Objective
When multiple-acquisition phase-cycled balanced steady-state precession (SSFP) acquisitions are combined, the phase profile is approximately linear with off-resonance. In this study, we have investigated if this behavior can be exploited to allow thermal measurements based on the proton resonance frequency (PRF) shift with balanced SSFP.

Methods
Computer simulations were performed to study the phase behavior (linearity and slope) for different imaging parameters (T1, T2, TR, flip) and number of phase cycles (n=2 with Δφ = 0°, 180°; n=3 with 0°, 120°, 240°; n=4 with 0°, 90°, 180°, 270°). In addition, the temperature dependent phase difference, $\Delta \phi_{PRF} = \frac{\Delta \phi(0)}{\alpha_{0}}$ with $\Delta \phi(0)$ being the phase change with temperature and $\alpha_{0}$ the uncertainty in the phase difference image, was determined and compared to a spoiled gradient echo sequence (SPGR).

The MR temperature maps of an agar phantom were acquired at 1.5T with the proposed balanced SSFP sequence (TR=10 ms, TE=TR/2-5 ms, flip=50°, n=2-4 phase cycles) and compared to SPGR images (TR/TE=30/15 ms). A temperature change was simulated by creating a linear field change of multiples of 0.64 Hz/cm with the gradient shim in the x-direction. With a temperature induced PRF change at 1.5T of ΔT = 0.64 Hz/cm, this corresponded to a maximum temperature change of 60°C at the edges of the phantom.

Results
Results of the simulations are provided for T1/T2=800/100 ms, which are similar to prostate values, flip=40° and T2=TR/2-5 ms. Figure 3 shows the profiles for n=2 phase cycles and Fig. 4 for n=3 phase cycles. For these values, averaging n=2 images leaves a small amount of ripples in the phase profile which disappears for n=3 averages. Increasing the averages to n=4 did not lead to any noticeable improvement in linearity, but would increase imaging time. In general, the amount of ripple in both magnitude and phase decreases significantly as the flip angle increases or as the T2/T1 ratio decreases [1].

Discussion
Further studies are needed to evaluate if and in which tissues and applications the proposed method is better suited to monitor temperature than an SPGR sequence.

References

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