New FOCI Pulse with Significantly Reduced RF Power Requirements

J. Shen[1], Z. Chen[1]

[1]Molecular Imaging Branch, NIMH, Bethesda, MD, United States

INTRODUCTION

FOCI pulses use time-varying gradients to increase the adiabaticity at the beginning and the end of the sech pulses and generate much smaller spatial localization error and sharper edges than those of the original sech pulses without the modulating gradients. The VERSE scheme can dramatically reduce the peak and overall RF power requirements of sech pulses using time-varying gradients. Here we combine the two procedures to generate an inversion pulse operating adiabatically at the same peak RF power as that of a 180^o five-lobe sinc pulse of the same duration while producing a slice profile which matches that of a sech pulse with $\mu = 6$. The new FOCI pulse (referred to as VERSE-FOCI pulse henceforth) has been tested experimentally on phantom samples and on rats for *in vivo* spin-echo echo-planar imaging using a surface transceiver coil at 11.7 Tesla.

METHODS AND SIMULATION

The VERSE-FOCI pulse is defined by $G(t) = A(t)G_{HS}$, $B_1(t)= A(t)\Omega_0\text{sech}(\beta\tau(t))$, $\Delta\omega(t) = -A(t)\mu\beta\tanh(\beta\tau(t))$ where G_{HS} is the corresponding gradient of the original sech pulse; A(t) is the FOCI modulating function with $A(t) = 2.5\text{-}3.75t/T$ for $t/T \leq 0.4$, $A(t) = 1$ for $0.6 \leq t/T < 0.4$, and $A(t) = -1.25+3.75t/T$ for $t/T \geq 0.6$; $\tau(t)$ is a time-dilation function with $d\tau/dt = 1.42\text{-}0.84\sin^2(\pi t/T)$. Fig 1 compares the RF and gradient amplitude modulations of an original sech pulse ($\mu = 3$, 1% truncation) with the corresponding VERSE-FOCI pulse. The parameters of VERSE-FOCI were chosen to make its peak RF power at the adiabatic threshold the same as that of a 180^o five lobe sinc pulse with $B_{1max}T = 2.8$. The inversion profiles of a 2 ms VERSE-FOCI pulse at its adiabatic threshold were simulated using Bloch equations and are shown in Fig 2 ((a) original sech and VERSE-FOCI; (b) off-centered slice by VERSE-FOCI; (c) chemical shift (cs) = 250 Hz; (d) cs = 500 Hz). All experiments were performed on a Bruker 11.7 Tesla vertical 89 mm bore spectrometer equipped with a Mini 0.5 gradient insert which can produce a field gradient of 30 G/cm at a rise time of 90 µs. A home-made 1.5-cm i.d. surface coil was used.

EXPERIMENTAL RESULTS

Fig. 3 shows comparison of the spin echo refocusing profile of the 2-ms 180^o five-lobe sinc pulse generated using non-selective excitation and slice-selective refocusing with that using two identical 2-ms VERSE-FOCI pulses set to the same peak RF power as that of the sinc pulse. For *in vivo* spin-echo echo-planar imaging of the rat brain Fig. 4(a) shows a 64 x 64 transverse echo-planar image of the rat brain obtained using a 2 ms five-lobe sinc pulse for excitation and the same pulse with a nominal flip angle of 180^o for refocusing. FOV = 2 cm. Slice thickness = 2 mm. NS =1. The corresponding echo-planar image using two 2-ms VERSE-FOCI pulses for refocusing was given in Fig. 4(b). To demonstrate adiabaticity the RF power of the VERSE-FOCI pulses was set to 6 dB above that of the refocusing sinc pulse in Fig. 4(a). Due to the adiabaticity of the VERSE-FOCI pulse the refocusing yield in Fig 4(b) is significantly higher than in Fig 4(a). The intensity in Fig. 4(b) was halved to allow anatomical details to be shown in both images obtained using the surface coil.

