Interleaved Multi-voxel in-Vivo Spectroscopy on the Human Brain Using Dynamic Shim Updating

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Introduction Many *in-vivo* spectroscopic studies seek simultaneous (interleaved) acquisitions from voxels in different regions of the brain. Two issues complicate such experiments. First, using standard localization gradients in an interleaved acquisition will cross excite voxels. This cross excitation imparts different T_1 signal weighting to each voxel in the experiment. The second complication arises from static field inhomogeneity. For voxels in different areas of the brain, a single shim setting is typically insufficient for adequate homogeneity in all voxels. Without sufficient homogeneity in each voxel, spectral widths broaden and water suppression becomes increasingly difficult.

As demonstrated by Ernst and Hennig [1], cross excitation can be circumvented using double oblique localization gradients. The field homogeneity problem can be mediated through dynamic shim updating (DSU) [2] [3], whereby optimum local shim settings can rapidly be updated in the hardware during a multi-volume acquisition. This allows for global shimming over large volumes to be accomplished in a local fashion. Combining these two methods, interleaved *in-vivo* spectroscopy on the human brain was performed using four voxels spanning the y-axis.

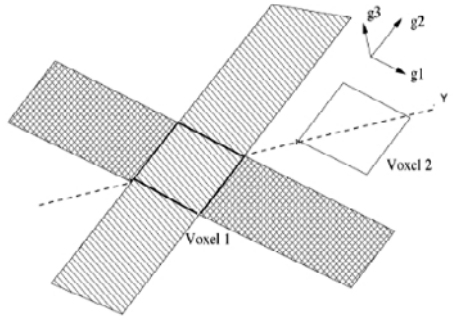

Figure 1: Oblique voxel localization in 2D.

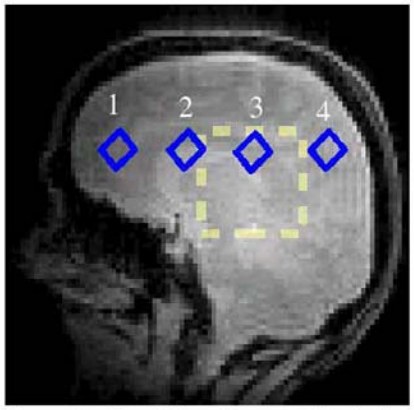

Figure 2: Voxel locations and indexing

Methods Experiments were performed on a 4.0 T Magnex magnet interfaced to a Bruker Avance spectrometer. A Magnex whole-body gradient system housed pre-emphasized linear imaging gradients, all 2nd order spherical harmonic shims, and a Z_0 coil. RF reception and transmission were carried out with a Bruker TEM coil. The DSU system was controlled by a custom built interface which stored and implemented shim changes on command from pulse programs with a minimum updating time of 10 ms. Optimal shim settings were uploaded to the shim interface hardware memory through a dedicated processing computer running Microsoft Visual Basic® software communicating with the DSU controller via RS232 connection. To maximize updating speed and minimize artifacts, a custom-built shim-change pre-emphasis system was also utilized.

Four 8cm^3 cubic voxels along the y-axis were obliquely localized using a stimulated echo acquisition method (STEAM). Figure 1 provides a 2D illustration displaying the oblique slice selection gradients for a multiple voxel experiment. Figure 2 illustrates the voxel positions used in this experiment. Voxels were oriented such that the y-axis ran through their cubic diagonal. Each voxel edge thus made an angle of 55° with respect to the y-axis. Gradient unit vector solutions for each localization gradient (g1,g3,g3) were calculated based on this and mutual orthogonality constraints.

An optimal static global shim was determined using a FASTMAP optimization over a 6.5 x 6.5 x 6.5 cm ROI centered on the rear of the corpus callosum (yellow outline in Figure 2). Optimal local shim settings for use with DSU were determined using FASTMAP optimizations over 9cm^3 ROIs centered on each voxel.

Interleaved *in-vivo* spectra were acquired with a spectral width of 2500 Hz, TR = 4 s, TE = 30 ms, and TM = 80 ms. Water spectra were measured using the optimal global static shim and optimal DSU settings. Using the water spectra from the DSU experiment, water frequency offsets were calculated for each voxel and the Z_0 shim updated to place all voxels on resonance. *In-vivo* metabolite spectra were then collected using DSU and CHESS water suppression with 3 modules during the TR period and 3 modules during the TM period. To attain sufficient signal to noise, 128 averages were used.

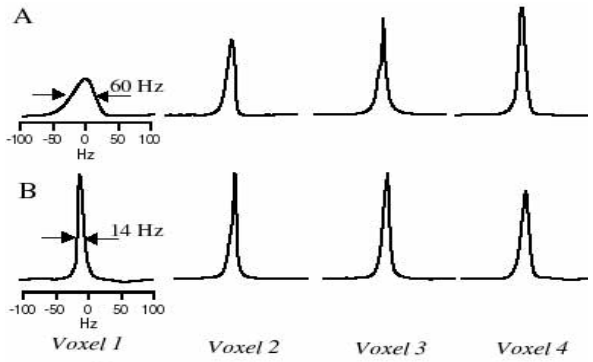

Figure 3: Interleaved water spectra acquired A) with a static global shim and B) with DSU.

Results and Discussion Water spectra with and without DSU are presented in Figure 3. The linewidth of all spectra was reduced when using DSU when compared to the spectra collected under a static shim setting. Voxel 1 (centered in the frontal cortex) showed the most dramatic improvement (60 to 14 Hz). This is to be expected because the static shim was optimized in the center of the brain, and this voxel is located far off center and in the vicinity of the most severe inhomogeneity within the human brain (near the sinus cavities). An *in-vivo* metabolite spectrum from this voxel, acquired during a water-suppressed interleaved multi-voxel acquisition, is presented in Figure 4. Major metabolites are clearly distinguishable. Without DSU, water suppression, and hence, a useful spectrum from this voxel would have been untenable.

The use of DSU in multi-voxel MRS allows for the acquisition of N spectra from N voxels in the same time it would take to acquire 1 voxel. Possible improvements include increased SNR through PRESS or LASER localization, arbitrary voxel placement (within limitations placed by cross-excitation), and extension to more sophisticated sequences such as spectral editing.

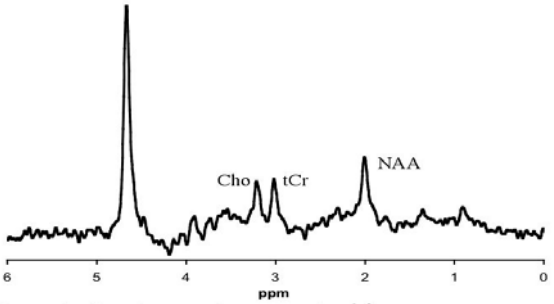

Figure 4: In-vivo spectrum acquired from voxel 1 in interleaved 4-voxel experiment

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