Improving In Vivo 1H-MRS with Robust Automated Shim Techniques: A Comparison Study of FASTESTMAP and GRESHIM

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Introduction: Magnetic field homogeneity, i.e., shim, is the single most important determinant of spectral quality in *in vivo* proton magnetic resonance spectroscopy (^{1}H-MRS). Shims directly affect SNR, resolution, minimum number of averages that must be acquired, the minimum voxel size that can be accommodated, the amount of information content visible, which regions can be reliably interrogated, the effectiveness of the water suppression, and the reliability of any metabolite quantification. The lack of a readily available, consistent, robust, and easy-to-use shim algorithm can arguably be considered the greatest impediment to the application of ^{1}H-MRS as a standard diagnostic tool in the clinical imaging environment. Currently, several shim algorithms have been proposed, the most well-known being the FASTMAP based techniques (1-3), but to our knowledge, none have been tested for their utilitarian capability across multiple brain regions. Here, we test and compare three shim techniques in single-voxel spectroscopy: FASTESTMAP (3), GRESHIM (4), and the standard vendor-offered shim product.

Methods: All measurements were performed on a clinical 3T scanner (Siemens Tim Trio, Erlangen, Germany) with a 12-channel phased-array head coil and under an IRB protocol. A total of twenty-one spectra were acquired from five different participants over six different brain regions: anterior cingulate, two from posterior cingulate for repeatability assessment, Broca's area, hippocampus, and the thalamus. The FASTESTMAP sequence was implemented as described in (3). Briefly, an adiabatic localization scheme was used to excite and refocus spins along narrow bars, and data from three orthogonal bars aligned with the three physical gradient axes were collected. One-dimensional frequency profiles were generated along each of the excited bars (2), and then used to estimate the required changes in shim currents to achieve a uniform B_0 field across the same voxel of interest (VOI) as used for the single-voxel spectroscopy acquisition. For GRESHIM (4), a field map was generated from a single-slab two-echo 3D GRE acquisition performed with two in-phase TEs for fat and water. Shim currents to improve B_0 homogeneity were calculated from the field map. As a reference, the standard vendor-offered product, advanced shim, was also investigated. The advanced shim technique uses a 3D dual-echo steady-state (DESS) gradient-echo sequence that acquires two signals within the same TR period, FISP and PSIF acquisitions. Advanced shim included an additional 3D phase map, but with opposite gradient polarity for eddy current correction. After eddy current correction, a 3D field map was generated from the two echoes for the calculation of the shim currents. For our experiment, the order in which shim techniques were applied were randomized for each volunteer. Immediately following each shim technique, spectra were acquired using a short TE STEAM sequence (TE/TM/TR = 10/12/3000 ms, number of excitations = 120, bandwidth = 2500 Hz, and vector size = 2048). The performance of each shim technique was evaluated by measuring the full width at half maximum (FWHM) of the in-phase unsuppressed water peak through fitting with a Voight line shape. Visual inspection of the water suppressed spectra provided a qualitative assessment of the perfomance of the different shim algorithms.

Results: Across the six brain regions studied, FASTESTMAP and GRESHIM performed similarly (Table 1.), providing high quality shims in four regions: centrum semiovale, anterior cingulate, posterior cingulate and Broca's area, and acceptable quality in the hippocampus. All three shim techniques failed in the thalamus region, providing unacceptably poor quality spectra. A simple comparison of spectra from the different brain regions suggests 7-Hz as the maximum line width for high quality spectra, and a maximum of approximately 10-Hz for acceptable but lower quality spectra.

Table 1 FWHM (Hz) of the In-Phase Unsuppressed Water Peak Across Different Brain Regions

Shim	Cingulate			Centrum Semiovale	Hippocampus	Thalamus	Broca's Area
	Anterior	Posterior	Posterior				
Adv	7.5	17.4	5.9	8.0	10.7	12.6	8.3
Fast	6.6	6.4	5.8	6.6	8.8	16.1	6.7
GRE	5.9	6.7	5.8	7.0	9.0	16.7	6.8

Discussion: The most obvious effects of shim quality are SNR and resolution, which are visually demonstrated in Figs. 1A and 1B. For example, in Broca's area, relative to FASTESTMAP and GRESHIM, the >1.5-Hz shim increase in line width for the advanced shim acquisition of the water peak translates to a 13% reduction in its SNR. Furthermore, for the advanced shim, the loss in resolution subsequently reduced the ability to resolve the two dominant glutamate C-4 peaks in water-suppressed spectra (Fig. 1B, arrow). Our analysis shows that FASTESTMAP and GRESHIM are comparable for single-voxel ^{1}H-MRS. The primary advantage of FASTESTMAP appears to be its relatively short scan time, ~12 s, versus 60 s for GRESHIM. However, for challenging regions, such as the hippocampus or Broca's area, FASTESTMAP required multiple iterations that actually extended the time beyond the acquisition time of GRESHIM. The main advantage of GRESHIM is its large shim slab that allows multiple spectroscopy scans without the need to repeat the shim acquisition. In practice, this advantage may be negated by patient motion between scans. With further integration into the vendor product platform, FASTESTMAP and GRESHIM shim techniques should provide reliable high-quality ^{1}H-MRS as a standard diagnostic tool in the clinical imaging environment.

Conclusion: FASTESTMAP and GRESHIM are robust automated shim techniques that should greatly improve the reliability of clinical spectroscopy.

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2. Shen et al. MRM 1997; 38:834-839.
3. Gruetter et al. MRM 2000; 43:319-323.
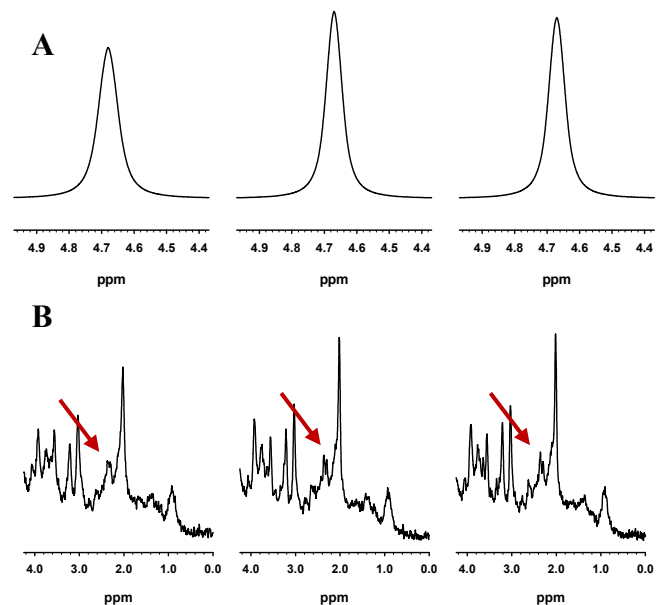4. Shah et al. 17th ISMRM 2009; 565.

Figure 1. Broca's area (A) unsuppressed water peaks for shim measurements from advance shim (left), FASTESTMAP (middle), and GRESHIM (right); and (B) the corresponding water suppressed spectra.