2D Arbitrary Shape Selective Excitation Summed Spectroscopy (ASSESS)

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Introduction:

For *in vivo* MRS, signal sensitivity and spatial specificity are two competing factors in both conventional single-voxel localization techniques and spectroscopic imaging. Spatially selective excitation offers a potential solution to this problem. This work demonstrates the utility of a novel group of multi-dimensional RF pulses to select any arbitrarily shaped ROI with a broad bandwidth (BW). This method, dubbed as 2D "Arbitrary Shape Selective Excitation Summed Spectroscopy" (ASSESS), uses interleaved radial *k*-space trajectories with different numbers of radial *k*-lines per excitation ($N_{k\text{-line}}$ = 1, 5 or 9). The construction and characteristics of ASSESS ($N_{k\text{-line}}$ = 9) are presented here with an *in vivo* demonstration in rat brain.

Theory and Methods:

To apply the *k*-space formalism of spatially selective excitation [1-2] to MRS, a broad BW of the RF pulse is required so that the entire range of chemical shifts in the spectrum is excited from the same ROI. The desired nutation-angle profile $\theta(x,y)$ is an N by N matrix with resolution Δx = FOE / N, where FOE represents the field of excitation. The radial trajectory was found to have a broad BW and low demand on RF peak power B_{1_max} [3]. For each rotational *k*-line, the initial gradient lobe brings the *k*-space trajectory from the origin to $k_{min} = -\pi / \Delta x$. The second lobe starts from k_{min}, scans through the origin, and reaches to $k_{max} = \pi / \Delta x$. It is brought back to the origin by the third lobe. The accompanying RF pulses, weighted only during the middle gradient lobe, are calculated using a superposition of the Fourier transform of point delta functions of all the pixels within the ROI (4). The minimum number of azimuthal angles (N_θ) needed to remove aliasing out of the FOE is $N_\theta = N \times \pi/2$. ASSESS ($N_{k\text{-line}}$ = 1) requires $N_i = N_\theta$ successive excitations and achieves a wide BW at the expense of a small nutation angle $\theta \approx 10°$ [1].

Large nutation angle excitation can be synthesized through a concatenation of a series of small excitation pulses with the same rotation axis [2]. Multiple radial *k*-lines per excitation ($N_{k\text{-line}} > 1$) and $N_i = N_\theta / N_{k\text{-line}}$ interleaved excitations cover the same k-space (Figure 1(A)) but yield higher nutation angles $\theta \approx N_{k\text{-line}} \times 10°$. Non-selective 180° refocusing pulses are inserted between each radial *k*-line to maintain the broad BW [5]. For $N_{k\text{-line}}$ = 9, the phases of 8 refocusing pulses (400 µs, $90_y180_x90_y$) are alternated as ++--+--+ to minimize the sensitivity to inhomogeneous B_0 and B_1 magnetic fields. Paired G_Z crusher gradients surrounding each refocusing pulse are critical to remove unwanted signals from the non-ideal refocusing (Figure 1(B)). Figure 1(C) shows the sequence diagram with ASSESS followed by outer volume suppression (OVS) pulses. First two 180° pulses suppress all unwanted signal outside a rectangular box encompassing the ROI. The third 180° pulse is through-plane slice selection. Spectroscopic acquisition starts immediately after the formed spin echo, followed by post-acquisition saturation.

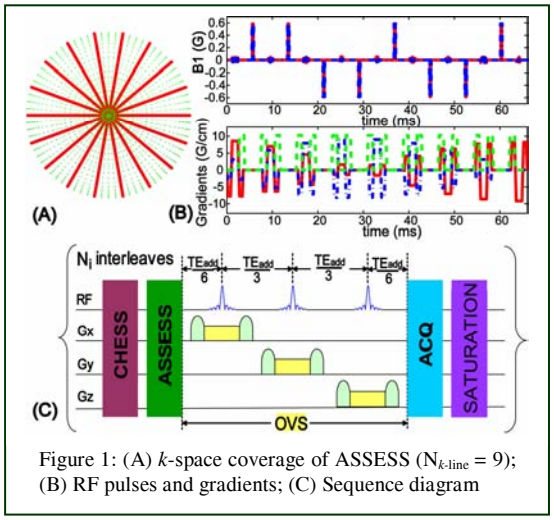

Figure 1: (A) *k*-space coverage of ASSESS ($N_{k\text{-line}}$ = 9); (B) RF pulses and gradients; (C) Sequence diagram

Experiments were performed on a 4 T Bruker small animal magnet (maximum gradient 13 G/cm in 170 µs). A cross-coil (volume transmit / surface receive) was used to generate a uniform transmitting B_1 field with high sensitivity. Axial scout images of rat brain were obtained from a multi-slice RARE sequence (echo train length = 8, TE = 60 ms, 128 × 128, FOV = 25.6 mm, slice thickness = 1 mm, TR = 3000 ms, NEX = 8). Multi-slice gradient echo images (64 × 64, 4 adjacent slices with slice thickness = 0.5 mm, TR = 500 ms) were acquired with 5 evolution delays ([5, 6 7, 9, 13] ms) so that the field maps can be calculated with a temporal phase unwrapping algorithm. 1st and 2nd order shim coil currents were adjusted accordingly to generate a homogeneous B_0 field within the arbitrarily shaped ROIs.

