Partial Volume SLIM for Separating Water and Lipid Compartmental Signals in Breast MRS

Patrick J Bolan[1], Gregory J Metzger[1], Steen Moeller[1], and Michael Garwood[1]
[1]*Radiology, CMRR, University of Minnesota, Minneapolis, MN, United States*

Introduction: Magnetic resonance spectroscopy (MRS) can provide clinically valuable metabolic information about breast cancer. Consistently acquiring high-quality MRS data in the breast, however, can be challenging. Single-voxel spectroscopy can produce high-quality spectra, but it requires expertise to interpret the images, plan the voxel, and make appropriate adjustments while the patient waits in the scanner. Chemical shift imaging (CSI) allows for retrospective selection of a region of interest because it provides spatial information, but CSI generally produces lower spectral quality than SVS in breast due to less-optimal B_0 shim and the "bleeding" of lipid signals between voxels that causes baseline distortions. In this work we investigate the feasibility of using the Spatial Localization by Imaging (SLIM) technique (*1*) for separating the signals from the water and lipid compartments in breast. SLIM uses high-spatial resolution image data to divide the object into discrete compartments, and then reconstructs a spectrum from each compartment that best fits the CSI measurements. We propose to use water-fat imaging techniques (*2,3*) for mapping the spatial distribution of water and lipids as well as mapping the B_0 field. Using SLIM, along with extensions of SLIM that incorporate B_0 offsets (*4,5*) and partial volume compartments (*6*), the B_0 and fat fraction maps can be combined with a CSI acquisition to reconstruct an average spectrum from both the water and fat compartments. This technique can be directly used to produce spectra of the water compartment (which contains the tCho of primary interest) in the breast, or it can be incorporated into an acquisition strategy using techniques such as SLOOP (*7*) or CSI with lipid-extraction SLIM (*8*).

Methods: Four normal female volunteers were scanned on a Siemens 3T TRIO (Erlangen) with an 8-ch Sentinelle breast coil. Using a 3D fat-suppressed gradient echo for planning, a unilateral, oblique coronal plane was selected for water-fat imaging (3D gradient echo, TR=9 ms, TE=2, 3 4 ms, resolution ~1 x 1 x 3 mm, 3 minutes) and for CSI acquisition (TR/TE=1500/30 ms, 12 mm slice, 16x16 matrix, 192 mm FOV, 6.4 minutes). The 3-point water-fat image data was reconstructed into a T_1-corrected fat fraction map and B_0 map using the method of Berglund et al. (*3*) from the ISMRM Fat-Water Toolbox (*9*). The reconstruction was performed in Matlab (Natick, MA). The SLIM model used was:

$$p_n(t) = \sum_{m=1}^{M} c_m(t) \int \chi_m(\vec{r})\; e^{-i\vec{k}_n\cdot\vec{r}}\, e^{-i2\pi\Delta f(\vec{r})t}\, d^3\vec{r}$$

where $p_n(t)$ is the measured, n^{th} phase-encoded time domain signal with k-vector k_n, $c_m(t)$ is the pure time-domain signal from compartment m, $\chi_m(\vec{r}) \in [0;1]$ is the fractional density of compartment m as a function of space r, and $\Delta f(\vec{r})$ is the spatial frequency offset. The equation was converted to matrix form and inverted using Tikhonov regularization (*4*) to solve for $c_m(t)$. The feasibility of the proposed method was first assessed using a simulation in which the breast was modeled as two homogeneous compartments consisting of lipid (a 10-peak model) and aqueous (water plus 10 mM tCho) compartments. The fat fraction and B_0 maps were taken from an *in vivo* measurement. A 2D k-t space sampling signal representing the 2D CSI acquisition was synthesized from this data (with measurement noise), which was then reconstructed using SLIM with the exact geometric model. Subsequently, the full *in vivo* dataset was reconstructed using the measured geometric and spectral k-t space data, and compared to a Fourier transformed CSI reconstruction.

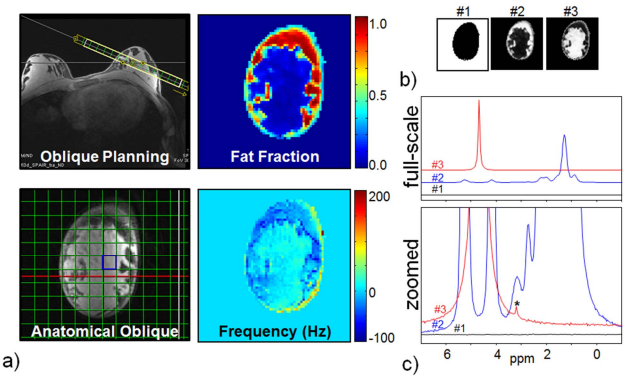

Figure 1 – Simulated SLIM reconstruction in breast. The images in (a) shows the oblique acquisition, the nominal CSI grid, and the reconstructed fat fraction and frequency maps. Using a 3-compartment model (b) of background, fat and water+choline based on the *in vivo* geometry, a synthetic k-space was generated and reconstructed with B_0-corrected SLIM (c).

Results: The results of the simulation are shown in Fig 1. Here it can be seen that the SLIM-reconstruction perfectly separates the water and lipid spectra. Note that the tCho peak is correctly separated from the lipid resonance at 3.2 ppm, even though these two components overlap in both spectral and spatial domains. The *in vivo* result based on the same subject is shown in Fig 2. Here it can be seen that the water and lipid compartments are well-separated, and the B_0 correction leads to narrower line widths compared to comparable spectral from the FT-CSI reconstructed data.

Discussion and Conclusion: The simulation of Fig. 1 demonstrates the potential strength of this technique. Under the conditions that 1) the compartments are homogeneous and 2) the exact geometric model is known, SLIM can perfectly reconstruct the two compartmental spectra even though they overlap both spectrally and spatially, which is not possible with either SVS or CSI localization methods. The first condition is homogeneity; this can be addressed by acquiring additional k space samples, as it has been shown that as the number of phase encodes increases the spectra converge to the compartmental average spectrum (*10*). The second condition is that the geometric model be accurate. Since this is a measured model (based on the water-fat imaging) it will include noise and potential errors such as motion, biases from T_1 and T_2^* weighting, etc., but such factors are generally correctable with optimized acquisitions and reconstructions. Fig. 2 shows the first *in vivo* example of SLIM in breast. Here the separation of water and fat is good but not perfect. This initial result can be improved with a more accurate geometric model that could incorporate array coil receive profiles (*11*), through-slice partial volume effects, T_2^* bias correction (*12*), or respiration-induced B_0 modulations. These will be addressed in future work.

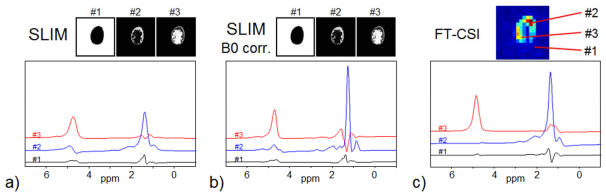

Figure 2 – SLIM reconstruction *in vivo*. In the same subject shown in figure 1, the CSI data were reconstructed using (a) SLIM and (b) SLIM with B_0 correction to produce average spectra of the background, lipid, and water compartments. In (c), selected spectra from the Fourier transform CSI reconstruction show results similar to non-B_0 corrected SLIM.

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Acknowledgements: NIH CA120509 (NCI) and BTRC P41-EB015894 (NIBIB)