The Efficiency of Background Suppression in Arterial Spin Labelling

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Introduction:

Arterial spin labeling (ASL) can provide quantitative flow information that may be very useful for clinical and research applications. The ASL signal change, however, is typically less than one percent of the background signal intensity and noise introduced by motion and other instabilities can greatly degrade ASL imaging results. Background suppression using multiple inversion pulses can be used to greatly attenuate the background signal and hence improve the quality and robustness of ASL(1-3). As the number of pulses used increases, the background suppression can be optimized for suppression of better than 100x across a wide range of T1(2). With perfect inversion pulses, the background suppression should have no effect on the ASL signal but even small imperfections can attenuate the ASL signal when a large number of inversion pulses are used. Understanding of this inversion inefficiency is important both for optimizing sequences and for absolute quantification of the ASL results.

The goal of this study is to analyze the degree of signal that is lost in background suppression using adiabatic hyperbolic secant (sech) inversions pulses (4) $B(t)=B_{01}(\text{sech}\,B(\Delta t))^{1+i\mu}$, where beta (pulse length parameter, *B)* and mu (side to width parameter, *μ)* are constants . Using a wide range of experimental parameters, simulations of adiabatic inversions were obtained in order to determine an optimal range of values that provides the most efficient inversions. These parameters were then tested *in vivo* and the results compared to theoretical inversion efficiency values.

Methods:

Simulations

Using numerically integrated Bloch equations for calculation of adiabatic inversion as described in (5), different mu and beta values were explored for blood and tissue T1 and T2 in order to find an optimal range for most efficient inversions. Simulations assumed a peak RF amplitude of .18 Gauss a range of off-resonance frequencies from 0 to 2000Hz, mu values from 2-10 and beta values from $500s^{-1}$-$3000s^{-1}$.

In vivo measurements

Experimental measurements of inversion efficiency were performed on a 3.0 Tesla GE VH/i scanner using the product head coil. A partially suppressed continuous ASL preparation with a post-labeling delay of 1s was placed before a stack of spirals volumetric acquisition. Eight shots were required to encode an entire image. Pairs of label and control images were acquired both without and with 6 closely spaced hyperbolic secant pulses applied immediately after the end of labeling. The difference between the two perfusion measurements was used as an indicator of inversion efficiency. An RF field of approximately 0.18 Gauss was used but the RF nonuniformity in the brain at 3 Tesla is typically less than 30%. Based on simulation values obtained for maximum inversion as seen in figures 2 and 3 for a bandwidth of approximately 800Hz, the following five mu and beta pairs were tried: 3,1400; 4,1400; 5,1400; 4,1000; 4,1800.

Result

Figure 1 shows percent inversion values for tissue at the center frequency, where the largest inversion is expected. The plot shows largest magnetization inversion for low mu values and high beta values just bordering on adiabaticity. Sweeping too rapidly through frequency violates the adiabatic condition but sweeping too slowly adds T2 decay during the inversion. Figure 2 shows a contour plot of the inversion values at 400Hz off resonance for this range of mu and beta and for typical tissue T1 and T2 values of 1.2s and 80ms respectively. The plot shows an optimal range for maximum inversion near values of 4 for mu and 1400 for beta. The inversion achieved in blood is better because of the longer time constants. The six additional pulses reduced the measured perfusion signal by 13-48%. Inferred single pulse inversion efficiencies are consistent with our simulation values for blood relaxation times.

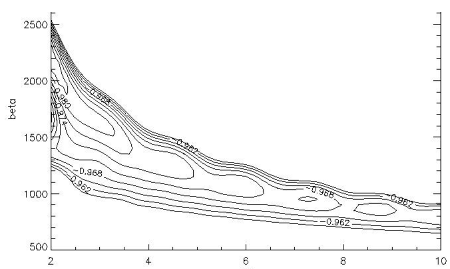

Figure 1. Relative magnetization inversion values at 0Hz. Tissue T1 and T2 values: 1.2, .08s.

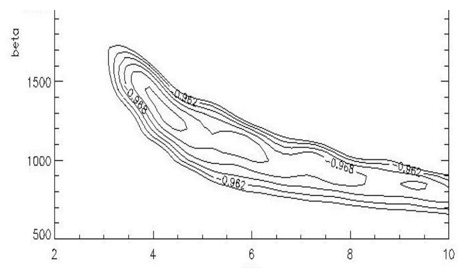

Figure 2. Relative magnetization inversion values at 400Hz. Tissue T1 and T2 values: 1.2, .08s.

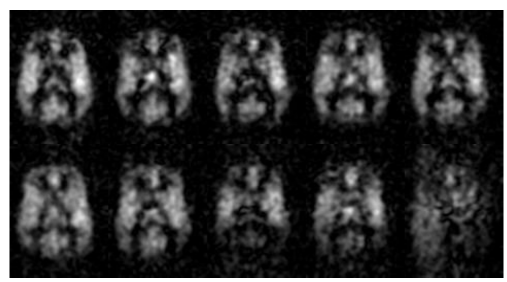

Figure 3. ASL perfusion images from one slice acquired. without, top row, and with, bottom row, 6 sech pulses with mu and beta of 3/1400., 4/1400., 5/1400., 4/1000., 4/1800 from left to right.

Mu	Beta	6 pulses	1 pulse
3.0	1400.0	0.873	0.978
4.0	1400.0	0.869	0.977
5.0	1400.0	0.773	0.958
4.0	1000.0	0.837	0.971
4.0	1800.0	0.622	0.924

Table 1. Efficiency for different mu and beta.

Discussion:

Background suppression can be remarkably efficient even with as many as 6 inversion pulses. Attention to the inversion pulse selection is important for assuring high efficiency because both excessive RF amplitude and insufficient RF amplitude can cause strong attenuation of signal.

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