DISCUSSION

The slice-selective spin echo scheme using VERSE-sech pulses has already been applied to 2D FT spin echo imaging of human brain. However, the VERSE scheme alone does not improve the inversion or spin echo refocusing profile. As compared to the original sech pulses or the VERSE-sech pulses, the inversion profiles of the VERSE-FOCI pulse are dramatically improved. This allows the VERSE-FOCI transformation of sech pulses with small phase factors (e.g., $\mu = 3$), therefore to lower their adiabatic thresholds to the peak power of the five-lobe sinc while significantly improving the inversion profiles. In Table 1, the inversion profile of VERSE-FOCI pulse was evaluated and compared to those of original sech pulses of different phase factors. As shown in Table 1, the sharpness of the inversion profile generated by the VERSE-FOCI pulse is close to that of the original sech pulse with a phase factor of 6. The improved slice definition derived from the VERSE-FOCI pulse should increase perfusion signal in FAIR and also increase the SNR in 2D spin-echo imaging while using a fraction of the RF power required by the FOCI pulses. Chemical shift and/or B_0 inhomogeneity in slice selection causes spatial localization error. Following the reasoning used in VERSE, the spatial localization error is predicted to be cs/G(0) for the VERSE-FOCI pulse. Spatial localization error is further reduced for the VERSE-FOCI pulse as compared to the corresponding FOCI pulses. The chemical shift and/or B_0 inhomogeneity also cause degradation of the inversion profiles as shown in Figs. 2(c-d). Since the degree of variation between the inverse gradient at its minimum and peak is larger in VERSE-FOCI pulses than in FOCI pulses the degradation of VERSE-FOCI inversion profiles due to chemical shift and/or B_0 inhomogeneity is more pronounced. Consequently we do not expect that the VERSE-FOCI pulses parameterized here will be useful for spectroscopy applications especially for heteronuclear spectroscopy at high-field strength where the dispersion of chemical shifts is very large. For water imaging applications, the localization error of fat in the slice direction due to its chemical shift is reduced because of cs/G(0) as discussed above. Additional localization error of fat in the slice selection direction comes from the pulse profile distortion caused by the secondary effects of the variation between the inverse gradient at its minimum and peak. The VERSE-FOCI pulse is also position-specific. A different phase modulation function is needed for each off-centered slice position in multi-slice imaging experiments.

Table 1. Ratio of the inversion bandwidth at $M_z = -0.95$ to that at $M_z = 0.95$ of sech pulses and VERSE-FOCI pulse (in bold)

µ	B_{1max}*T	Ratio
3	5.1	0.45
3‡	**2.8**	**0.68**
4	5.8	0.56
5	6.5	0.63
6	7.2	0.69

‡VERSE-FOCI

Fig. 1

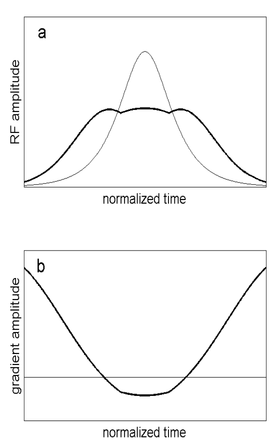


Fig. 2

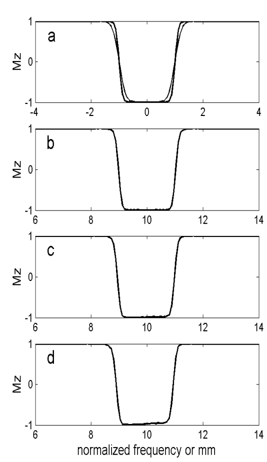


Fig. 3

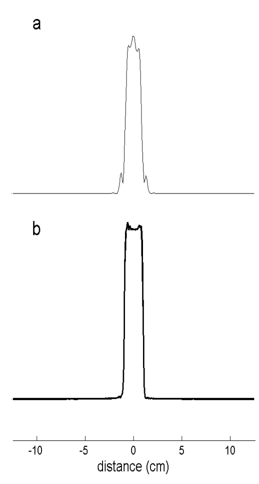
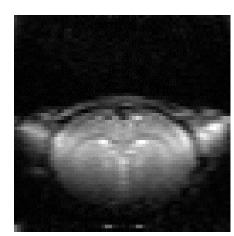


Fig. 4(a)



(b)