A T_2^* selective higher-order soliton preparation pulse for MRI

M. Jankiewicz[1,2], J. Moore[1,3], A. W. Anderson[1,4], and J. C. Gore[1,4]
[1]Institute of Imaging Science, Vanderbilt University, Nashville, TN, United States, [2]Department of Radiology, Vanderbilt University, Nashville, TN, United States, [3]Department of Physics, Vanderbilt University, [4]Department of Biomedical Engineering, Vanderbilt University

Purpose

The soliton pulses of Rouke and Bush [1] represent a promising solution to the problem of designing T_2^* selective preparation pulses. The pulses are characterized by a set of complex parameters. Their interpretation is only partially understood in the context of MRI. For example, some of them correspond to values of relaxation times for which the magnetization vector will be nulled. A preliminary analysis of the behavior of such pulses is presented here with the goal of demonstrating the versatility of such pulses in producing a range of T_2^*contrasts.

Methods

<u>*Theory*</u>*:* Given an initial magnetization vector $(M_x,M_y,M_z)=(0,0,1)$, a class of RF pulses (so-called solitons) exist that can realize the following final magnetization response

$$M_x(T;T_2^*)=0, \qquad M_y(T;T_2^*)=0, \qquad M_z(T;T_2^*)=\prod_{j=1}^{n}\frac{1/T_2^*-1/g_j}{1/T_2^*+1/\bar{g}_j}$$

where T is the pulse duration; T_2^* is a relaxation time, '‾' denotes complex conjugation, and g_j are arbitrary complex parameters from the right half complex plane, such that all non-real parameters must be in the $(g_j,\bar{g}_j)$ pair [1,2], and n is the order of the soliton pulse. Strictly real parameters g_j correspond to values of relaxation times (T_2^*) of spins for which the longitudinal magnetization together with the transverse magnetization will be nulled at the end of the pulse. Multiple species of spins with different relaxation times can in principle be nulled at the same time. RF pulses generating the magnetization responses characterized by the g_j parameters can be calculated using the *dressing method* from *inverse scattering theory* [1].

<u>*Analysis of Dressing Data g_j*</u>: The interpretation of complex parameters g_j that supplement a real set of g_j is not obvious, and their role has to be analyzed from the point of view of MRI. A parameter space, over which magnitude A_j and phase ϕ_j of a complex g_j were varied, was defined from 0 to 50 (in units of ms) in the A_j direction and from 0 to π in the phase direction (because of the symmetry constrain $(g_j,\bar{g}_j)$). Subsequently, the final longitudinal magnetization response was calculated as a function of T_2^* in the range form 0.1 to 100 ms, for the corresponding dressing data. In all of the cases g_1 was chosen to be real and to null spins with T_2^*=1ms. An analysis was performed on the 3rd order soliton pulse, i.e., n=3 with A_2 and ϕ_2 being the only free parameters. A comparison was made to the 1st order soliton with g_1=1ms. All other cases can be obtained from the one studied here by proper rescaling of the parameters.

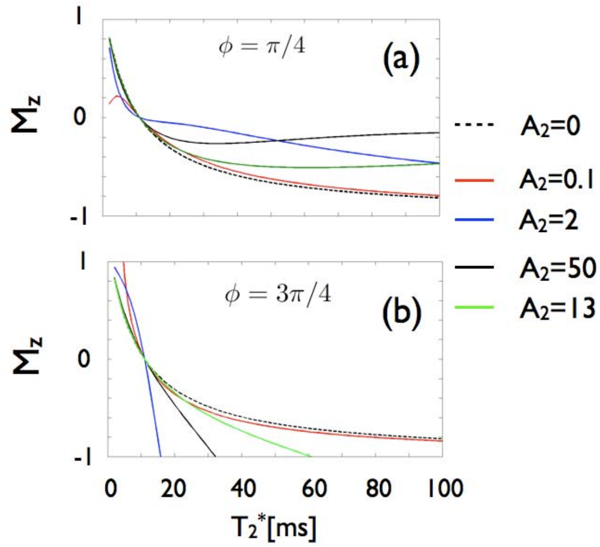

Fig.1: Longitudinal magnetization response for the 1st (dotted) and 3rd order (solid) soliton pulse. A variation in performance of these pulses presented as a function of phase ϕ and amplitude A_2 of the dressing parameter g_2. For the phases below π/2 the magnetization asymptotically approaches 0 (a); for phases above π/2 there is a maximum value of T_2^* relaxation time for which pulse is physically realizable (b).

Results and Conclusions

<u>*Results*</u>: The final longitudinal magnetization response for a variety of cases is presented in Fig. 1. As can be see from Fig.1(a), a variation of the amplitude A_2 changes the slope of the M_z magnetization such that the magnitude of M_z is always smaller/larger than the response of the 1st order soliton for $T_2^*>g_1$ / $T_2^*<g_1$ and phases smaller than π/2. For phases π/2 and above Fig.1(b) shows that an increase in the amplitude leads to the magnitude of M_z always being larger/smaller than the response of the 1st order soliton for $T_2^*>g_1$ / $T_2^*<g_1$ and there exists a maximum

$$T_2^*=-i\,A_2\Big/\sqrt{1+2\frac{A_2}{g_1}\cos(\phi_2)}$$

for which the M_z response is physical (Fig. 1(b)). Depending on the application, the magnetization response presented above, together with optimization of the dressing data, can lead to quite flexible magnetization response profiles. In contradiction to common belief [3], more complicated and clinically interesting magnetization responses can be obtained. For example, a step filter can be constructed that selects to null only spins with relaxation times smaller then a target relaxation. An opposite response is also possible, where the magnetization of the spins with T_2^* longer than a target relaxation is effectively nulled. Future work will focus on optimization of the performance of the pulses described here for utilization in ultra-high field MRI. Higher order pulses will be included in the analysis. As soliton pulses are susceptible to off-resonance and B_1 inhomogeneities, modifications to the parameter space will be necessary.

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