Semi-Laser 5D Echo-Planar J-Resolved Spectroscopic Imaging: Pilot validation in Prostate Cancer

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Target Audience: Basic scientists interested in Compressed Sensing (CS) reconstruction of semi-laser based multi-dimensional spectroscopic imaging (3 spatial and 2 spectral dimensions), as well as clinicians interested in spectroscopic imaging of in vivo prostate.

Purpose: Alongside lung cancer, prostate cancer is one of the leading causes of cancer death in men [1]. J-resolved spectroscopy (JPRESS) is a technique that utilizes a two-dimensional (2D) acquisition to spread overlapping resonances into a second spectral dimension, and has shown to be useful in assessing severity of prostate cancer [2, 3]. Spectroscopic imaging of this technique provides greater spatial coverage [4], however in order to acquire data in a clinically feasible time, an echo-planar readout becomes a necessity to acquire one spatial and one spectral domain simultaneously [5]. In order to further reduce scan time, a non-uniform undersampling (NUS) scheme can be applied to the incremented dimensions, and the resulting data can be reconstructed using CS reconstruction [6]. Due to the limited bandwidth of classical 180º pulses, chemical shift displacement error (CSDE) is apparent. Using a pair of adiabatic 180º pulses to replace these smaller bandwidth pulses has shown to limit CSDE [7]. The purpose of this study was to develop a 5 dimensional (5D) technique (3 spatial and 2 spectral dimensions) capable of covering the entire prostate utilizing an echo-planar readout, a NUS scheme on the (k_y,k_z,t_1) dimensions with CS reconstruction, and semi-Laser pulses to reduce CSDE. This sequence, called semi-Laser 5D echo-planar J-resolved Spectroscopic Imaging (5D EP-JRESI), was used to investigate the prostate for healthy volunteers and prostate cancer patients.

Methods: A semi-Laser 5D EP-JRESI sequence with a maximum echo sampling scheme was developed and used to scan four healthy volunteers (mean age = 54.5 years old) and two prostate cancer patients (mean age= 54 years old) using a multi-channel body array coil for healthy or a single channel endorectal coil for patients. For the semi-laser based sequence, the overall structure was similar to the 5D EP-JRESI sequence [8], however each 180º pulse was replaced with a pair of 180º adiabatic pulses [7]. The t_1 increment was placed in between the two pairs of adiabatic pulses. The pulse sequence diagram can be seen in Figure 1. The following parameters were used for data acquisition: TE=41 ms, TR=1000 ms, spectral bandwidth=1190/1000 Hz, number of t_2 points = 256, number of t_1 points = 64, FOV = 16x16x12 cm^3, and resolution = 1x1x1.5 cm^3, and the total scan time was approximately 17 minutes. The echo planar readout was used to simultaneously acquire 32 (oversampled) k_x points and 256 t_2 points, and the other spatial dimensions were acquired using 16 points for k_y and 8 points for k_z. A NUS scheme was applied to achieve an acceleration factor of 8x. Before the data were reconstructed, the data were truncated to only include the spectral region of interest (F_2 = 1.2-4.3 ppm) in order to ensure minimal water contamination. The data was reconstructed using a modified split Bregman algorithm that minimizes total variation (TV) [6]. Select voxels from healthy and unhealthy regions in the prostate, as determined from biopsy, were qualitatively assessed.

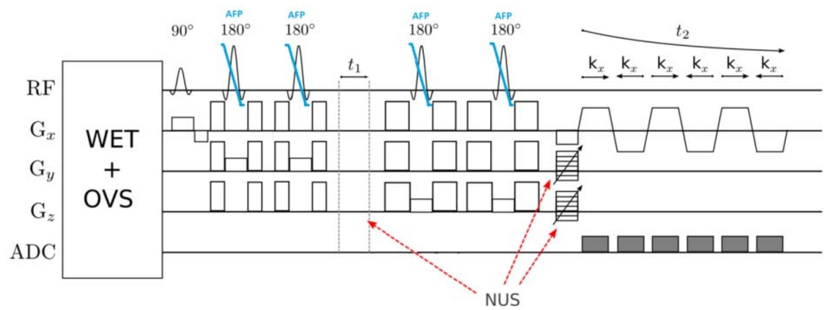

Figure 1. The pulse sequence diagram for semi-Laser 5D NUS Echo-Planar J-resolved Spectroscopic Imaging (5D EP-JRESI).

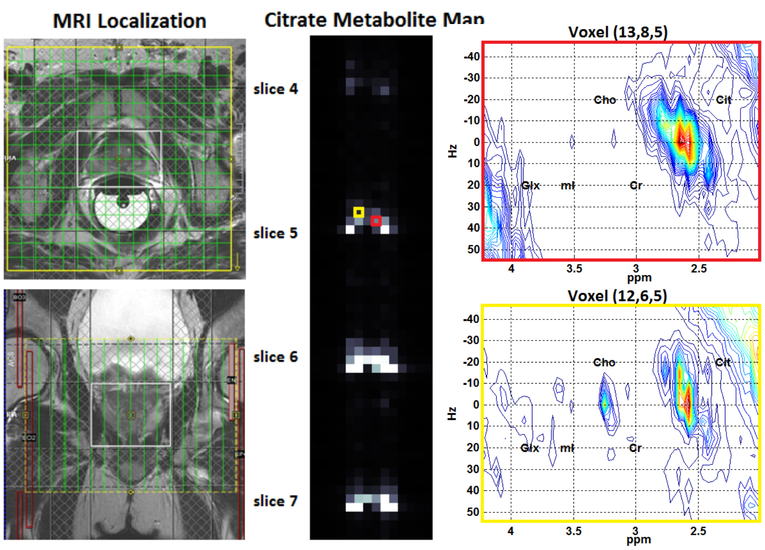

Figure 2. MRI localization (left) of axial (top) and coronal (bottom) views of a cancer patient's (age = 51 years old) prostate are shown. A citrate metabolite map (middle) shows signal from three different slices. Two spectra (right) are shown corresponding to the colors on the citrate metabolite map. Red is the healthy region, determined from the biopsy, and yellow is the unhealthy region.

Results: Qualitative analysis of the 2D spectra from the 51 year old cancer patient, displayed on the right in Figure 2, shows that lower citrate and higher choline are present in the voxel that corresponds to the unhealthy region of the prostate (as determined from a biopsy).

Discussion: The results show that for this patient, healthy and unhealthy prostate regions could be differentiated based on the 2D spectra. However, due to motion during the scan, several voxels contained severe lipid contamination (hyper-intense regions on the citrate metabolite map). This contamination may be minimized by using an inversion pulse for lipid suppression [9], and will be implemented in the future.

Conclusion: Semi-Laser 5D EP-JRESI has been implemented in healthy volunteers and prostate cancer patients, and is capable of full prostate coverage. Future work will focus on recruiting more healthy volunteers and patients, quantifying the 2D spectra using prior knowledge fitting, and further optimizing the sequence to avoid lipid contamination.

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