Spectrally-Presaturated Modulation (SPM): an Efficient Fat Suppression Technique for STEAM-based Cardiac Imaging Sequences

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Introduction: Stimulated-echo acquisition mode (STEAM) is a key pulse sequence in MRI in general, and in cardiac imaging in particular [1,2]. STEAM imaging is based on modulating the magnetization with a certain frequency during the magnetization preparation stage, storing the modulated magnetization in the longitudinal direction until the imaging timepoint, and finally recalling the stored magnetization back for imaging through magnetization demodulation. The STEAM concept involves providing a couple of desirable features: 1) Marking the modulated magnetization, such that it is set apart from other magnetization components that form during the imaging process; and 2) Saving the prepared magnetization from T_2 relaxation, which is an order of magnitude faster than T_1 relaxation in the myocardium. Speeding up the temporal resolution of STEAM-based sequences is desirable, although it is compromised in cases when fat-suppression is applied. In this work, we present an efficient fat-suppression technique (Spectrally-Presaturated Modulation (SPM)) for STEAM-based sequences without affecting the temporal-resolution.

Methods: Figure 1 shows the pulse sequence of the SPM technique. A spectrally-selective pre-saturation pulse is applied before the modulating RF pulses. The resonance frequency of the presaturation pulse is tuned to excite only the protons of the fat tissue. Consequently, only water, but not fat, magnetization is modulated by the STEAM sequence. It is important to note that although there is no longitudinal magnetization component of the fat at the time of the modulation pulse, the transverse component still exists. Therefore, spoiling of the transverse component is required in order to avoid refocusing of the fat magnetization by the subsequent gradients.

In vivo images of a healthy human volunteer were obtained on 1.5T scanner using CSPAMM tagging and black-blood STEAM sequences. Fat suppression in these two applications was achieved using the following fat-suppression techniques: 1) SPM, 2) spectral-spatial selective-pulses (SSSP) technique using 1-3-3-1 combination of RF pulses [3,4], and 3) chemical-shift selective (CHESS) technique [5]. The TR/TE for the SSSP, CHESS, and SPM were 22.3/4.5, 31.5/1.1, and 15/1.1ms, respectively.

Results: Figure 2(a) shows a short-axis view of CSPAMM cardiac images acquired at four different cardiac-phases. The SPM technique resulted in the highest SNR comparable to that when no fat-suppression was implemented. The SSSP technique resulted in low SNR, especially at later cardiac phases. Figure 2(b) shows STEAM images of the same slices in Figure 2(a). Although the same shimming settings were used for the SPM technique, it did not show the artifact observed with CHESS. The SPM technique allowed for acquiring 40 cardiac phases compared to 19 and 28 phases for the CHESS and SSSP techniques, respectively. The resulting specific-absorption rate (SAR) level was 0.2, 0.37, and 0.15 W/kg for the SPM, CHESS, and SSSP, respectively.

Discussion: The results shown above verified the potential of the SPM technique as an efficient method for fat suppression in different STEAM-based applications. The high temporal resolution provided by the SPM technique has many advantages for cardiac imaging. First, it increases the number of cardiac phases that can be captured, especially when a longer spectral RF pulses is used to reduce the pulse's bandwidth and achieve better fat suppression without affecting the water signal. The increased number of cardiac phases leads to accurate measurement of key functional parameters, e.g. peak systolic strain and time-to-peak strain. Second, the performance of the algorithms that track myocardial motion, e.g. from the CSPAMM tagged images, could be improved due to the high temporal resolution provided by the proposed technique. For example, the phase wrapping problem would be less likely of an issue with tracking techniques such as displacement encoding (DENSE) and harmonic phase (HARP).

The SPM technique resulted in the highest SNR among the studied fat suppression techniques. Moreover, the SNR did not drop with time as it did with the SSSP and CHESS techniques. This is mainly because in SPM, the fat suppression module is applied only once at the beginning of the sequence, compared to repeated application of the module in the other techniques. Another advantage of the proposed technique is that, due to the elimination of the extra fat saturation pulses before each excitation RF pulse, the SAR level of the SPM technique is significantly reduced compared to that of CHESS. The reason for the low SAR of the SSSP technique is splitting the excitation RF pulse into a series of four smaller RF pulses. However, this feature comes at the expense of increasing TE by about 4 folds compared to SPM or CHESS, which inversely affects image quality.

Conclusions: An efficient technique has been developed for suppressing fat signal in a number of STEAM-based imaging techniques. The proposed technique improves the temporal resolution of the acquired images without sacrificing SNR, SAR, or scan time, which could result in accurate parameter measurement and improved image analysis.

References: [1] JMR 64(81):81-93; [2] MRM 22(1):133-142; [3] MRM 15(2):287-304 ; [4] MRM 40(2):194-202; [5] Phys Med Biol 30(4):341-344.

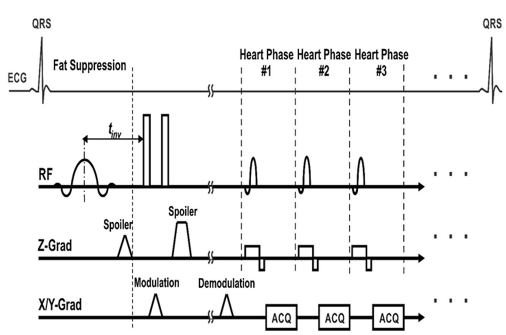

Figure 1. Pulse sequence of the SPM technique. Spectral-selective RF pulse is applied only once prior to magnetization modulation to suppress the fat signal. Therefore, there is no need to implement fat suppression in each heart phase, which improves temporal resolution and SNR and reduces SAR.

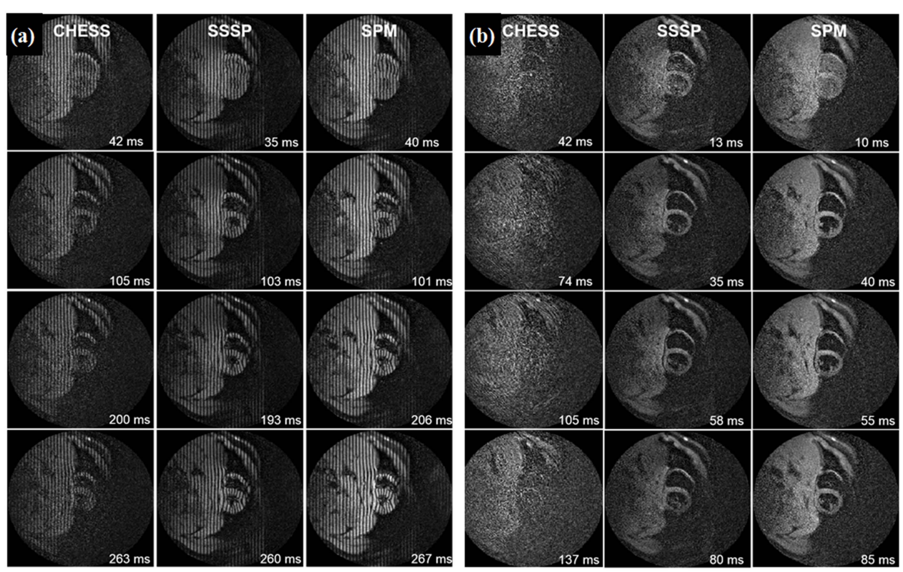

Figure 2. (a) CSPAMM and (b) black-blood STEAM images acquired at different times in the cardiac cycle with CHESS (left), SSSP (middle), and SPM (right) fat suppression.