Visualization of the Paramagnetic Markers in Interventional MRI Using Spatial-Spectral Pulses

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Introduction: Several approaches have been proposed to passively visualize the guide wire in MR endovascular interventions. The two notable approaches are the white marker phenomenon [1] and spectrally selective RF pulses [2]. These approaches exploit the susceptibility difference ($\Delta\chi$) between the paramagnetic marker mounted on the guide wire or catheter and the surrounding water to generate positive contrast. In this work, one more approach to visualize the passive markers with positive contrast exploiting the $\Delta\chi$ between water and paramagnetic marker, using spatial-spectral (SPSP) pulse is proposed. Furthermore, FATSAT pulse was utilized to suppress the fat signal enhancement. The technique was applied *in vitro* to demonstrate the effectiveness of the marker detection.

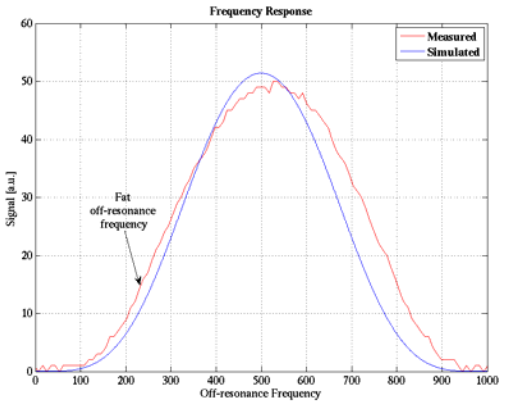

Figure 1: *Off-resonance frequency response of the SPSP pulse with flip angle weightings governed by binomial pulse of order three (1-3-3-1). The blue curve is simulated response whereas the red curve is a measured response.*

Theory: The SPSP pulse consists of series of N slice selective RF subpulses with tip angles α_i (where i=1 to N} and a τ seconds delay between the two adjacent subpulses applied in conjunction with an oscillating slice select gradient [3]. Each subpulse selects the slice at location z, whereas the phase accumulation from one subpulse to the next along the train selects the spectral frequency υ. The spectral response of this SPSP pulse is governed by N-point Finite Impulse Response (FIR) filter, which is periodic, with a period of $1/\tau$ Hz. The most popularly used FIR filter for this purpose is a binomial filter. So far the SPSP pulse has been used to selectively *excite* the water or to selectively *saturate* the fat exploiting the chemical shift between the water and fat. The susceptibility difference ($\Delta\chi$) between paramagnetic markers and the surrounding water causes frequency shift in the surrounding water tissues. After simulations and experimental measurements it has been found that this frequency shift is around 500 Hz (at B_0 =1.5T) for our paramagnetic markers. In this work, the SPSP pulse is used to selectively excite these off-resonant tissues only. If we want to excite these offset frequencies without touching water then we must ensure that: $1/\tau \geq 2\, B_0\gamma\, \Delta\chi$ with γ being gyromagnetic ratio of water protons. In the present case, the center frequency of excitation of SPSP pulse is set on water resonance and a phase of π radians is added between the two adjacent pulses, which shifts the frequency response by 500 Hz when the separation between two spectral lobes is 1 kHz (τ =1 ms). The simulated off-resonance frequency response of the SPSP pulse for binomial filters of order three is shown (blue in color) in the Figure 1.

Materials and Methods: The standard Gradient Recalled Echo (GRE) sequence was modified by replacing the standard excitation scheme by SPSP pulse, whose flip angles were weighted by binomial filter of order three (1-3-3-1). All the measurements were performed on a Siemens Espree 1.5T scanner. The measured off-resonance frequency response of this SPSP pulse is shown (red in color) in Figure 1. *Phantom:* Two sample bottles were embedded in a water phantom containing **1.** vegetable oil resembling fat (left bottle in Figure 2A) and **2.** guidewire with paramagnetic marker located on it (right bottle in Figure 2A). *MR Imaging:* The sequence parameters were: slice thickness 40 mm; TR 20 ms; TE 4.7 ms; FOV 200mm × 200mm; Matrix 256×256; flip angle 40˚. From the frequency response of the Figure 1 it can be seen that the fat frequency, which is around 220 Hz at 1.5T falls in the range of excitation frequency range because of broader spectral lobe of binomial filters. To overcome this fat excitation problem, spectrally selective RF pre-pulse (FATSAT pulse) was applied to saturate the fat signal [4] with a bandwidth of 340 Hz and central excitation frequency shifted 110 Hz away from water. The FATSAT pre-pulse was applied after every 50 phase encoding steps.

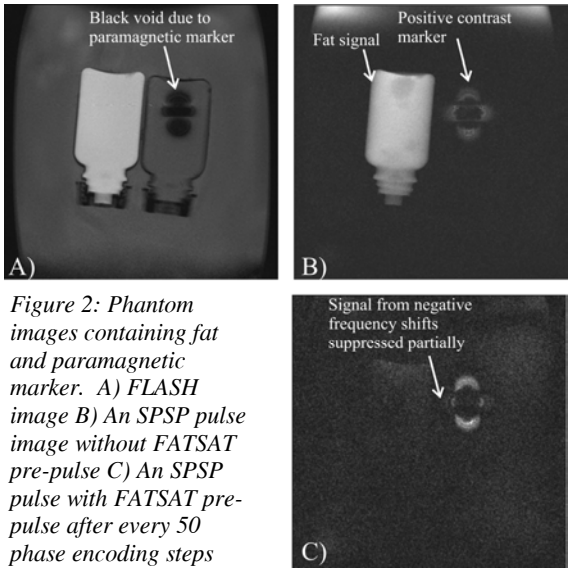

Figure 2: Phantom images containing fat and paramagnetic marker. A) FLASH image B) An SPSP pulse image without FATSAT pre-pulse C) An SPSP pulse with FATSAT pre-pulse after every 50 phase encoding steps

Results: Figure 2 A) shows the negative contrast image obtained using the standard FLASH sequence. Figure 2 B) shows the positive contrast image obtained using SPSP pulse. It can be clearly seen that the there is almost no signal from water tissues whereas bright contrast appears due to paramagnetic marker. Figure 2 B) also illustrates that the signal from fat appears brighter as expected. Figure 2 C) demonstrates the bright marker and suppressed fat signal image obtained using combined FATSAT pre-pulse and SPSP excitation pulse.

Conclusion: We propose positive contrast imaging of the passive markers by adopting a SPSP pulse in a standard GRE sequence with additional FATSAT pulse to suppress the signal due to fat. To demonstrate the utility of this technique in clinical applications, further *in vivo* experiments are necessary.

Reference: [1] Seppenwoolde et al., MRM 50:784-790, 2003. [2] Cunningham CH et al., MRM 53, p.999, 2005. [3] Yuval Zur, MRM 43, p. 410-420, 2000. [4] Haase et al., Phys Med Biol. 30:341-344, 1985.