Automatic Outer Volume Suppression (OVS) Slice Placement for Proton-Echo-Planar-Spectroscopic-Imaging (PEPSI)

T. Li[1], M. Martinez-Ramon[1], G. Heileman[2], S. Posse[3]

[1]MIND Institute, Albuquerque, NM, United States, [2]University of New Mexico, Albuquerque, nm, United States, [3]MIND Imaging Center, Albuquerque, nm, United States

Introduction: Outer volume suppression is used in MR spectroscopic imaging to reduce contamination from peripheral lipid signals. The placement of lipid suppression slices (sat bands) by a human operator is time-consuming and introduces variability. Placement of sat bands is particularly challenging for volumetric studies due to the irregular shape of the human head. Further, manual sat band placement becomes unmanageable as the number of sat bands increases.

In this study we present a method which segments a high-resolution MRI to identify peripheral lipid containing regions and computes an optimized placement of sat bands in 3-D, based on the maximization of a criterion of optimality. This criterion gives a scalar that increases when the coverage of peripheral lipid containing regions increases and decreases with the loss of peripheral cortical areas.

Methods: Prior to the spectroscopic scan, a high-resolution T1-weighted MP-RAGE scan (256x256, 32 slices, TR 1430) is collected and the images are downloaded to an offline workstation for segmentation and computation of sat band placement. To obtain a mask for the lipid containing regions, we use FSL[2] to extract the brain and subtract it from the original images. The core of this methodology is the optimization of the cost function $C=aI_L-bI_o-cI_b$ where I_L, I_o *and* I_b, are, respectively, the volumes of the intersections of the sat bands with peripheral lipid containing regions, with brain regions and the space around the head. The cost function reflects the balance between maximal lipid coverage, minimal loss of brain regions containing metabolite signals and reduction of sat band thickness outside of the head to minimize chemical shift artifacts. In order to compute the volumes of these intersections we first need to compute the convex hull described by the sat bands. This algorithm is initiated by selecting the lowest MRI slice within the (thick) spectroscopic slab as a starting point. A program developed in MATLAB 7.0 computes the optimal bands placement in 2-D for this particular slice by maximizing the cost function. The maximization is done by iteratively computing the gradient of the cost with respect to the geometrical parameters of the sat bands, which are the azimuth angle φ, the elevation angle θ, the distances of the outer and inner surfaces of each sat band from the origin d1 and d2. Since there is no analytical expression for the cost function, the gradient computation is performed by a numerical parametric approximation of first order. Since the algorithm is stable and converges, there is no justification for higher order approximations. Then, a 3-D version of the program applies the same gradient descent method to the entire lipid volume, gradually tilting the sat bands such that they follow the outer curvature of the brain. By using the output of the 2D program as the initial setting of the sat band parameters, we provide a reasonable starting point for the 3D optimization that assures the stability and convergence of the algorithm. This program provides parameters that uniquely define a set of optimally placed saturation bands in 3-D in 12 minutes computation time.

In vivo experiments on 3 healthy subjects with multiple scan replications in different sessions were performed on a Siemens 4T scanner using a CP head coil. The sat band parameters were communicated to a Proton-Echo-Planar-Spectroscopic-Imaging (PEPSI) pulse sequence [3] developed under Siemens Syngo-MR via text file. A maximum of 8 outer volume suppression slices can be defined. Upon loading, the sat bands are displayed on the graphics monitor overlaid on the high resolution MRI slices. Spectroscopic imaging data were collected with the PEPSI sequence using TR: 2 sec, TE: 15msec, spatial matrix: 32x32, FOV: 240 mm, slice thickness: 15 mm, 8 averages and a total acquisition time of 8.5 minutes. A non-water suppressed reference scan was acquired for automatic phase and frequency shift correction as described previously [3]. Data were reconstructed using even-odd echo separation as described previously [3]. Spectroscopic images were computed based on LCModel [4] fitting of 15 resonances. Spectral maps were thresholded at a CRLB of 50 %. To compare the performance of the algorithm against a human operator, we use the following two metrics: (a) the integrated residual lipid signal divided by the integrated creatine signal across the entire spectroscopic slice and (b) the number of usable voxels with clearly identifiable metabolite signals.

Results: Automatic placement of sat bands was reproducible across different scanning sessions in the same subject. Figure 1 shows automatically placed sat bands, which are similar to the placement by a highly trained human operator shown in Figure 2. Figure 3 shows metabolite maps obtained from LCModel fitting using automatic band placement. Figure 4 shows the corresponding maps obtained with manual sat band placement, which look very similar except for slight differences in peripheral gray matter. Table 1 shows the metrics defined above and Kramer Rao lower bounds of different metabolites for automatic and manual sat band placement, confirming that the two method yield similar results.

