussion: The three curve fits for each set of ROI parameters are plotted in Figure 1. For each ROI, as displayed next to the fitted curve, the calculated value for r_c was found to be on the scale of the expected lengths of microscopic MFIs (GP: r_c = 13.42±1.42 μm, Put: r_c = 18.41±3.61 μm, Th: r_c = 14.41±1.82 μm) generated by iron-rich tissue structures [11, 12]. This data indicates that the decrease of MFC with time that has been previously demonstrated in phantom studies is also evident in vivo. Fitting the data to Eq. (1) and extracting reasonable length scales for r_c supports the notion that microMFC in vivo may be particularly useful in early detection of iron imbalance-related diseases when the associated MFC changes are on a microscopic level.

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