FrequencySelectiveBalancedSSFPImagingwithRandomisedTR

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SYNOPSIS
The balanced SSFP signal amplitude shows strong dependency on off-resonance frequencies (banding artifact). Several methods have been proposed to broaden the stopband for fat/water suppression, however, a suppression is not possible for the whole range of off-resonance frequencies. Here we present a method that accomplishes the frequency selection by randomizing TR for each sequence repetition step and acquiring several acquisitions. It offers selectivity only to the on-resonance signal and suppresses off-resonance frequencies. The method is useful for applications which require averaging, such as low gamma nuclei CSI due to low SNR.

INTRODUCTION
The frequency response function (FRF) of balanced SSFP sequences (TrueFISP, FIESTA, b-FFE) show a high sensitivity to the dephasing angle $\theta$ during TR. Experimentally it emerges as periodic banding artifacts in balanced SSFP imaging. The dark parts represent a narrow stop-band at a certain $\theta > 2\pi\xi/(\xi + 1)$, achieved for $\xi$ which is only sensitive to on-resonance signals and cancels out the signals of all off-resonance frequencies. This is achieved by randomising the repetition time TR down the signal for all off-resonance frequencies would be averaging over N full k-space acquisitions and randomising TR from acquisition to acquisition from TR to $\xi$TR. This results in a dephasing from $\theta$ to $\phi$. The FRF for $N = 50$ is shown in Fig. 1a) as bold line. Significant suppression of off-resonance frequencies is achieved for $\theta = 2+540°/(\xi + 1)$, however the signal still shows a nonvanishing amplitude. Frequency selectivity can be improved by varying TR from repetition to repetition within one k-space acquisition and averaging over N acquisitions thereafter. The FRF for a randomised TR after 500 repetitions and 1 acquisition is depicted in Fig. 1b). Steady state is only built up for on-resonance frequencies, while the signal shows strong off-resonance amplitude and phase fluctuations. By averaging over N acquisitions the off-resonance signal can be damped down to zero. A simulation for $N = 500$ averages is shown in Fig. 1c). Compared with Fig. 1a) it shows superior frequency selectivity, offering signal suppression for $\theta = 2+180°/(\xi - 1)$ (in Fig. 1a this point only appears as a narrow gap at $\theta = 90°$) and complete cancellation for all off-resonance spins while total acquisition time remains unchanged.

RESULTS
2D Phantom experiments were performed on a Siemens Sonata 1.5T System. To randomise TR a waiting time was implemented symmetrically around the imaging gradient pulses to keep the echo time at TR/2. The RF excitation scheme was $\omega\alpha/2$, $-\omega\alpha/2$ with $\omega = 60°$. The images in Fig. 2a) and 2b) were taken with randomised TR from 3.15ms to 9.45ms and averaging over 50 acquisitions. A shim gradient (0.15mT/m) in readout direction was applied to create a range of off-resonance frequencies. Fig. 2a) shows the image taken with randomising TR only over the acquisitions, corresponding to the simulation in Fig. 1a). Fig. 2b) shows randomising TR over the repetitions and acquisitions. As in the simulation in Fig. 1c) the gain in frequency selectivity is obvious. In Fig. 2c) the TR was randomised from 3.15ms to 7.9ms. In Fig. 2c) TR was randomised over the acquisitions, showing the fat resonance falling into the lobe at $\theta = 180°$ in Fig. 1a) and appearing bright in the image. In Fig. 2d) the fat resonance is suppressed due to the higher frequency selectivity.

DISCUSSION
The method of randomising TR and averaging over a number of acquisitions offers a tool for effective frequency selection when complete signal suppression over a range of off-resonance frequencies is required. The drawbacks are the long acquisition time due to the intrinsic need of averaging and slight eddy current artifacts. Therefore for only fat/water suppression more efficient methods exist [1,2]. However, the method can be useful in tasks which require several acquisition to improve SNR, for example low gamma nuclei CSI [3]. The frequency selection can also be shifted by applying appropriate RF pulse phase patterns. Total acquisition time can be lowered by k-space weighted averaging.

REFERENCES