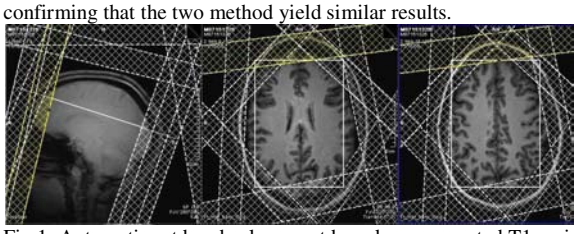

Fig 1: Automatic sat bands placement based on segmented T1-weighted MRI

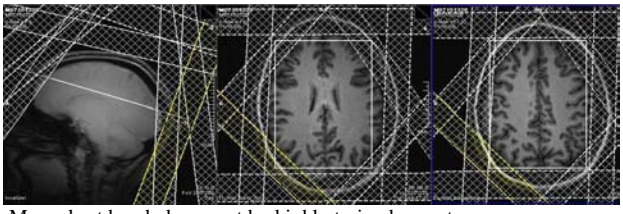

Fig.2: Manual sat band placement by highly trained operator

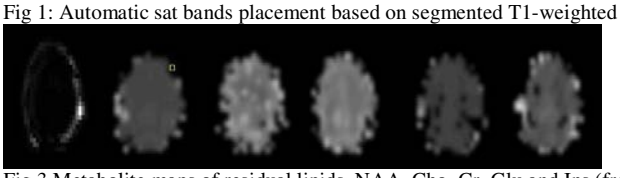

Fig 3 Metabolite maps of residual lipids, NAA, Cho, Cr, Glu and Ins (from left to right).

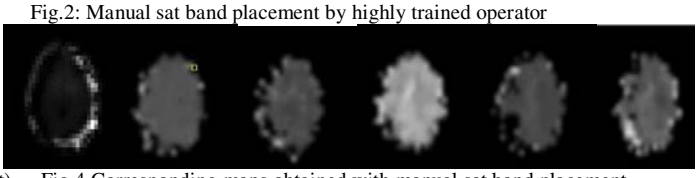

Fig 4 Corresponding maps obtained with manual sat band placement

	# of usable voxels	Integrated residual lipids/ integrated Cr	NAA	Cho	Cr	Ins	Glu
Automatic placement	277	0.765640/0.775243	Min: 2 Max: 46 Avg: 7.7	Min: 5 Max:40 Avg: 18	Min: 3 Max:49 Avg: 11	Min: 4 Max:47 Avg: 18	**Min: 5** **Max:46** **Avg: 18**
Manual placement	**302**	**0.785335/0.802686**	**Min: 2** **Max: 49** **Avg: 8.6**	**Min: 7** **Max:49** **Avg: 18**	**Min: 4** **Max:40** **Avg: 18**	**Min: 5** **Max:48** **Avg: 17**	**Min: 3** **Max:48** **Avg: 16**

Table 1 Metrics for comparison between automatic placement and manual placement

Discussion: Automatic sat bands placement produces sat bands setting similar to a highly trained human operator. The method avoids variability due to human error in identifying lipids containing regions and optimization of sat band placement, and facilitates placement of sat bands for volumetric studies. This method reduces operator interaction and has the potential to save precious scan time. Manual optimization of the sat band placement for fine tuning is still possible as an option. The method is currently being implemented in C++ to reduce computation time. To our knowledge this is the first implementation of automated sat band placement on clinical scanners. A related method [1] to select an irregularly shaped volume inside brain using multiple sat bands with a block optimization algorithm has been presented last year. Our method is unique in that it enables a tradeoff between lipid coverage and .loss of peripheral brain regions due to saturation. Further improvement of our method is under way to adapt to non-convex lipid containing regions.

References: [1] L. Ryner et all, ISMRM XIII, p. 76, 7- 13 May 2005. **[2]** S.M. Smith et all, NeuroImage, 23(S1):208-219, 2004. **[3]** Posse, S. et al. Magn Reson Med. 1995; 33:34. **[4]** S. Provencher. Magn Reson Med 1993; 30(6):672

Acknowledgements: Supported by NIDA 1 R01 DA14178-0 and the MIND Institute - Mental Illness and Neuroscience Discovery DOE Grant No. DE-FG02-99ER62764.