Accelerated Correlated Spectroscopic Imaging in Two Spectral-Three Spatial Dimensions with Slice-selective Adiabatic Refocusing Pulses in Human Calf Muscles

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Synopsis

An optimized version of the five-dimensional (5D) echo-planar correlated spectroscopic sequence using an adiabatic full passage (AFP) RF pulse pair has been implemented on a 3T MRI/MRS scanner equipped with a 15-channel transmit/receive coil. The sequence was initially tested using a corn oil phantom. The calf muscle of twelve healthy subjects (age 27.5±3.1 years) and six diabetic type 2 subjects was studied (age 62.3±9.8 years). The AFP pulse pair enabled a sharper profile and minimal chemical shift misregistration. The localization of the volume of interest showed differential distribution of metabolites and lipids in human calf muscle and tibial marrow.

Introduction:

Echo-planar correlated spectroscopic imaging (EP-COSI)[1], which combines L-COSY[2] with an echo-planar (EPI)[3] readout for correlated SI, acquires better-resolved two dimensional (2D) spectra from multiple spatial regions and has been implemented in rat brain[1] and in humans[4,5]. Recently, using accelerated technique based on compressed sensing, EP-COSI has been extended to acquire five dimensional (3 spatial and 2 spectral dimensions) EP-COSI data[6] in human calf muscle. Like other point-resolved spectroscopy (PRESS) based in vivo SI techniques with conventional pulses, EP-COSI also suffers from large chemical shift displacement error (CSDE), non-uniform refocusing, and spatially dependent magnetization transfer resulting in reduced cross peak intensity. It has been demonstrated that using adiabatic selective refocusing pulses with relatively higher bandwidth, these artifacts can be minimized[7,8]. Adiabatic localization has been incorporated into COSY sequences[9-11]. Here, we present an enhanced version of accelerated 5D EP-COSI by introducing adiabatic radiofrequency pulses for localization along the refocusing dimension and preliminary results in human calf muscle *in vivo*. We hypothesize that adiabatic pulses will improve slice selection profile and reduce chemical shift artifacts along the refocusing dimension.

Materials and Methods:

The standard 5D EP-COSI sequence which uses a 90°–180°-Δt_1-90° scheme for localization was modified by employing a pairs of adiabatic pulses (AFP) in place of the 180° pulse (Fig. 1). A non-adiabatic, optimized slice-selective 90° excitation pulse as well as the slice selective 90° before the bipolar EPSI read-out trains was still used. In this way, only a pair of AFP pulses was used to keep the RF power within the SAR limits and also TE relatively short. A corn oil phantom was used for acquiring 10 *in vitro* measurements. The sequence was tested and implemented in the calf muscle of twelve healthy volunteers (age 27.5±3.1 years) and six diabetic type 2 patients (age 62.3±9.8 years). All data were collected on a 3T Prisma MRI scanner using a 15 channel knee 'transmit/receive' coil. The following parameters were used for acquiring the 5D NUS- based EP-COSI phantom data: TR/TE = 2s/30 ms, voxel resolution=3.37cm^3, 64 Δt_1 increments, 512 bipolar echo pair, FOV= 24x24x12cm^3, F_1 and F_2 bandwidths of 1250 Hz and 1190 Hz respectively. A non-water-suppressed EP-COSI data with t_1=1 was also recorded. For *in-vivo* NUS data, TR was 1.5s with scan time ~26min. Other scan parameters were the same as that of the phantom. Acquired data were extracted, reconstructed and post-processed[6] with a library of custom MATLAB-based program.

Results:

Figure 2 shows the comparison of slice profile of the 2D diagonal peak of creatine (Cr) at 3.0 ppm for EP-COSI with and without adiabatic pulses from a corn oil phantom experiment. In adiabatic based EP-COSI the peak was localized within the PRESS excitation volume better with minimal leakage and the slice profile was more homogeneous indicating better excitation. *In vivo* human calf muscle spectra from 5D NUS-EP-COSI using the adiabatic pulse acquired in a 62 years diabetic patient can be seen in Figure 3 from the bone marrow (d), tibias anterior (e) and the soleus muscle (f). The absence of the Cr3.9 peak in the marrow was expected and shows that the spatial information is preserved using the adiabatic EP-COSI. It also preserves features such as the residual dipolar coupling of creatine in the tibialis anterior. The Cr (3.9 ppm) spatial profile for all the slices are shown in Figure 3(c). Fig, 3(a) and (b) show axial and coronal MRI localization of the volume of interest. Fig. 4 shows the results from the 5D adiabatic NUS-EP-COSI of a 35 years healthy volunteer showing spectra from bone marrow (b), tibias anterior (c) and the soleus muscle (d).

