CHEMICAL-SHIFT ARTIFACT REDUCTION IN HADAMARD-ENCODED MR SPECTROSCOPIC IMAGING AT HIGH (3 AND 7 T) MAGNETIC FIELDS

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Background: ^{1}H MR spectroscopic imaging at higher magnetic fields ($\mathbf{B_0}$) encounters increasing metabolite localization uncertainties from chemical shift displacement errors, when spatially-selective excitation pulses are used. This phenomenon is exacerbated by the decrease in available RF field strength, $\mathbf{B_1}$, at higher $\mathbf{B_0}$s, that precludes its suppression with stronger gradients. To address this, we propose two new, cooperative, methods.

Theory and Methods: Hadamard spectroscopic imaging (HSI) is the localization method of choice when few, ‹8, slices are required to cover the FOV. Previously, HSI pulses were synthesized by a superposition of *N* SINC pulses, which require *N*-fold high $\mathbf{B_1}$ than a single SINC pulse. We propose two schemes to lower the RF power needs to increase the slice-select gradient and decrease the chemical shift displacement error. First method is multi-slab acquisition by segmenting the FOV into *M* slabs, acquired sequentially during each *TR*. Since these slabs are thinner than the FOV, they allow proportionally stronger slice-select gradient. Second method is pulse cascading in HSI. To sequentially "play out" (cascade) rather than superimpose the individual components of these selective pulses can further reduce the overall peak $\mathbf{B_1}$ down to that of a single slice. The combination of these two approaches, segmenting the FOV into thinner slabs and cascading the HSI pulse components, allows us to increase the slice-select gradient ×4–×8 per given $\mathbf{B_1}$, to 12–18 mT/m for 2–4 cm VOI in the human brain. This reduces chemical shift displacement errors to under 0.02-0.05cm/ppm at 3-7T.

Experiment and Results: The experiments were done on a cylindrical phantom with four 1.25 cm partitions. Each partition contained a different, metabolite yielding a singlet line at a distinct chemical shift: Meth, NaAc, *t*-BU, and Na-3-Si as shown in Fig 1. Four ^{1}H-MRSI experiments were performed at 3 T and 7 T. All shared the same 4th order HSI, along a 5 cm VOI, encoded with 5.12 ms long RF pulses, of 0.96 kHz peak $\mathbf{B_1}$, to excite: (i) a single 4th order superposition(1.8mT/m), (ii) two slabs each of 2nd order superposition pulses(3.6mT/m), and (iii) the same as (ii) but each slab comprising two cascaded HSI pulses(7.2mT/m), (iv) broadband excitation. Spectra from a column of four voxels along the ×4 HSI-encoded (IS) direction from each experiment and field, are shown in Fig. 1. Chemical shift displacements are immediately apparent as interslice "leakage," at each field. Note that leakage greater at 7 T than at 3 T, indicate displacement errors rather than slice profile imperfections, since the same sequence was used at either $\mathbf{B_0}$.

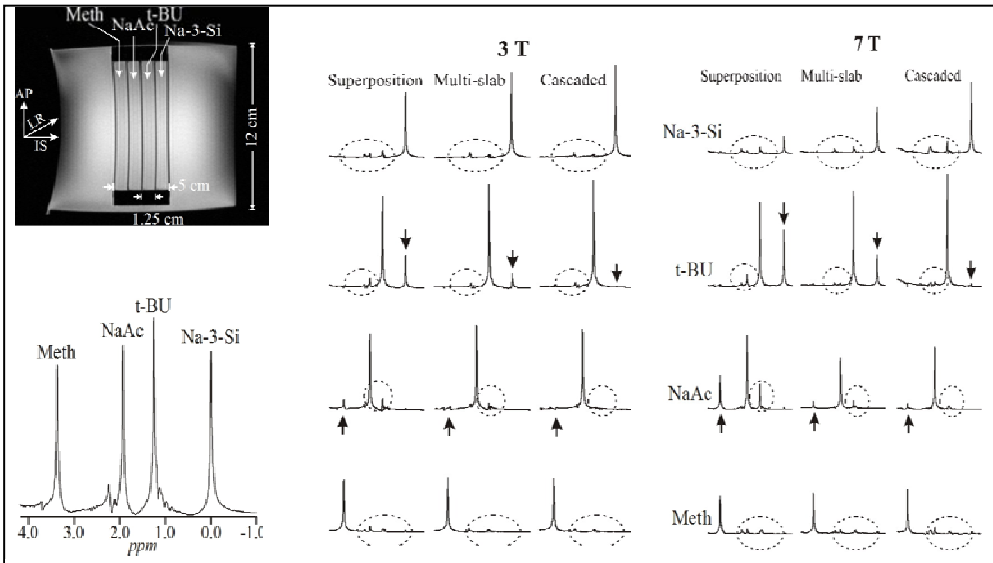

Fig.1. Left, top: Sagittal image of the phantom showing the position of the 4 partitions with their 100mM constituents: Meth, NaAc, *t*-BU and Na-3-Si. Left, bottom: Absolute spectrum at 3T from one $1_{AP}\times1_{LR}\times8_{IS}$ cm^3 voxel showing their singlet resonances at 3.4, 2.2, 1.2 and 0.0 ppm. Note the similar peak heights reflecting 100 mM concentrations (to within the T_1 weighting of the localization 2D CSI sequence). Middle(3T) and Right(7T): Spectra from 4 voxels along the IS direction encoded with superposition, multi-slab and cascaded multi-slab pulses under 1.8, 3.6 and 7.2 mT/M at 3 and 7 T. Spectra at each $\mathbf{B_0}$ are on a common frequency and intensity scales. RF pulse durations (5.12 ms) peak $\mathbf{B_1}$ (0.96 kHz), *TE* and *TR,* are common to all. Note the more severe artifacts *(i)* at 7 versus 3 T; *(ii)* for the weaker gradient (superposition) versus the strongest (cascade); and for *(iii)* the metabolites with grater chemical shift offsets (Meth and Na-3-i) from carrier at 2 ppm. Also note that the top and bottom rows of the VOI display no leakage since there are no metabolite outside the VOI to "bleed in" and no encoding outside to detect "bleed out."

Conclusions: Multi-slab with or without cascading, can dramatically reduce the peak $\mathbf{B_1}$s needed to affect RF phase encoding schemes. This reduction can be exploited towards (i) increasing the slice-selection gradient strength in order to reduce the chemical shift displacement along that orientation to insignificance, even at 7 T; or (ii) to lower $\mathbf{B_1}$ for quadratic decrease in SAR. This is a critical safety concern and limitation at the very high end of $\mathbf{B_0}$s approved for human use.

Reference: [1] Kim DS, et al. High-field magnetic resonance techniques for brain research. Curr Opin Neurobiol 2003;13:612-619. [2] Vaughan JT, et al. 7T vs. 4T: RF power, homogeneity, and signal-to-noise comparison in head images. Magn Reson Med 2001;46:24-30. [3] Gonen O, et al. Hybrid three dimensional phosphorus localized spectroscopy of phantom and human brain. Magn Reson Med 1995;33:300-308. [4] Goelman G, et al. Optimizing the efficiency of high-field multivoxel spectroscopic imaging by multiplexing in space and time. Magn Reson Med 2006;56:34-40.