To validate the feasibility of different ASSESS pulses and compare those with conventional PRESS like localization method, a 9 × 3 = 27 mm^2 rectangular shaped ROI in the axial plain was defined from a 64 × 64 excitation matrix with reduced FOE = 12.8 mm. The OVS pulses after ASSESS suppressed anything outside a 12 × 4 × 3 mm^3 volume, which in the axial plain was slightly larger than the ROI and in the third dimension localized a 3 mm slice. RF pulses and gradients of ASSESS were generated with step duration Δt = 20 µs. Spectroscopy acquisitions (SW=2.5 kHz, 1024 complex points) were obtained with TE = 144 ms / TR = 3000 ms. For ASSESS ($N_{k\text{-line}}$ = 1) pulses, N_i = 100, NEX = 3; For ASSESS ($N_{k\text{-line}}$ = 5) pulses, N_i = 20, NEX = 14; For ASSESS ($N_{k\text{-line}}$ = 9) pulses, N_i = 12, NEX = 24.

A second ROI, with two discontinuous, convolved regions in the axial plane (10.3 mm^2 with 2 mm thick slice) within the hippocampus, was chosen to demonstrate the advantage of ASSESS in selecting complex shapes for spectroscopic measurements. Only ASSESS ($N_{k\text{-line}}$ = 9) was used in this second experiment. rFOE and OVS were kept the same with those of the first experiment. N_i = 12 interleaved 2DFT images were acquired with ASSESS both on resonance and 600 Hz off resonance during excitation. Spectroscopic acquisitions were performed for about 14 minutes (N_i = 12, NEX = 24, TR = 3000 ms) and then repeated six times to achieve sufficient SNR. The six separately stored FIDs were frequency corrected before addition to correct for magnetic field drift.

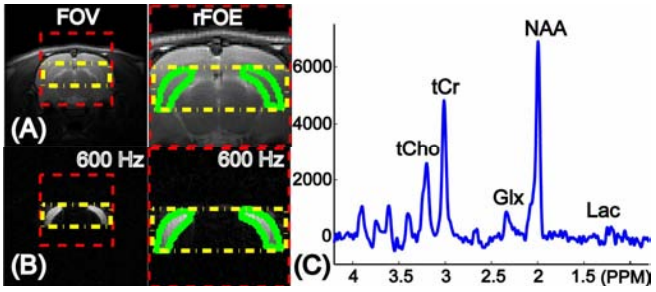

Figure 2: (A) Scout image (FOV, rFOE); (B) summed image with 600 Hz off resonance at excitation (FOV, rFOE); (C) summed spectrum of 6 sequential groups each with NEX = 24.

Results and Discussion:

Summed spectra of all ASSESS pulses ($N_{k\text{-line}}$ = 1, 5 or 9) from the first rectangular ROI were compared with the result from a PRESS like method (data not shown). Given the spectra were all collected from the same ROI, with same receiver gain, same acquisition parameters and total duration (14 min), the difference of the intensities of the major metabolite peaks (tCho, tCr, NAA) are mainly a reflection of the increase of nutation angles (10°,50°,90°, for $N_{k\text{-line}}$ = 1, 5 or 9 respectively).

Figure 2(A) shows one of two scout images of adjacent slices each with 1mm thickness. The ROI is circled by the green solid lines within the rFOE (red dash lines) and OVS (yellow dash dot lines). The summed images are shown in Figure 2(B). The broad bandwidth of ASSESS is demonstrated by the intact localization within the targeted ROI even at 600 Hz off resonance. Figure 2(C) shows the field-drift corrected and summed spectrum from 6 groups of sequentially saved spectra each taking 14 min, all from the same hippocampus ROI imaged above.

By both imaging and spectroscopy of ROIs in the rat brain, *in vivo* results show the feasibility and utility of 2D ASSESS pulses for ^{1}H NMR measurements from arbitrarily shaped ROIs. The spectral quality (i.e. resolution, water suppression, absence of lipids) is identical to that of localization methods like PRESS. However ASSESS offers the additional flexibility of MRS acquisitions from arbitrarily shaped ROIs, thereby offering either an increased sensitivity or reduced partial volume effect over conventional methods.

References:

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