Discussion:

We have implemented the NUS-based 5D EP-COSI with a pair of AFP for localization along one of the slice directions and performed a feasibility study using the corn oil phantom and human calf muscle. The high bandwidth AFP RF pulses used with slice select gradients enabled sharper excitation profiles than conventional Mao RF pulses used for localization. Comparison study on corn phantom showed a homogeneous metabolite profile and sharper excitation in EP-COSI with AFP. This translates to less signal leakage outside the VOI and might also translate to lesser need for outer volume suppression (OVS) to eliminate extraneous signal. This will also improve peak volume resulting in accurate quantification. There are still few limitations to the work including extending adiabatic half passage (AHP) for other slice localization directions, but this may result in longer TE and higher SAR.

Conclusion:

The 5D EP-COSI sequence with AFP offers a sharper slice selection profile, and reduction of chemical shift artifacts along the refocusing dimension.

Acknowledgements

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Figures

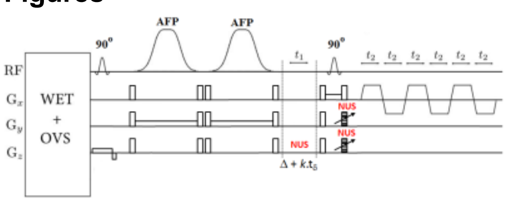

Fig. 1: Schematic representation of the 5D NUS-based EP-COSI sequence with adiabatic refocusing pulses.

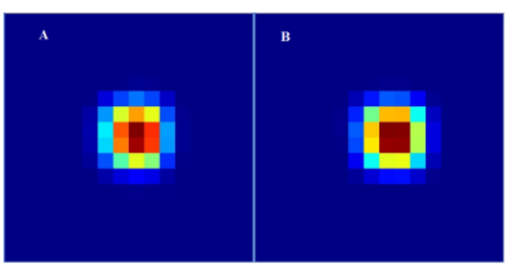

Fig. 2: Comparison of metabolite map of Cr (3.0 ppm) for a slice from 5D NUS based EP-COSI without (A) and with (B) adiabatic pulse from a corn oil phantom acquisition.

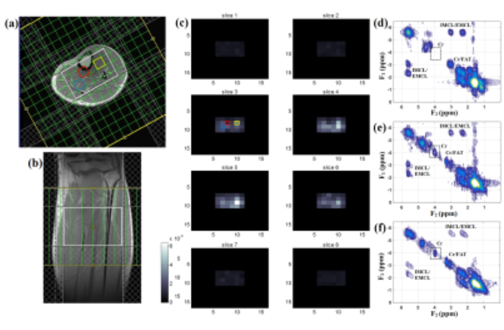

Fig. 3: Results from a 62 years old diabetic patients acquired with NUS-based 5D EP-COSI with adiabatic using a fifteen-channel knee coil. Shown: (a) axial and (b) coronal MRI localization of volume of interest; (c) spatial distribution of Cr3.9 peak for all the eight slices; 2D COSY spectra in highlighted voxels in (d) marrow (red), (e) tibialis anterior (yellow), and (f) soleus (blue). IMCL=Intramyocellular lipids, EMCL=Extramyocellular lipids.

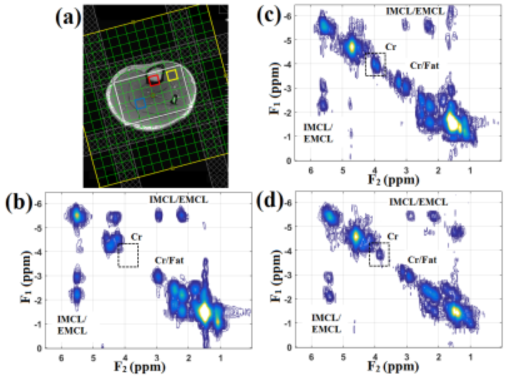

Fig. 4: 2D spectra from a 35-year-old healthy male volunteer with NUS-based 5D EP-COSI with AFP using a fifteen-channel knee coil in the (b) marrow (red), (c) tibialis anterior (yellow) and (d) soleus (blue); (a) shows spectroscopic VOI in the axial plane.