7T MRSI using Semi-Adiabatic Spectral-spatial Spectroscopic Imaging (SASSI) for improved B1-insensitivity in refocusing and reduced chemical shift artifact

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Target Audience: MRI physicists and technologists interested in performing ultrahigh field MR spectroscopic imaging.

Introduction: Magnetic resonance spectroscopic imaging (MRSI) can be used to non-invasively investigate metabolite concentration changes in the brain correlated to neurological and psychiatric diseases, brain tumors and radiation damage. High magnetic fields, such as 7T, permit us to leverage increased signal-to-noise ratio (SNR) and spectral separation between metabolite peaks for more sensitive metabolite detection and quantification as well as higher resolution spectral grids. However, with higher field strengths come challenges such as increased RF power deposition, which may approach specific absorption rate (SAR) limits, B_1 inhomogeneity, and increased chemical shift (CS) artifacts. Adiabatic pulses provide B_1-insensitive refocusing and reduced CS artifact, and have been used successfully in the semi-LASER (sLASER) sequence [1]. Adiabatic pulses are SAR-intensive and since sLASER requires 4 adiabatic full passage pulses to fully refocus the quadratic phase and excite the desired volume, the total SAR of the sequence is very high. Adiabatic spectral spatial pulses (SPSP) have been used in MRSI sequences to simultaneously provide B_1-insensitive selection and reduced CS artifact [2]. An added advantage of adiabatic SPSP pulses is that spatial selectivity is achieved by linear-phase spatial subpulses and the quadratic phase deposited in the spectral dimension by the first adiabatic 180° pulse is refocused by the second pulse, obviating the need for pulse pairs and reducing total SAR when compared to sLASER. However, since conventional hyperbolic secant adiabatic pulses were used to create the adiabatic SPSP pulses in [2], spectral bandwidth (BW) was severely limited by peak RF, necessitating a spectrally interleaved approach. In this work, we used the adiabatic Shinnar Le-Roux (SLR) algorithm to create two high spectral-BW 180° adiabatic SPSP pulses that capture the main metabolites of interest at 7T. The 180° SPSP pulses were paired with a 90° SPSP pulse to excite a 3D volume in a Semi-Adiabatic Spectral-spatial Spectroscopic Imaging (SASSI) sequence. The sequence was designed to generate spectroscopic grids with reduced chemical shift artifact and improved B_1-immunity while having lower SAR than existing adiabatic implementations.

Methods: We used the adiabatic SLR algorithm to generate a refocusing pulse [3] to act as the spectral envelope for the SPSP pulse. The adiabatic RF envelope was then sampled at 28 evenly spaced locations and used to scale small-tip-angle, linear-phase spatial subpulses, creating a 180° adiabatic SPSP pulse with a spectral bandwidth=1.02 kHz, duration of 9.8 ms, and peak amplitude=14.36 μT. A 4.2 ms SPSP 90° pulse was also designed, using a linear-phase SLR envelope, with a spectral bandwidth=1.05 kHz and peak amplitude=16.61 μT. Fig. 1 shows the RF, phase, and gradient waveforms for the SASSI pulse sequence which used the SPSP 90° pulse and adiabatic SPSP 180° pulses to select along the three spatial dimensions and generate a double spin echo. The pulse sequence parameters were: Δ frequency=-2.32 ppm, TE=40 ms, TR=2830 ms, FOV=6 cm, matrix=32x32, slice=3 cm, time=24 min. Scans were performed on a spherical phantom containing the main brain metabolites at 7T (Siemens MAGNETOM). For comparison, spectra were also obtained using a conventional product MRSI which used non-adiabatic pulses for selection and a sLASER with the same acquisition parameters. SAR in the phantom was recorded for each acquisition relative to sLASER SAR. Metabolite fitting and integration under peaks was performed to obtain concentrations of NAA and Cr. To investigate signal loss due to B_1-inhomogeneity and CS, metabolite maps were generated. NAA integral was reported for the three voxels indicated in white, blue, and yellow in Fig. 2A.

Results: A metabolite spectrum obtained from the blue voxel using SASSI is shown in Fig 2B. Metabolite maps of NAA and Cr are shown in Fig. 2 for the conventional non-adiabatic MRSI sequence (C&D), sLASER (E&F), and the SASSI sequence (G&H). SAR relative to the sLASER sequence (at 100%) was 34% for SASSI and 17% for the conventional MRSI sequence. The NAA integral for the white, blue and yellow voxels are listed in Table 1, and were: 40, 34 and 24 for the conventional MRSI sequence; 56, 73, and 76 for the sLASER sequence and; 62, 72 and 68 for SASSI sequence.

