The Role of Higher Order B0 Shimming and Intrinsic Gray-White Matter Susceptibility on Spectral Resolution at 7T in the Human Brain

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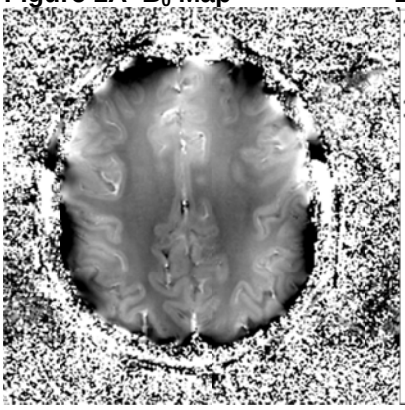
Introduction: Potential improvements in SNR and spectral resolution are often cited as a primary advantage for MRSI in moving to higher field strength. However, the improvement in metabolite linewidth is governed by a number of factors including, macro and microscopic (σB_0^{Macro}, σB_0^{Micro}) inhomogeneity and the intrinsic T2. Under the most optimal shimming conditions ($\sigma B_0^{Macro}=0$) it is anticipated that the linewidth will be determined by residual σB_0^{Micro} and the intrinsic T2. However, the susceptibility difference between gray and white matter represents a contribution to σB_0^{Macro}, which is spatially complex and are not correctable by shimming over extended brain regions. At 3T, Chadzynski reported that NAA does not experience the same field effects as the water resonance experiencing minimal absolute frequency shift in moving from gray to white matter. The goal of this work was to: 1) determine the relationship between metabolite linewidth and σB_0^{Macro} (B_0 maps) and 2) the frequency dependence of the major singlets in white versus gray matter at 7T.

Methods: All data were acquired with a 7T human system with a 4th order/degree shim insert and an 8 element transceiver array. Data were acquired from the frontal lobes at the level of the supplementary motor area (SMA) and mid-temporal lobes at the level of the hippocampi (MTL). A non-iterative multi-slice B_0 mapping method was used to acquire B_0 maps were used for shimming and measuring the macroscopic heterogeneity (σB_0^{Macro}). σB_0^{Macro} was estimated by calculating the standard deviation in B_0 over a 27 pixel block (9x9x10mm) matching the ~1cc MRSI voxel volume. Spectroscopic imaging data (40ms spin echo TE) were acquired using a slice selective excitation pulse (10mm) and RF shimming based outer volume suppression with 24x24 encodes over a FOV of 192x192mm^2 (TR=1,5Sec 14.4min). The slice position of the spectroscopic image was shifted by -610Hz (2mm) to match the water study. The creatine resonance was fit with a voigt line shape including a 3Hz lorentzian component to simulate the intrinsic T2. Gray and white matter voxels (6 for each) for 5 subjects were selected with the average determined for each volunteer.

Results: Fig 1 shows a high resolution B_0 map after 4th order shimming in the SMA (A) and a plot of the gaussian component of the fitted creatine linewidth (y axis) versus σB_0^{Macro} (x axis) for the MTL (black) and SMA (red) (B). With 4th order shimming, the residual inhomogeneity in superior slices is largely due to intrinsic differences in gray and white matter susceptibility (Fig 1A). A linear regression analysis of this data (R=0.87, p<0.0001) yielded a slope of 0.86 and an intercept of 1.72Hz; equivalent to 4Hz FWHM (i.e. $\sigma B_0^{Macro}=0$). This is consistent with the narrowest creatine linewidth detected, 7.3Hz, when the additional 3Hz of broadening due to T2 is included. Displayed in Fig 2 are: a scout image (A), a B_0 map (B) and spectra showing the water (C) and NAA shifts (D) as a function of position across the brain (A). The NAA resonance shifts in parallel to the water resonance as one moves from gray matter (periphery and center) to white matter (flanking center). Averaging across subjects the difference in frequency between the water and NAA resonance between gray and white matter was 1.2±0.6Hz ~ ¼ of the susceptibility difference in water between gray and white matter.

Figure 1A B_0 Map



1B Regression σB_0^{Macro} vs linewidth

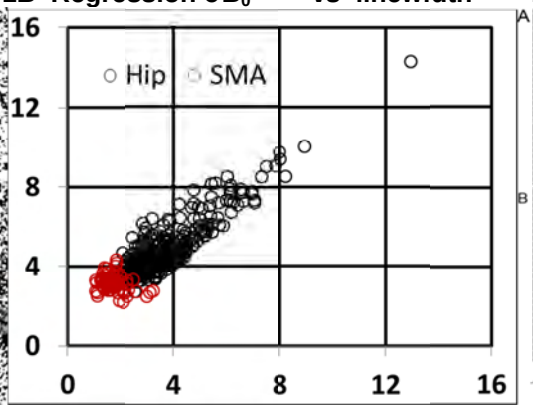
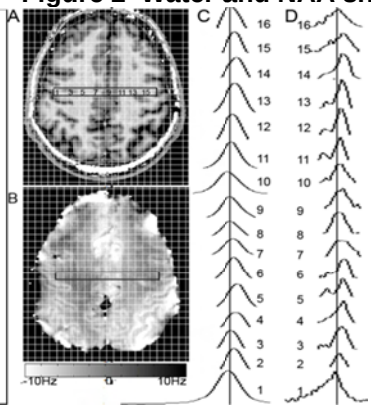


Figure 2 Water and NAA shifts



Conclusions: The data demonstrate that σB_0^{Macro} as determined from B_0 maps is a good predictor of the spectral linewidth over a large range of residual inhomogeneity. With 4th order shimming, the residual inhomogeneity for superior brain locations is predominantly due to the intrinsic susceptibility differences between gray and white matter. The frequencies of the NAA and creatine metabolites in gray and white matter shift in the same direction as water. Thus spectral broadening due to gray and white matter mixing can be a limitation to the achievable linewidth for MRSI studies even under ideal shimming conditions.