Velocity Selective Inversion Pulse Trains for Velocity Selective Arterial Spin Labeling

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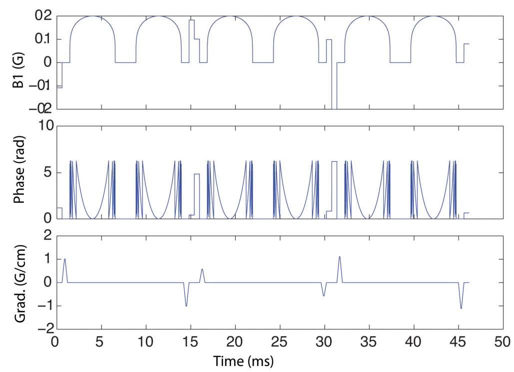
Introduction

In velocity selective arterial spin labeling (VSASL) (1), blood is tagged based on flow velocity, without spatial selectivity. The most attractive feature of this tagging approach is that it is in principle immune to transit delay effects, and is therefore of potential utility in ischemic diseases such as stroke. A primary drawback of existing implementations of VSASL is that the tagging pulse train produces velocity selective saturation rather than inversion, resulting in reduced SNR. We present here the design of velocity selective inversion pulse trains for use in VSASL.

Methods

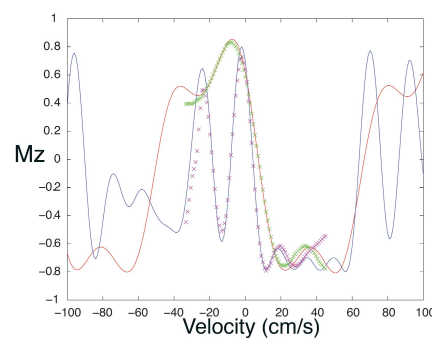
The pulse train is a combination of our original dual adiabatic spin echo pulse train (1) and the modular approach of Norris (2). The basic module is a pair of hard α pulses at the beginning and end with phases ϕ, dual non-selective adiabatic spin echo pulses (3) and bipolar flow sensitizing gradients (see Figure 1). The dual adiabatic spin echo provides B_0 insensitivity without introducing B_1 sensitivity. Ideally, B_1 insensitive rotation pulses would be used for the α pulses, but we have not found such pulses with sufficient accuracy for this application. Instead, we use simple hard α pulses, and search numerically for combinations of flip angles and pulse phases that provide maximal inversion across the desired range of velocities and B_1 inhomogeneity. For each pulse module there are 5 free parameters: two flip angles, two pulse phases, and the gradient moment. Pulse trains were optimized using Bloch equation simulation and constrained optimization (fmincon) in Matlab (Mathworks, Boston, MA). The target was M_z=1 for velocities from -0.5cm/s to 0.5cm/s and M_z=-1 from 4cm/s to V_{max} (see Results), for a range of B_1 that varied from 0.7 to 1.3 times the nominal value.

Results



For a single pulse module, the optimal solution is simply α={90° -90°} and ϕ={0 0}, which leads to a cosinusoidal velocity profile, and a sinc shaped profile with laminar flow (1). For two or more pulse modules, inversion is possible across a larger range of velocities. An optimized pulse train using three pulse modules is shown to the right, and was designed for Vmax=60cm/s. The calculated response for 2 and 3 module pulse trains is shown as red and blue solid lines in the figure below. The response measured in a mechanically rotated phantom for a portion of this velocity range is shown as green and magenta crosses in the same figure. For a range of Vmax, the calculated Mz for 2 and 3 module pulse trains is shown in the color figure below. Preliminary VSASL images acquired using 1, 2, and 3 pulse modules is also shown below, demonstrating mean gray matter ASL signals that are 28% and23% higher using the 2 and 3 module pulse trains than using the single module pulse.

Discussion



Using the pulse trains shown here, velocity selective inversion is feasible across a broad range of velocities with relative insensitivity to both variations in B_0 and B_1. Because of the inherent insensitivity to transit delays, VSASL with efficient velocity selective inversion pulses can in principle generate higher SNR than both conventional pulsed and pseudo-continuous ASL methods. However, because there are limits to both the velocity range and the B_1 insensitivity, careful attention must be paid to the range of these parameters present in a given application.

References

1. Wong et al. MRM 55 p.1334, 2006.
2. Norris et al. JMR 137 p. 231 1999.