Algorithm for Lipid Suppression by Real-Time Isotropic Filter Design in Spectroscopic Brain Imaging

J. Lee[1], and E. Adalsteinsson[1,2]
[1]Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, United States, [2]Harvard-MIT Division of Health Sciences and, Massachusetts Institute of Technology, Cambridge, MA, United States

Introduction: Estimates of brain metabolites using whole-slice or large-volume magnetic resonance spectroscopic imaging (MRSI) are severely hampered by strong lipid signals even though the interfering signal arises from regions outside of the brain, namely subcutaneous tissue, scalp, and bone marrow. Many lipid suppression methods have been proposed, including outer-volume suppression (OVS) [1-4], inversion-recovery [5-7], selective brain-only excitation (PRESS [8], STEAM, Spielman [9]). Alternatively, variable-density sampling of k-space with accompanying proportional filtering [10-13] uses an alternate approach for lipid suppression, whereby it reduces the interfering lipid signals arising from the subcutaneous tissue by dramatically reducing the spatial side-lobes within the brain due to the extra-brain lipid sources. Prior work on variable-density sampling in MRSI relied on a filter design that minimizes the side-lobes in the spatial point spread function. Here, we present an improved algorithm that achieves a direct design of a subject-specific, optimal, spherically symmetric spatial filter in two or three dimensions to minimize lipid contamination estimated by pre-scans. The proposed method is demonstrated with single-slice MRSI to achieve 30~40 dB or lipid suppression in the absence of OVS or inversion recovery pulses.

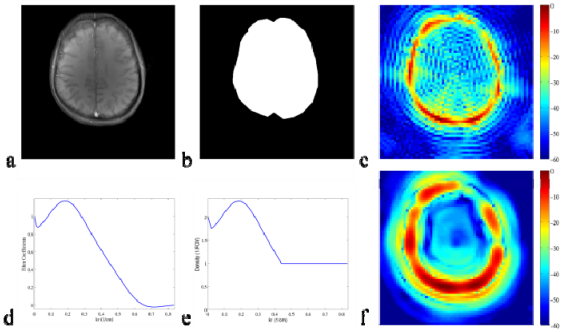

Fig. 1: Flow of real time filter design and MRSI scans: (a) Step 1: acquire a high spatial resolution gradient echo image, (b) Step 2: estimate the brain mask, (c) Step 3: acquire a high spatial resolution MRSI pre-scan to estimate the lipid amount for any filter with a smaller k-space extent and the lipid amount in dB scale is shown, (d) Step 4: Design the filter, (e) Step 5: Design k-space trajectory whose density is proportional to the filter designed but with minimum sampling ratio (Nyquist rate) (f) Step 6: Scan spiral MRSI scan and in this figure the lipid amount in dB scale is shown.

Methods: For the proposed method to be most effective, a real-time procedure must be developed where prior data, including a spatial brain mask and a lipid mask, are acquired with a fast preparatory scan and incorporated into the design while the subject remains in the scanner. The brain mask was derived from a GRE (FOV_{xy} = 240 mm, slice thickness = 10 mm, voxel size = 0.47mm*0.47mm, TE = 3.81ms, TR = 9.9ms, scan time = 5s, flip angle = 20°), followed by a manually drawn boundary (Steps 1-2 in Fig 1). An MRSI lipid map scanned by a constant-density spiral trajectory MRSI (FOV_{xy} = 240 mm, slice thickness = 10 mm, voxel size = 0.2 cm^3, TE = 144ms, TR = 1000 ms, scan time = 52s) (Step 3). These brain and lipid priors enable an estimate of the lipid response within the brain for any filter. We then designed an isotropic filter that minimizes the estimate of the lipid contamination inside the brain (Step 4). The minimization process is the following: Given the voxel size and the smoothness constraint of the filter coefficients, we determine the filter that minimizes the energy of the lipid inside the brain. K-space trajectory is designed to be proportional to the filter designed, but adjusted to achieve at least Nyquist sampling rate (1/FOV) for all k-space locations (Step 5). The SNR penalty due to the mismatch between the filter coefficients and the sampling density trade-offs the over-sampling ratio and thus the scan time. In this implementation with a fast MRSI scan (less than 2 minutes) and therefore only two-fold oversampling at the k-space origin, the SNR tradeoff is 38%. The design process, including data transfer, manual brain masking, and filter optimization, took about five minutes. To evaluate the performance of the proposed lipid suppression, we collected a spin echo spiral-MRSI scans with a constant density without apodization, a variable density spiral MRSI scan whose density is proportional to the pre-calculated 1D Equiripple filter, and a variable density spiral MRSI scan whose density is proportional to the real-time filter given the same voxel size (1.5 cm^3) imaging time (104s), TE (144ms), and TR (2000ms). These data were processed by gridding, FFT and 32-channel coil combination. Two healthy volunteers were scanned on a 3T Siemens Tim Trio scanner with a 32-channel head coil. The scout and spin echo MRSI scans were selective excitation of the head in an axial section with the slice thickness of 10mm. For MRSI data, conventional CHESS water suppression was used but no RF pulses to suppress the lipid were used.

