Slice-Selective Coherence Transfer Using Symmetric, Linear Phase Pulses. Applications to GABA Editing

J. Shen¹, Z. Chen²

¹NIMH, Bethesda, MD, United States

Synopsis

Symmetric, linear phase, selective RF pulses were analyzed theoretically for performing slice-selective coherence transfer. It was shown using numerical simulations of product operators that, when a prefocusing gradient of the same area as that of the refocusing gradient is added, these pulses become slice-selective universal rotator pulses, therefore, capable of performing slice-selective coherence transfer. As an example, a slice-selective universal rotator pulse based on a seven-lobe hammering-filtered sinc pulse was applied to in vivo single-shot, simultaneous spectral editing and spatial localization of neurotransmitter GABA in the human brain.

Introduction

In in vivo localized spectroscopy applications, use of selective pulses is usually limited to spatially and/or spectrally selective excitation, inversion and refocusing. When a pulse is needed for conversion of multiple quantum coherences or for polarization transfer a nonselective hard pulse is usually used. Here we demonstrate that symmetric, linear phase, selective pulses can be configured to act as slice-selective universal rotator pulses and to perform slice-selective coherence transfer such as polarization transfer and conversion of multiple quantum states with significantly low RF power requirement and short pulse duration as compared to conventional prefocused universal rotator pulses. The application of these pulses to in vivo single-shot localized detection of neurotransmitter GABA in the human brain is demonstrated experimentally.

Results

Fig. 1 shows results of numerical simulation of the overall quaternion elements of a 90° 1.5 ms hammering-filtered seven-lobe sinc pulse configured as a slice-selective universal rotator pulse. The strength of the slice selection gradient used is 1 G/cm. The areas of the prefocusing and refocusing gradient pulses are 50% of that of the slice-selection gradient pulse. As seen in Fig. 1, within the selected slice a relatively pure phase and uniform 90° rotation is obtained as quaternion elements \(-A \approx D \approx 0.707\); and \(B \approx C \approx 0\) across the passband of the slice.

Fig. 2 compares simulated spatial profiles of the polarization transfer yield and the double quantum yield of the 90° slice-selective universal rotator passband of the pulse using the slice-selective universal rotator RF-gradient pulse scheme described in Fig. 1. For 2IzSx \(\rightarrow\) 2IzSx and 2IzSx + 2IxSz \(\rightarrow\) DQC+, ~100% polarization transfer yield and double quantum yield are obtained respectively within the passband of the pulse using the selective universal rotator pulse.

The GABA editing pulse sequence is depicted in Fig. 3. It uses a doubly selective DANTE pulse for GABA-3, 4 DQ preparation. The second 90° pulse is configured to act as a slice-selective universal rotator pulse for conversion of antiphase single quantum coherence into double quantum coherence along the \(z\) direction. After DQ labeling, the GABA-4 is rephased by a pair of identical 3.5 ms hyperbolic secant pulses (\(\mu = 5\), 1% truncation) along the \(y\) direction. Fig. 4 shows the in vivo spectra with TE = 68 ms from a 2 x 3 cm³ voxel in the occipital lobe of a volunteer obtained at 2.1 Tesla. First, the unedited spin-echo spectrum (top trace) was acquired with NS = 8. A 4-Hz line broadening was used for post-acquisition processing. Then GABA editing pulse sequence depicted in Fig. 3 was applied to the same voxel. The edited spectrum (bottom trace) was acquired with 128 scans. The same post-acquisition line broadening was applied. The doubly selective double quantum filter suppressed the dominant creatine singlet at 3.0 ppm and revealed the underneath GABA-4 doublet at 3.0 ppm. The doubly selective double quantum filter also suppresses other singlets and coupled spins such as choline, NAA, glutathione, and macromolecules.

Discussion

Compared to 90° U-BURP and Q5 pulses, the linear phase pulses generally require much less RF power, therefore, they are particularly suitable for in vivo applications. For not very large flip angles (\(\theta \leq 90°\)) the linear response theory based pulses can be set to arbitrary flip angles. Also, inhomogeneity has negligible effects on the integrity (selectivity, phase, and uniformity) of the excitation profile of these pulses provided that the nominal flip angle is not very large. The advantage of the slice-selective pulses over the equivalent non-selective "hard" pulses in localized spectroscopy is that the slice-selective pulses minimize excitation of outer volume magnetization. In a previous GABA editing method using a doubly selective DANTE refocusing pulse for selective preparation of GABA-3, 4 double quantum spatial localization was achieved using the 8-step three-dimensional ISIS method. In this sequence, only the first 90° pulse and the second 180° pulse are available for conventional spatial localization because the doubly selective DANTE pulse is necessary to suppress overlapping glutathione and mobile macromolecules around 3.0 ppm. Application of the slice-selective universal rotator pulse has made it feasible to achieve simultaneous spectral editing and three-dimensional spatial localization of GABA in a single shot. This new GABA method eliminates ISIS subtraction errors due to potential patient movement and instrumental instability.