Discussion: We designed and implemented a MRSI sequence which uses high-BW adiabatic SLR SPSP pulses to achieve B_1-insensitive volume selection with reduced chemical shift and RF power deposition when compared to the conventional or sLASER MRSI sequences. The need for B_1-insensitive MRSI is evident in Fig. 2D, where significant signal loss occurs due to a peak in the B_1-profile as indicated in the Cr metabolite map by the black arrow. Severe CS artifact is also observed for the NAA peak which shifts by almost 20% of the selected slab thickness for the conventional MRSI sequence, which when combined with the signal loss due to the B_1-inhomogeneity creates a highly distorted metabolite map (Fig 2C). sLASER uses pairs of adiabatic pulses to achieve improved B_1-immunity as shown in Figs. 2 E & F. The SASSI sequence presented here is capable of obtaining similar SNR to sLASER over most of the volume, with dramatically lower SAR and improved immunity to CS. Low SAR translates to increased spatial coverage within reasonable scan times, without exceeding RF power deposition limits. An added advantage of using the SASSI sequence is that partial water suppression is inherently achieved by the spectral selectivity of the 90°-180°-180° pulse trio. This removes the need for chemically selective water saturation pulses, resulting in improved water suppression and further reduction of SAR. In the current implementation, the spatial subpulses comprising the adiabatic SPSP pulses have less selective spatial profiles (wider transition bands) than the RF pulses used in the sLASER sequence. This may be the cause of the lower NAA integral observed for the edge (white) voxel for SASSI (68) compared to sLASER (76). Using more selective subpulses or widening the selected volume and using spatial saturation bands to suppress signal along the edges of the volume could improve the sharpness of the selected region.

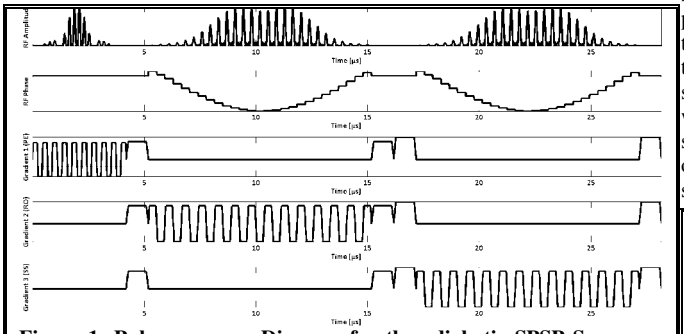

Figure 1: Pulse sequence Diagram for the adiabatic SPSP Sequence. The adiabatic pulses refocus the quadratic phase in the spectral domain. The alternating gradients result in a true null design

Sequence	relative SAR	NAA integral [au] white	blue	yellow
Conventional MRSI	17%	40	34	24
sLASER	100%	56	73	76
SASSI	34%	62	72	68

Table 1: SAR and integral under the NAA peak of three MRSI sequences

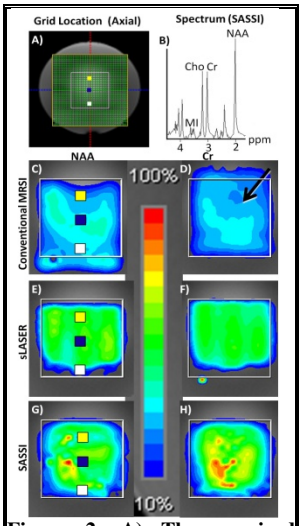

Figure 2: A) The acquired FOV (yellow), grid (green), and the excited volume (white). B) SASSI spectrum from the blue voxel . C) NAA and D) Cr map acquired using the conventional MRSI sequence. E) NAA and F) Cr map acquired using sLASER. G) NAA and H) Cr map acquired using SASSI

References: [1]Scheenen TW, et al. MAGMA 2008 Mar 21(1-2):95-101 [2]Balchandani P, et al. Magn Reson Med. 2008 May; 59(5)973-9 [3]Balchandani P, et al. Magn Reson Med. 2010 Sept; 64(3):843-51.

Acknowledgements: NIH-NINDS R00 NS070821, Icahn School of Medicine Capital Campaign, Translational and Molecular Imaging Institute, and Department of Radiology, Siemens Healthcare.