Exotic Phase Cycling in Ultra-Short TE Spectroscopy

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Introduction

With the advent of increasingly higher strength MRI systems, shorter TEs are necessary to offset signal losses due to their T_2 relaxation times. Gradient spoiling is particularly sacrificed in ultra-short TE (≤ 5-ms) single voxel localized spectroscopy sequences. These sequences require extensive outer volume suppression (OVS)[1], phase rotation[2,3], or supposedly exotic phase cycling[4] to suppress coherences originating from regions outside the volume-of-interest (VOI). Exotic phase cycling is an untested RF phase cycling technique that allows suppression of specific coherences without the memory demands of phase rotation. Here we implement and examine the performance of an exotic phase cycle in an ultra-short TE (UTE) localized STEAM spectroscopy sequence.

Background

Recently, we presented the concept of exotic phase cycles[4]. These are RF phase cycles that provide greater phase dispersion for specific unwanted coherences than standard phase cycle, hence increasing the likelihood of signal cancellation over the averaging cycle. For a STEAM localization sequence, our studies have suggested that only the third FID and spin echo from intersection of the second and third RF (SE23) pulses contribute unwanted coherences to the spectrum[5]. Thus an exotic phase cycle should focus on maximizing the phase dispersion of those two coherences. We specifically developed a cycle with 24-steps to provide greater phase dispersion than any current phase cycle sequences because of the weak gradient spoiling for the third FID in ultra-short TE STEAM localization. Following steps previously described[4], we set $\Delta\varphi_1$= 150°, $\Delta\varphi_2$=345°, $\Delta\varphi_3$=165°, and $\Delta\varphi_{ADC}$=0°, which resulted in a phase increment for SE23 of $\Delta\varphi_{23}$=345°. In phase rotation, the coherence location diagram is useful in determining the shift of unwanted coherences relative to the stimulated echo. For exotic phase cycling, the phase dispersion, i.e, the number of phases sampled over 360° is the focus as increasing phase steps approximate the ideal case of a uniform distribution of phases over the entire averaging cycle. As implemented, the negating phases (angles that differ by 180°) for the third FID are acquired in pairs to minimize gross motion that might enhance potential subtraction errors (Table I). Ideally the phase increment $\Delta\varphi$ of all the coherences should be unique to provide maximum dispersion across any potential signal contaminations sources during signal averaging, except the stimulated echo. For the standard eight coherences, this exotic cycle yields only five unique phases: FID1 and the double echo have the same phase increment, FID3 and SE23 have the same phase increment. Also, the spin echo coherences from the intersection of the first and second RF pulses (SE12), and the intersection of the first and third pulses (SE13) have the same phase increment. FID2 and the stimulated echo have unique phase increments. However, the key here is that both FID3 and SE23 have 24-step cycles.

Table I. 24-Step Phase Cycle

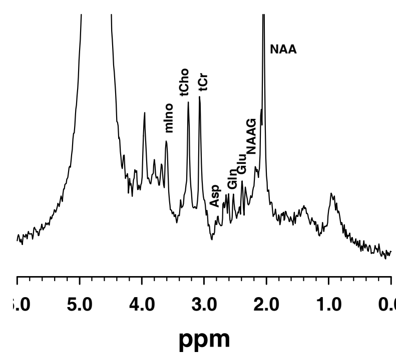
n	$\Delta\varphi_1$	$\Delta\varphi_2$	$\Delta\varphi_3$
1	150	345	165
2	150	165	345
3	300	330	150
4	300	150	330
5	90	315	135
6	90	135	315
7	240	300	300
8	240	120	120
9	30	285	105
10	30	105	285
11	180	270	270
12	180	90	90
13	330	255	75
14	330	75	255
15	120	240	240
16	120	60	60
17	270	225	45
18	270	45	225
19	60	210	210
20	60	30	30
21	210	195	15
22	210	15	195
23	0	180	180
24	0	0	0

Methods

We implemented an UTE STEAM sequence on a 3T MRI system (Siemens Medical System, Erlangen, Germany) with the following parameters: 4 ms TE, 12 ms TM, 3250 ms TR, 2048 points, 2500 Hz SW, 144 averages. Asymmetric RF pulses were employed as previously described[6]. Only one OVS cycle (8 spatial saturation bands) was employed to suppress potential skin/scalp fat signal. All acquisitions also included an unsuppressed water reference for phase correction. The sequence was tested in four volunteers to assess contamination. All studies were performed using a standard clinical, receive-only, 12-channel head coil, and data averaging done online by the system's standard spectroscopy software. Water-suppressed spectra were phase corrected and apodized.

Results and Discussion

The spectrum to the right shows typical results from this UTE sequence acquired in the posterior centrum semiovale of a healthy participant. None of the expected artifacts from contamination are visible in any of the spectra. Particularly hopeful is that the macromolecule resonances below 2.0 ppm show none of the scalp lipid resonances that can sometimes contaminate that region. These results show the first successful implementation of an exotic phase cycle in an UTE sequence. To our knowledge it is one of the few UTE sequences implemented using a standard receive-only phased array coil and so can be run on any clinical system.



Representative spectrum acquired with TE/TM/TR = 4/12/3250-ms with a 24-step exotic phase cycle

References

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