Integration of magnetization preparation sequences into SSFP sequences: A fat saturation example.

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Introduction: Steady state MRI-sequences are widely used for clinical applications. In particular, balanced steady-state free precession (b-SSFP) has become increasingly important for diagnostic and interventional imaging [1]. However, contrast modification by using magnetization preparation sequences, (like fat suppression or regional signal suppression), requires the use of transient steady state sequences, i.e. after applying a preparation sequence the magnetization is obtained during the transient phase of the steady state [2]. Since the magnetization preparation has to be interleaved frequently, the steady-state has to be re-established after each preparation sequence. A number of techniques have been proposed to ensure a short transition into the steady state in order to avoid amplitude and phase modulation of the steady magnetization and thus imaging artifacts [3,4]. However, none of these techniques can ensure a perfect transition. Here, we proposed a new technique that integrates magnetization preparation into balanced steady state free precession (b-SSFP) sequences without the need to stop and then reestablish the steady state. An application to fat saturation is presented, but the method could be also applied to other magnetization preparation sequences, e.g. regional saturation (REST) or spin labeling.

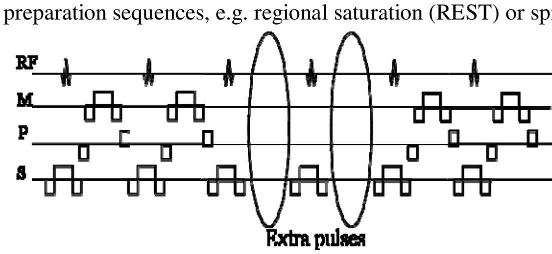

Figure 1. Integration of magnetization preparation into SSFP sequence is possible by performing extra RF and gradient pulses.

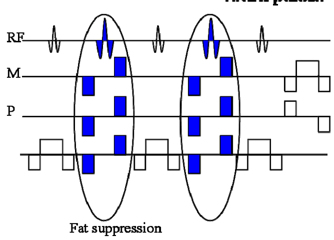

Figure 2. A fat saturation sequence can be integrated into the steady state. Pairing the complete sequence in consecutive TR reduces eddy current artifact due to the additional pulses.

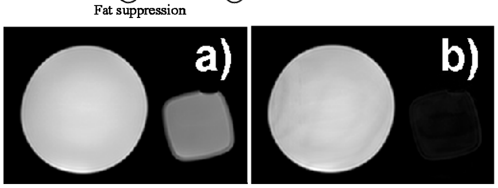

Figure 3. A phantom consisting of a bottle of water and a bottle of oil was scanned without (a) and with the proposed fat saturation technique. Notice the reduced fat signal in b).

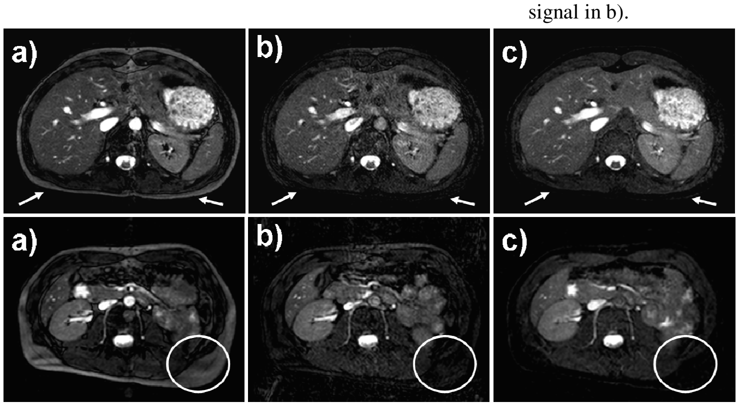

Figure 4. Abdominal images obtained from a healthy volunteer without (a) fat suppression. (b) with the proposed fat saturation technique and (c) with a fat suppression technique similar as described in ref 2. Notice the reduced fat signal in b) and c), however some artifact are observer in the lower row using the proposed approached.

Materials and Method: To integrate magnetization preparation sequences within the normal steady state, we propose to perform extra pulses between the normal excitation scheme (see Fig 1) every certain time interval. These extra pulses can be used to modify the contrast of specific tissues within the same or at a different location as the imaging volume, whilst preserving the steady state. Figure 2 shows an example of a fat suppression sequence, where a frequency selective RF pulse and gradient spoilers were integrated in a b-SSFP sequence without disturbing the steady state. The RF pulse was designed to have the minimal duration to fit into a given TR. For instance for a TR= 5ms the duration of the rf-pulse was set to 2.4 ms resulting in a bandwidth (HWHM) of 725 Hz, which is not enough to differentiate between water and fat. To overcome this limitation the center frequency of the RF pulse was shifted by 850HZ. Gradient spoilers in all three directions were designed so that they only spoil the magnetization exited by the extra rf-pulse (figure 2). In order to reduce eddy current artifacts produced by the extra gradients and extra phases introduced by the rf-pulse. the complete scheme was paired, This ensures that all accumulative phases are compensated by the nature of the rf-phase cycling of b-SSFP sequences [4]. **Experiments:** The modifications were implemented on a 1.5 T Philips clinical scanner. A phantom consisting of a bottle of water and oil was scanned using the proposed technique with and without the extra pulses. Moreover, abdominal images from volunteers were obtained. Scan parameters were: one single transversal slice, 8 mm thickness, in-plane resolution of 1.7mm^2, TR/TE = 5/2.5 ms , flip angle 60°; The fat saturation sequence was repeated every 70 ms, the flip angle of the extra RF pulse was set to 90°-120°). For comparison, additional images were acquired using a fat suppression technique similar as described in ref 2.

Results: The images obtained from the phantom scans are shown in figure 3 without (a) and with (b) the extra pulses for fat suppression. It is observed a reduced fat signal in b), and also a few distortions in the water. In figure 4 abdominal images obtained from a volunteer are shown, (a) without fat suppression, b) with new fat suppression integrated into SSFP and c) with the fat suppression technique similar to ref 2. It can be seen a reduced fat signal in b and c (arrows and circle areas). However some level of artifacts can be appreciated in the second row using the proposed technique.

Conclusions and Discussion: We have introduced a new method that allows us to integrate magnetization preparation sequences into SSFP sequences without disturbing the steady state. An application for fat saturation has been implemented and demonstrated in phantom and *in vivo*. Results showed a reduced fat signal, but also some artifacts were observed. These could have been caused because the water signal was also influenced by the extra rf-pulse, since its bandwidth was not perfectly limited to fat. The integration of extra gradient pulses into the steady state requires a careful design and some considerations have to be taken into account: (a) The phase introduced by the extra gradients has to be zero (balanced gradients), and (b) phase effects due to eddy currents of these additional gradients can be reduced by pairing them in consecutive TRs [6]. Moreover, the extra RF pulse changes the effective magnetic field B_{eff}, which introduces an additional phase to the magnetization. However, this can also be reduced by paring the RF pulse. Other magnetization preparation techniques that do not require a spectral RF pulse can also benefit form this method, such as regional saturation (REST) or spin labeling. Moreover, the integration of an extra slice for imaging or navigation can be integrated by performing a spatial selective excitation.

References: 1 Scheffler K et al, Eur Radiol 2003;2 Scheffler K et al, 2001; 3 Deimling M et al ISMRM 1994.;4 Hargreaves BA et al,MRM 2001; 5 Bieri et al, MRM 2005.