Quantitative Comparison of Shim Algorithms for *In Vivo* ^{1}H-MRS

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Target Audience: This paper could be of interest to the researchers doing either development or applications of the proton magnetic resonance spectroscopy (^{1}H-MRS).

Purpose: As the single most important determinant, magnetic field homogeneity, i.e., shim, directly affects the spectral quality of *in vivo* ^{1}H-MRS, such as SNR, resolution, 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. A readily available, consistent, robust, and easy-to-use shim algorithm is of great interest and a must for the ^{1}H-MRS applications to be used as diagnostic tools in the clinical imaging environment. A previous study (1) has qualitatively tested and compared three shim techniques in single-voxel spectroscopy for their utilitarian capability across multiple brain regions: the well-known FASTESTMAP (2-4), a recent emerging GRESHIM (5), and a standard vendor-offered shim product called Advanced Shim. The purpose of this work was to extend the previous study described in (1) to include quantitative analysis and comparison among these three techniques. In addition, the reliabilities of the three shim techniques in the shuffled order are investigated.

Methods: Three shim techniques, FASTESTMAP, GRESHIM and Advanced Shim, were used in this study. The FASTESTMAP sequence used an adiabatic localization scheme to excite and refocus spins along narrow bars, where data from three orthogonal bars aligned with the three physical gradient axes were collected and Fourier transformed into the 1D frequency profiles, and then used to estimate the required changes in shim currents to achieve a uniform B_0 field (3,4). In the GRESHIM technique, a field map was generated from a single-slab two-echo 3D GRE acquisition with two in-phase TEs with respect to fat and water, and then used to calculate the shim currents to improve B_0 homogeneity (5). The Advanced Shim technique uses a 3D dual-echo steady-state (DESS) sequence that acquires two signals within the same TR period, i.e. FISP and PSIF acquisitions, and included an additional 3D phase map 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.

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 36 spectra were acquired from 12 participants over multiple brain regions: anterior and posterior cingulate, centruum semiovale, and temporal lobe along the sylvian fissure. FASTESTMAP, GRESHIM and Advanced Shim were performed before the spectroscopy data acquisition. The order of the GRESHIM and FASTESTMAP was swapped, either first or third, while the order of the advanced Shim was unchaged in the middle so as to reset the system shim condition between GRESHIM and FASTESTMAP experiments. Immediately following each shim technique, spectra were acquired using an ultra-short TE STEAM sequence (TE/TM/TR = 4/12/3250 ms, 120 averages, 2500 Hz bandwidth, and 2048 points), a water reference, and a 2-shot RRAMSC (6) experiment for absolute quantification. The performance of each shim technique was evaluated by measuring the full width at half maximum (FWHM) of the in-phase water reference peak through fitting with a Lorentzian line shape. The effect of the shim were measure by comparing metabolite concentrations and Cramér-Rao Lower Bounds (CRLB) values from LCModel (7).

Results: Since each data set had at least one subject move, the worst line width from each shim set was removed, and the average line width, coefficient of variation (CV), and range (relative to the average line width) calculated from the water references for each shim set (Table 1). Comparing line width, Advanced Shim performed best in two cases, FASTESTMAP in four cases, and GRESHIM in six cases.

Table 1 Quantitative assessment results from three shim techniques.

	Advanced	FASTESTMAP	GRESHIM
Mean (Hz)	6.7	6.2	6.1
CV (%)	16.2	14.7	9.0
Range/Mean (%)	51.3	48.2	37.0

To assess the effect of the shims on quantification, we compared the CRLB values from LCModel for ten metabolites and combinations: Cr, GABA, Glu, GSH, NAA, tCho, NAA+NAAG, Ins+Gly, tCr, and Glx. These were the only metabolites measurements with non-zero concentrations across all 36 data sets. The average CRLBs for each shim set was: Advanced, 13.9%; FASTESTMAP, 11.6%; and GRESHIM, 10.5%. Mean differences in these concentrations was greatest between Advanced Shim and FASTESTMAP, 17.8%, and lowest between FASTESTMAP and GRESHIM, 16.4%. The difference between Advanced Shim and GRESHIM was 17.0%.

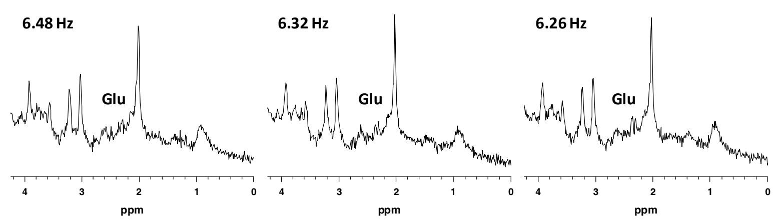

Figure 1 Example water suppressed spectra from advance shim (left), FASTESTMAP (middle), and GRESHIM (right).

Discussion: Shim effects on spectra are easily assessed visually (Figure 1). In comparison, the quantitation effects on shim are less readily measureable and even in poor cases may be obscured by the sample or system variance in the experiment, and contrary to simple analysis may improve with poorer shims; for example: poor shims can cause NAA and NAAG peaks to merge, providing a supposedly very stable total NAA peak with low CRLB values, but no measureable NAAG peak. Thus, NAAG+NAA typically yield lower CRLB values, and lower sample standard deviations than NAAG or NAA alone. In a previous study which mainly focused on qualitative assessment (1), we showed that FASTESTMAP slightly outperformed GRESHIM. In this work which focused on quantitative assessment, we have the opposite results, with GRESHIM slightly outperforming FASTESTMAP. In the current study, voxels were positioned to follow the natural morphology of the brain, hence most were oblique. The performance of FASTESTMAP is known to be somewhat compromised by oblique voxel selection. In the two instances where the Advanced Shim outperformed the other methods, in one case a participant had dental appliances, and in the second case, it was a strongly oblique voxel located in the frontal lobe (Figure 2). The latter case provided the worst performance of not only FASTESTMAP but the entire study, yielding shims of 11-Hz.

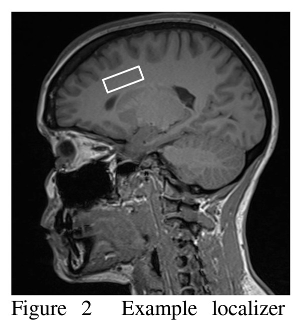

Figure 2 Example localizer image showing a strongly oblique voxel located in the frontal lobe.

Conclusion: Our analysis shows that FASTESTMAP and GRESHIM are comparable for single-voxel ^{1}H-MRS. FASTESTMAP and GRESHIM are robust automated shim techniques that should greatly improve the reliability of clinical spectroscopy. Replacing the current Advanced Shim technique employed on the clinical scanner in this study by either GRESHIM or FASTESTMAP should be high priority to improve the reliability of short TE spectroscopy studies.

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