Grid-based shimming of single-voxel MRS

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Introduction: Shimming of single-voxel MRS is important for optimal quality of acquired spectra. [1] Poor shimming results in frequency variations that can lead to misregistration, lost signal and reduced spectral resolution. [2] The chemical shift between water and lipid renders regions where these tissues are present in close proximity, such as the breast, difficult to shim. [1-3]

Methods: To shim within the MRS voxel, the volume-of-interest (VOI) is partitioned into a 3×3×3 array of "grid voxels". Spectra are obtained from each grid voxel and the water frequency and peak height for each grid voxel is computed. The spectral quality within the 3×3×3 grid is evaluated along each 3×1×1, 1×3×1, and 1×1×3 column and the spectrum with the lowest water peak is excluded from further analysis. Assuming negligible eddy currents, linear B_0 gradients within the VOI are found by least-squares fit to

$$f_i = \alpha_1 + \alpha_2 x_i + \alpha_3 y_i + \alpha_4 z_i + \alpha_5 x_i y_i + \alpha_6 x_i z_i + \alpha_7 y_i z_i + \alpha_8 (z_i^2 - \tfrac{1}{2}(x_i^2 + y_i^2)) + \alpha_9 (x_i^2 - y_i^2) + \varepsilon_i \quad (1)$$

where f_i are the measured water frequencies (Hz), x_i, y_i, and z_i are the center coordinates of the i^{th} grid voxel (mm). The α_1, α_2, …, α_9 coefficients represent the unknown contribution of each spherical harmonic to B_0 inhomogeneity (Hz, Hz/mm, Hz/mm^2). Updated shim values are obtained from

$$S'_j = S_j + C_j \alpha_j \quad (2)$$

where S_j and S'_j are the present and updated shim settings, respectively and C_j is a calibration factors which can be determined by acquiring grid shimming data on a phantom while systematically varying the shim settings.

Reduced acquisition time: Acquisition of each grid voxel using PRESS involves three slice-selective pulses that affect spins within 18 of the 27 total grid voxels. The spins inside the remaining 8 grid voxels are unaffected. If the next grid voxel is acquired from among these unaffected 8, then the relaxation time for spins is longer than the acquisition TR. In fact, the acquisition order of the grid voxels can be selected to ensure that all acquired voxels are unaffected by the pulses of the preceding acquisition. Table 1 lists the grid voxel acquisition schedule used in this study. Because each coordinate corresponds to a specific PRESS slice-selection, as long as each component of a voxel's position differs from the previous acquisition, the next grid voxel is not affected by the previous acquisition slices. In contrast, 2D and 3D CSI-based shimming techniques excite the entire VOI.

i	*x*	*y*	*z*	*i*	*x*	*y*	*z*	*i*	*x*	*y*	*z*
1	0	0	0	*10*	0	-1	-1	*19*	-1	-1	1
2	-1	-1	-1	*11*	1	0	0	*20*	1	0	-1
3	1	1	0	*12*	0	1	1	*21*	-1	1	0
4	0	0	1	*13*	1	-1	-1	*22*	0	-1	1
5	-1	-1	0	*14*	-1	0	0	*23*	1	1	-1
6	1	1	1	*15*	0	1	-1	*24*	-1	0	1
7	0	0	-1	*16*	1	-1	1	*25*	0	-1	0
8	1	-1	0	*17*	-1	0	-1	*26*	-1	1	-1
9	-1	1	1	*18*	0	1	0	*27*	1	0	1

Table 1: Grid voxel acquisition schedule to ensure each acquisition is unaffected by the previous acquisition. (x,y,z)=(0,0,0) represents the centermost grid voxel.

Results and Discussion: Grid shimming was implemented on a 4 T Varian INOVA whole-body imager for localized shimming of 2×2×2 cm^3 VOI. Once the VOI is selected, grid voxels are automatically prescribed as 0.5x0.5x0.5 cm^3 voxels separated by a 0.25cm gap to reduce crosstalk and to improve spectral resolution. The grid voxels are then acquired using PRESS (TE=23 ms, TR=1.5 s, spectral width=8192 Hz, 8192 points). Despite the TR of 1.5 s, the acquisition schedule (Table 1) guarantees that each grid voxel has relaxed for at least 3 s. The total time required to acquire the grid is 40.5 s. Both 1st order only and combined 1st and 2nd order shim updates are computed in less than 4 s.

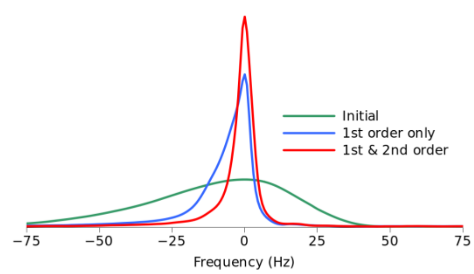

Fig. 1: Single pass grid shimming of a 2×2×2 cm^3 VOI in a poorly shimmed phantom. Both 1st and combined 1st and 2nd order updates are computed.

Fig. 1 demonstrates the use of grid shimming on a spectroscopy phantom in single-average PRESS spectra (TE=23 ms) obtained both before and after grid shimming. The 1st and 2nd order shims were deliberately misset to increase the full-width at half maximum (FWHM) of the water peak to 56 Hz prior to shimming. The 1st order shim update improved the FWHM of the water peak to 9 Hz, whereas the combined 1st and 2nd order update reduced the line width to 6 Hz and improved the peak shape. These results demonstrate that grid shimming is an effective technique for shimming within single-voxel VOI. Grid shimming is expected to be beneficial when the VOI contains irregular regions of predominantly lipid and water. Use of the technique in vivo is currently being investigated.

References:

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