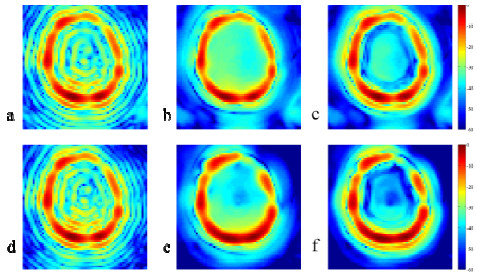

Fig. 2: Lipids (dB) as the sum of absolute spectral values from 0.9 ppm to 1.7 ppm: (a-c) Estimated data using the pre-scan data, (d-f) Acquired data using spin echo spiral MRSI sequence. (a,d): No Apodization, (b,e): Equiripple filter, (c,f): optimally designed filter

Results: To quantify the of lipid suppression of our method, we estimated the lipid map as the sum of the absolute value of the spectra from 0.9 ppm to 1.7 ppm. Fig. 2 shows the estimated lipid maps using the pre-scan, the high spatial resolution spiral CSI with a short TR, and the acquired lipid maps by the spin echo MRSI scans in dB scale in Fig.2. The pre-scan naturally has inadequate SNR for metabolite observation, but offers sufficient SNR for lipid estimation. The spatial side-lobe ringing of the lipid can be estimated for any arbitrary apodization with a smaller k-space extent. As it is shown in Fig. 2, the estimated lipid maps can be used to predict the acquired lipid maps and 30~40dB of lipid suppression was achieved. In Fig. 3, the spectra of the NAA, Cr, Cho, and lipid from 1.2 ppm to 3.8 ppm in the yellow rectangle indicated in Fig. 3d are shown.

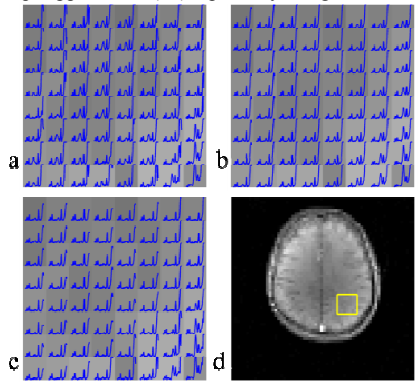

Fig. 3: Spectra of the NAA, Cre, Cho, and lipid (1.2 ppm ~3.8 ppm) inside the yellow rectangle in (d): (a) No Apodization, (b) 1D Equiripple Filter, (c) Real Time Filter, (d) Underlying Structural image (Gradient Echo Image) of the same slice.

Conclusion: We presented a design method for an isotropic filter in a fast MRSI scan (less than 2 minutes) to minimize the lipid contamination inside the brain by measuring an additional high spatial resolution lipid scan. Even in the absence of other means of lipid suppression, such as outer-volume suppression or inversion recovery, this method can spatially confine the source of the contaminating lipid signals to regions outside of the brain to achieve 30~40 dB lipid suppression in cortical brain spectra. The mismatch between the filter and sampling density results in a tradeoffs in metabolite SNR, which can be minimized by higher oversampling ratios during the MRSI acquisition.

References: [1] Luo, MRM 45: 1095-1102, 2001. [2] Le Roux , JMRI 8:1022-1032, 1998. [3] Tran, MRM 43:23-33, 2000. [4] Duyn, Radiology 188:277-282, 1993. [5] Ebel, MRM 49:903-908, 2003. [6] Bydder, Tomogr. 9:659-675, 1985. [7] Spielman, JMRI 2:253-262, 1992. [8] Bottomley. Ann N Y Acad Sci 508:333-348, 1987. [9] Spielman, MRM 18:269-279, 1991. [10] Adalsteinsson, MRM 42:314-323, 1999. [11] Lee, ISMRM 2008; 1574. [12] Lee, ISMRM 2008; 1579. [13] Lee, ISMRM 2009; 2378.

Support: NIH: R01EB007942, R01EB006847, NCRR P41RR14075; Siemens Healthcare, Erlangen; Siemens Medical Solutions USA; Siemens-MIT Alliance