Fast dynamic fat-water separation using shorter spatial-spectral excitation and novel temporal acquisition

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\textbf{Introduction:} Many dynamic applications can benefit from reliable fat-water separation. Examples include temperature monitoring for ablation therapy (where fat signals can corrupt temperature measurements) and cardiac imaging (where fat infiltrations can indicate disease). Spectral-spatial pulses (SPSP) \cite{1} are a common way of exciting only the water or fat content of an imaged slice or volume. However, the duration of SPSP pulses may be as much as 10 ms or more, making them impractical for short-TR sequences. Furthermore, their fat-water separation properties may be degraded by $B_0$ inhomogeneities. A different fat-water separation technique, related to the UNFOLD temporal strategy \cite{2}, is combined here with a SPSP pulse. The duration of our SPSP pulse was reduced to only about 2 ms, making it readily compatible with most short TR/TE sequences. Fat signals imperfectly suppressed by the short pulse were further suppressed by the temporal strategy. The resulting hybrid approach should outperform SPSP pulses in the presence of field inhomogeneities and/or in cases where pulse duration must be significantly reduced, and outperform the temporal scheme from when very dynamic motion is present.

\textbf{Methods and Results:} The SPSP pulse was designed using a 2DRF pulse library \cite{www.ncigt.org}. TE was made to vary by $ATE$ with a periodicity of 4 frames $\{0, 0.8\mu s, 0, 0.4\mu s\}$ while TR was kept constant. Due to the offset frequency of fat ($\nu_f$), the $ATE$ variations induced periodical phase variations of $2\pi\nu_f ATE(t)$ in the fat signal. These phase variations acted as a ‘fingerprint’ in identifying fat signal through temporal processing. Following an FFT along the time axis, fat signals were identified using an approach closely related to a matching pursuit algorithm \cite{3}. The proposed strategy for fat-water separation was implemented on a SSFP sequence, and tested at 3T using a moving phantom and in vivo free-breathing abdominal imaging. For both phantom and abdominal imaging, a 3*680\textmu s SPSP pulse was used. The phantom moved back-and-forth along the S/I direction over a range of 2 cm, with a periodicity of about 5s. The phantom’s motion is evidenced by the changes in radius for the fat compartment, which consisted of olive oil in a tapered bottle (see Fig. 1). Figure 1 shows the phase image for time frames 1-16. The phase variations through all frames are plotted in Fig. 2 for the two pixels highlighted in Fig. 1. Figure 3 compares images from a regular RF pulse (Fig. 3a), the SPSP pulse without the temporal scheme (Fig. 3b), the fat signal imperfectly suppressed by the SPSP pulse but identified as fat by the temporal scheme (Fig. 3c), and the final fat-suppressed result where both the SPSP pulse and the temporal scheme contributed to the suppression (Fig. 3d). For all time frames, the water/fat ratio was more than an order of magnitude better using the hybrid approach compared to the SPSP pulse alone (Fig. 4). Figure 5 shows in-vivo free-breathing abdominal results, using an 8-channel torso array, where the proposed approach was used for fat suppression. The short SPSP fails partly in subcutaneous fat suppression because of the susceptibilities near the boundary. By combining the temporal processing at the reconstruction stage, the residual fat is successfully removed.

\textbf{Discussion:} SPSP is sensitive to field inhomogeneity (see Fig. 5b and Fig. 5e) but insensitive to motion. On the contrary, temporal processing is more sensitive to motion than inhomogeneity, as sudden motion may partly confuse the temporal encoding scheme (e.g., see Fig. 3c near the boundary). By combining these two strategies, their respective strengths can be combined, and their individual weaknesses overcome. This novel fat-water separation technique is promising to benefit fast dynamic imaging applications. \textbf{Acknowledgement:} NIH grant 1U41RR019703-01A2