Fat attenuation using a dual steady-state balanced-SSFP sequence

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Introduction:

In refocused-SSFP sequences (e.g. balanced-FFE), it has been recently shown that the off-resonance profile can be modified using a different RF-phase scheme. This phase modification can lead to fat attenuation [1-2]. In this work, we propose a new sequence that also realizes fat attenuation, without modifying the common phase alternation of b-FFE. The sequence uses periodic variable flip angles and produces a dual steady state. Fat attenuation has been observed in phantoms and abdominal images.

Methods:

The sequence consists of a modified b-FFE with the following periodic flip angles series: -α; +3α/2; -α; +α/2. Pulses are separated by a delay TR and the sequence has a total period of 4 TR. In order to obtain a symmetric trajectory, the sequence is initiated by a +α/4 - TR/2 preparation. Numerical simulations were performed with MatLab 6.5 using the matrix form of the Bloch equations (signal sampled at t=TR/2) to analyze the signal behavior and the off-resonance properties of the sequence. Experimental data were acquired with a Philips Gyroscan Intera 1.5T and reconstructed off-line: we tested fat attenuation in a fat/water phantom and in volunteers (abdominal images).

Results and discussion:

The on-resonance magnetization trajectory is shown in Fig.1: there are two symmetric inner and outer parts, which can be sampled separately to give the dual signal evolution shown in Fig.2. In fact with a periodicity of 4 TR, there are four different parts of the signal, reaching four different steady states. But as TR << T1,T2 and due to the RF angles scheme, the sequence reaches a dual steady state. Moreover with an appropriate choice of sequence preparation (+α/4 - TR/2), the transient phase also presents this dual state. Fig.3. shows the off-resonance modulus profile of the upper steady state: the broad stopband can be centered on fat frequencies (choosing an appropriate TR) to attenuate fat signal. Moreover a combination of upper and lower profiles (Fig.4) can lead to a better fat attenuation. An abdominal image from a volunteer is shown in Fig.5.

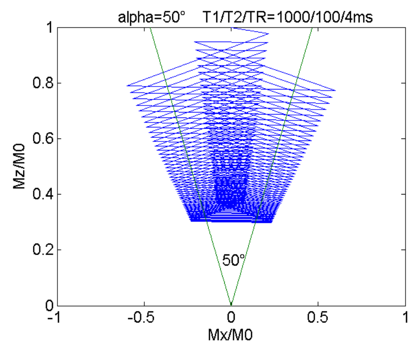

Fig.1 : on-resonance magnetization trajectory.

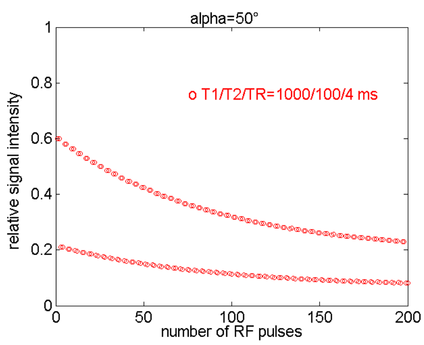

Fig.2 : signal evolution with time.

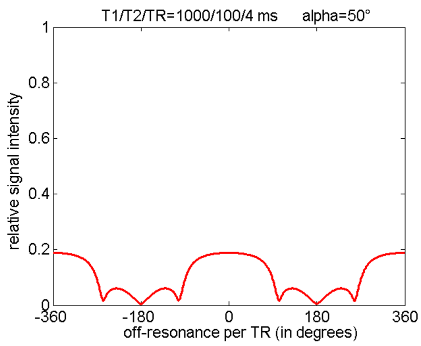

Fig.3 : off-resonance modulus profile of the upper steady state.

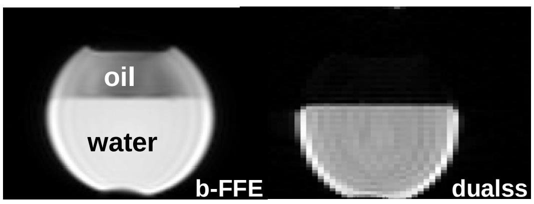

Fig.4 : Phantom experiments with a bottle containing oil and water. (left) standard b-FFE with flip angle α=50°; (right) dual steady-state sequence (middle angle α=50°). Image obtained after modulus subtraction of upper and lower signals. Fat attenuation is clearly visible. TR=2.3ms, TE=TR/2.

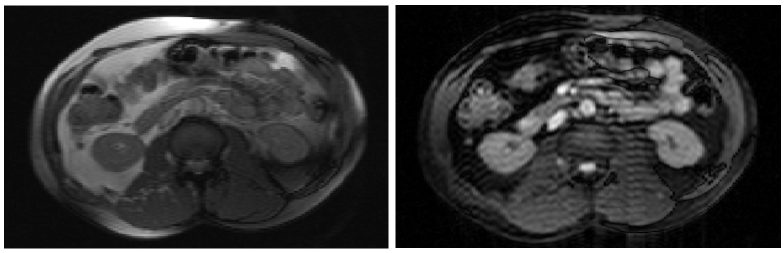

Fig.5 : Abdominal images from a volunteer. (left) standard b-FFE, α=50°; (right) dual steady-state sequence : modulus subtraction of upper and lower signals. TR=2.3ms, TE=TR/2.

Conclusions:

In conclusion we present a dual magnetization sequence that preserves the phase alternation of b-FFE and uses moderate flip angles, allowing fat attenuation. Interestingly similar steady-state results have been recently obtained by a very different approach involving variable RF phase scheme (FS-OSSFP) [2].

References:

[1] Vasanawala SS, Pauly JM, Nishimura DG [1999] Magn.Res.Med.42:876-883; [2] Overall WR, Nishimura DG, Hu BS [2003] Magn.Res.Med. 50:550-559.