Subcutaneous lipid suppression via variable-density spiral sampling for full cortical coverage in chemical shift imaging

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Introduction: Estimates of metabolites in the brain using large-FOV chemical shift imaging (CSI) are severely hampered by strong lipid signals even though the interfering signal arises from subcutaneous tissue. Since SNR in MR is proportional to voxel size [1] the low metabolite concentration, and therefore low SNR in spectroscopic imaging dictates large voxel size, and in turn, the spatial extent of side lobes in the spatial impulse response is a significant contributor to interfering and undesired signals in spectra within the brain. This problem is all the more challenging due to both the narrow spectral separation between lipid components in the 0.9-1.3ppm range and the dominant NAA resonance at 2.0ppm (which corresponds to a separation of 86-135Hz at 3T), as well as the spatial proximity of the cortex to the source of the undesired signals. Many lipid suppression methods have been proposed, including outer-volume suppression (OVS) [2-5], inversion-recovery [6-8], selective exciting brain-only (PRESS [9], STEAM, Spielman [10]), and are effective, but inevitably trade off some amount of brain metabolite signals. Variable-density sampling of k-space with accompanying proportional filtering [11-13] to maintain SNR, in fact, does not suppress the excitation of the lipid signal from the subcutaneous tissue, but reduces the interfering lipid signals arising from the subcutaneous tissue by dramatically reducing the spatial side-lobes. Such methods require extended k-space sampling with controlled density of sampling to maintain favorable SNR properties, and can be implemented with spiral-based k-space trajectories. The filter coefficients are determined through an optimization algorithm [12] that minimizes the ratio of the energy in filter stop-band to the energy in the pass-band. As is shown in [12], the direct filter design method of a three-dimensional spherically symmetric filter produces the smaller spatial side-lobes in the point spread function than three-dimensional filters based on 1D designs given the same voxel size and sampling extent. Even though, in many locations, the peak of NAA is distinguishable from the lipid spectrum, the spatial side-lobes of the lipid signals are only around one tenth (-20dB), as is in Figure 1. (dB scaled, the same as Fig 1.(b) but color-scaled) of the maximum due to the interfering lipid signals are accumulated constructively inside the brain as well as the under-sampling artifacts in some part of the k-space especially in the top and the bottom slices, which has only one angular interleave [13]. To reduce the constructive accumulation, we added linear weighting factors on calculating the energy in the stop-band. The magnitude of the spatial side-lobe becomes smaller with a trade-off the increased width of the main-lobe. We also modified the spiral trajectory design method that keeps the proportionality of density and filter coefficients, but uses at least four angular interleaves even in the top and the bottom slices [14].

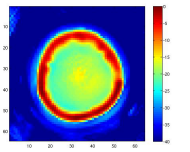


Fig. 1. Lipid map (dB scale) from ref. [12]

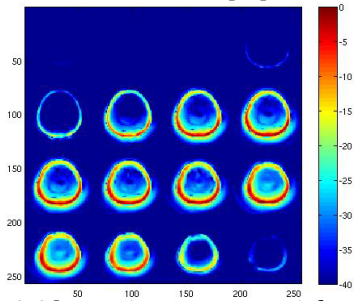
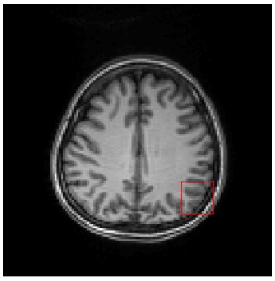


Fig. 2. Lipid map (1.00~1.66 ppm) for all slices in dB scale

Methods: To evaluate the performance of the lipid suppression, healthy volunteers were scanned on a 3T Siemens Trio scanner with a 32-channel head coil. The variable spiral trajectory was implemented with a conventional PRESS excitation for spatial excitation only in the S/I direction to yield a 3-cm thick axial section. The filter specifications included a voxel size of 0.47 cc, and the trajectory sampled k-space for FOV_{xy} = 24 cm, FOV_z= 6.2cm, in a scan time of 16 min. This scan is performed in-vivo with TR of 2s and TE of 144ms. For a high spatial-resolution scan, we also collected a 3D MPRAGE in a scan time of 5 min.



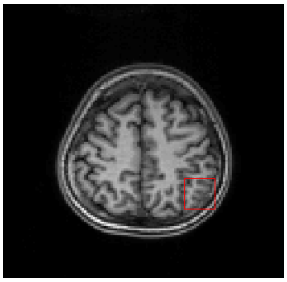
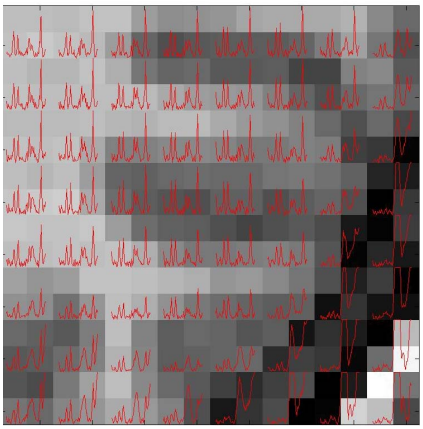
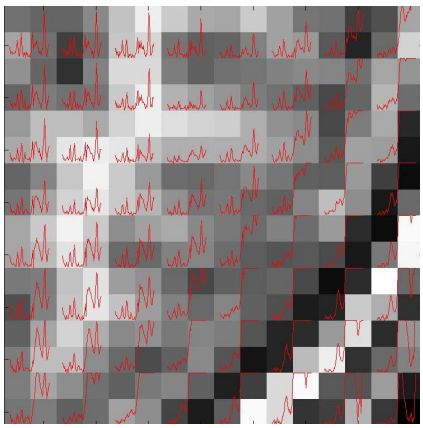


Fig. 3 (a, left) 7th slice: Structural image. (b, right) 7th slice: spectra in red rectangle of (a). (c, bottom left) 11th slice: Structural image. (d, bottom right) 11th slice: spectra in red rectangle of (c).





Results: Figure 2 shows a representative lipid map, the summation of the absolute value of the spectrum over the range of 1.00~1.66 ppm for all 16 slices. At least 30 dB spatial side-lobe suppression is achieved inside the brain except few locations. Figure 3(b, d) shows spectra of NAA, Cre, and Cho from the region of red rectangle in Figure 3(a, c) located in the region of the most demanding lipid suppression.

Conclusion: The constructive accumulation of the interfering lipid signal arising from the subcutaneous lipid are substantially reduced by adding weighting factor and modifying the sampling density of the spiral trajectory, which generates at least four angular interleaves for all the slices, but keeps the proportionality of the density and the filter coefficients. Even in peripheral regions of the cortex NAA is distinguishable from the lipids.

References: [1] Macovski, MRM 36:494-497, 1996. [2] Luo et al, MRM 45: 1095-1102, 2001. [3] Le Roux et al, JMRI 8:1022-1032, 1998. [4] Tran et al, MRM 43:23-33, 2000. [5] Duyn et al, Radiology 188:277-282, 1993. [6] Ebel et al, MRM 49:903-908, 2003. [7] Bydder et al, Tomogr. 9:659-675, 1985. [8] Spielman et al. JMRI 2:253-262, 1992. [9] Bottomley et al. Ann N Y Acad Sci 508:333-348, 1987. [10] Spielman el al, MRM 18:269-279, 1991. [11] Adalsteinsson et al, MRM 42:314-323, 1999. [12] Lee et al, ISMRM 2008; 1574. [13] Lee et al, ISMRM 2008; 1579. [14] Lee et al, ISMRM 2009, #3924; submitted.