Phase cycled steady state free precession with multipoint fat-water separation

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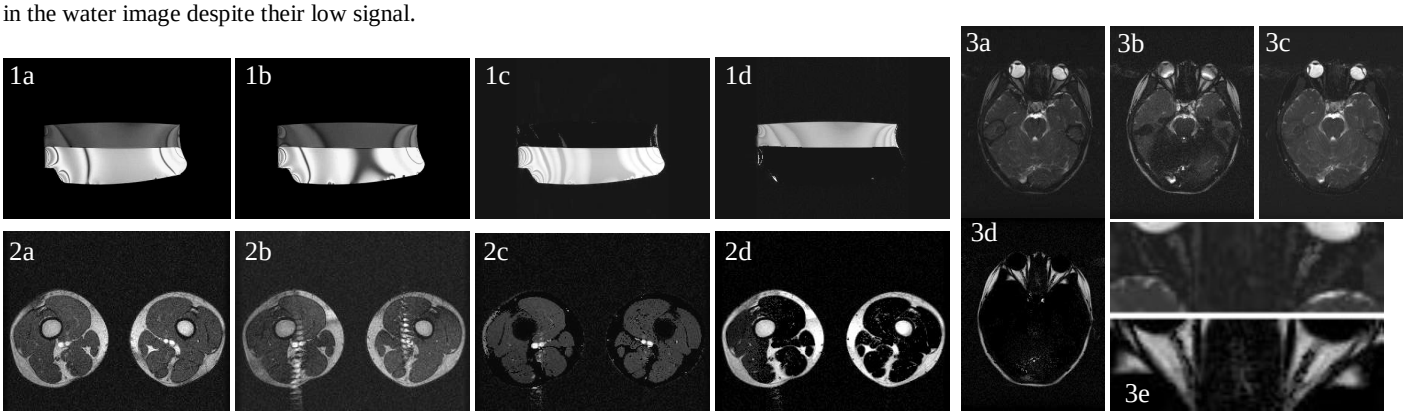
Introduction: Steady state free precession (SSFP) imaging offers high fluid and fat signal independent of repetition time, which often necessitates the distinction between the two spin types. Some proposed techniques rely on the spectral response of the imaged spins to the particular pattern of excitation phase and flip angles [1-3]. However, these techniques rely on an extremely short repetition time (2.2-2.4 ms), which places high demands on resolution and excitation pulse characteristics. More recent methods have distinguished lipid and water with the phase of the acquired signal, either with several acquisitions with incrementing TE's [4], or with a single echo at a specific TE and TR[5]. While potentially more robust and less demanding on gradient hardware, all of these methods are susceptible to field inhomogeneity, producing imperfect fat-water separation or banding artifacts at longer repetition times.

In this study, we evaluate the feasibility of combining phase cycling [6] with a multiecho SSFP sequence for fat-water separation. While TR is extended by the acquisition of additional echoes, phase cycling can reduce the associated artifacts, and greater proportion of time is spent acquiring signal between rf excitations relative to the multi-acquisition method. While a variety of field correction algorithms may also be applied, this work develops the details in implementing such a sequence.

Methods and experiments: An SSFP sequence was modified by inserting two additional readout lobes before the refocusing lobes, acquiring three full echoes per TR. The polarity of the center readout lobe was opposite that of the other two. Each slice was acquired with two RF cycling schemes: once with 180° RF phase alternation as in conventional SSFP, followed immediately with another full scan with constant RF phase for each TR. The sequence was evaluated with a 1.5 Tesla clinical scanner (GE Medical Systems, Milwaukee, WI) in the head and thighs of normal volunteers, and a cylindrical oil and water phantom. Longer TR values than necessary were applied to observe effects of field inhomogeneity. For the head and phantom slices were acquired with a standard birdcage head coil, imaging parameters were: TE = 2.26 / 4.34 / 6.42 ms (spacing = 2.08 ms), TR = 11 ms, FA = 60°, FOV = 260x195mm, acquisition matrix = 256x192, slice thickness = 5 mm, receiver bandwidth = 125 kHz, 1 signal average, acquisition time = 4.3 sec for both cycles of a single slice. Slices in the thigh were acquired with the body coil using identical parameters except TE = 2.0 / 3.9 / 5.8 ms (spacing = 1.9 ms) and FOV = 360x270mm.

Fat/water separation on the three echoes of each phase cycle was performed with a separate 1.2 Ghz personal computer using Matlab software (MathWorks, Natick, MA). First, a simple linear phase correction [7] was applied to each image. Since DC phase offset errors may occur from the linear phase correction as well as the differences in readout polarities, relative phase evolution maps were generated for the two intervals between the three echoes. For each interval, a small phase evolution shift was applied if necessary to satisfy the assumption that the phase differences during this interval was within $\pm\pi$. The two phase evolution maps were then averaged, and these phase values were used to generate complex pixel values. Since relative phase evolution between water and lipid for both time intervals is close to pi, a simple phase correction scheme was applied, somewhat similar to that by Hargreaves et al. This was performed by choosing a line passing through the origin that maximizes the number of pixels from the averaged phase evolution map whose phase lie within $\pm\pi/8$ radians of the line. Finally, the pixels were separated into two groups based on the radial proximity of their phase evolution to that line. Optionally, pixels close with near zero phase evolution between the first and third echo in the acquisition without rf chopping were set to zero to reduce flow artifacts [8]. With fat and water images generated for both phase cycles, a maximum intensity projection between the phase cycles produced the final fat and water images.

Results: Images of the phantom, a pair of thighs, and a head are shown in figures 1, 2, and 3, respectively. For each subject, two phase cycle images and reconstructed water and lipid images are shown. Reduction in through-plane flow artifacts was observed in thigh images (2b vs. 2c). A magnified comparison of the area behind the eyes of the head image is shown if figure 3e, demonstrating preservation of the optic tract and muscles in the water image despite their low signal.



Conclusions: Multiecho SSFP is capable of providing sufficient quality phase information for fat and water separation, while the addition of phase cycling will reduce some of the artifacts caused by field inhomogeneity. Areas of rapid change in resonance offset angle may experience imperfect intensity correction from phase cycling. While flow artifacts are more pronounced without phase cycling, artifacts tend to be of a consistent phase. More advanced algorithms may involve field correction and orientation filters, which could better correct such intensity bands and / or flow artifacts associated with SSFP.

References

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