A SINGLE POINT, ECHO TIME INDEPENDENT WATER/FAT SEPARATION METHOD

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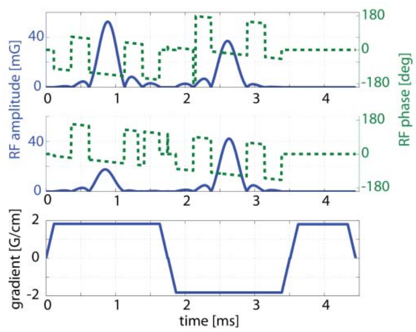
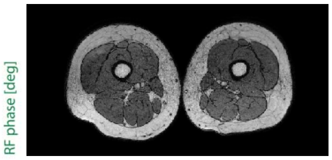
Purpose: Dixon sequences [1] are used to characterize disease processes, obtain good fat or water separation in cases where suppression fails and to obtain pseudo-CT datasets, e.g. [2]. The technique is flexible as the separation takes place by post-processing images obtained with at least two different echo times, which are usually constrained to values where water and fat are in/out-of-phase. The necessity of using multiple echo times to separates water and fat causes prolonged repetition and acquisition times and complicates application in dynamic imaging (e.g. DCE-MRI). Use in acquisition of pseudo-CT datasets ideally requires in-phase images and short echo times to maximize signal from bone, which are mutually exclusive in the usual Dixon technique. This work mitigates these problems using a spectrally selective RF pulse for water/fat separation as was previously proposed by Schick [4]. The pulse imposes a chemical shift selective phase shift cycled over every other phase encoding line, resulting in a spatial shift for either water or fat in the reconstructed image, similar to that in CAIPIRINHA [5]. However, at that time (1) the spectral-spatial selective RF pulses were relatively long (~15 ms) and (2) the method was time inefficient since it needed a factor of two FOV increase in the phase encoding direction to prevent fold-over of water/fat images. Here a modern multi-shift RF pulse design technique [6] is used, that yields much shorter pulses. Moreover, using this algorithm the phase after excitation can be controlled so as to yield in-phase images at arbitrary echo times. Fold-over artifacts resulting from the spatial shift and normal FOV are resolved using the encoding power of a multi-element receiver array.

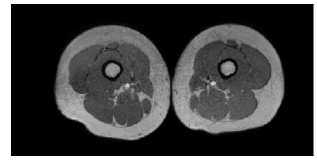
Methods: Measurements were performed on a 1.5T clinical scanner in a healthy volunteer's legs. Two dual channel flexible coils (anterior/posterior) were used for signal reception. The scanner software was modified to allow alternation of two excitation waveforms. RF pulses were designed using a numerical multi-shift algorithm as introduced in [6], which was modified to allow spectral control based on the binomial composite pulses principle [7]. An axial gradient echo image was acquired with T_E/T_R = 2.3/4.7ms, flip angle 20˚, FOV 45x22.5cm^2, matrix 480x216, slice thickness 5mm, yielding an out-of-phase image. An RF pulse with duration of 3.5ms (see (a)) was designed to counteract the chemical shift for fat at this echo time, thus yielding an in-phase image (same scan parameters). A second RF waveform (same duration, also in (a)) was designed that excites fat with 180˚ phase offset with respect to water; the two pulses were alternated for odd and even phase encoding lines (see [5]). This sequence was performed with the FOVs of 45x45cm^2 (also doubled matrix) and 45x22.5cm^2 (all other parameters remained the same). A Dixon image was acquired with $T_{E,1}/T_{E,2}/T_R$=2.2/4.6/7ms. All image reconstructions were done in Matlab (Roemer reconstruction unless indicated otherwise) using the ReconFrame toolbox (Gyrotools, Zurich, CH).

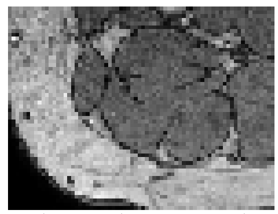
Results and discussion: The out-of-phase gradient echo image (b) clearly shows black lines at water/fat interfaces, which is successfully counteracted using the fat phase compensating RF pulse (c) in-phase image (see also zoomed regions in (d) and (e). The Dixon image is shown in (f). RF pulse alternation yields a fat image offset from the water image by FOV/2 (g) sampled at double sized field of view (sum-of-squares (SoS) reconstruction). With the original FOV the water and fat images fold over (h) (SoS), which can be resolved using in-plane SENSE reconstruction (i). Compared to the Dixon image we achieved excellent water/fat separation with the proposed technique using only a single echo time. In principle it should be possible to extent the method to other sequences for which CAIPIRINHA has been demonstrated such as bSSFP [8] as well as to other metabolites. Spectral-spatial selective excitation as used here is susceptible to B_0 inhomogeneity as well as B_1^+ inhomogeneity effects that may become apparent at higher field strengths (3T and above). This is valid for the usual Dixon sequence as well, although multi-point Dixon methods may be used to take B0 inhomogeneity into account explicitly during reconstruction. The RF pulse design technique used here can take the B_0 and B_1^+ field deviations into account in the pulse design [6].

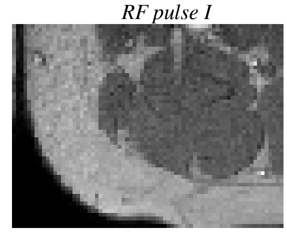


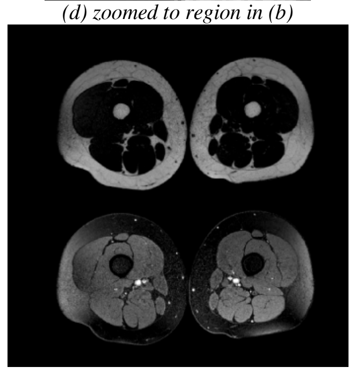
(a) RF and gradient waveforms for pulse I/II

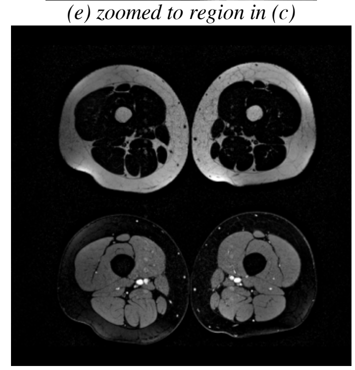

(b) out-of-phase gradient echo

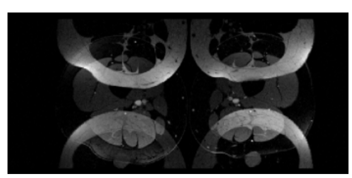

(c) in-phase gradient echo using RF pulse I

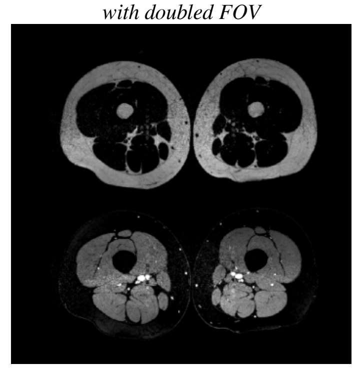

(d) zoomed to region in (b)


(e) zoomed to region in (c)


(f) Dixon image


(g) separation using proposed method with doubled FOV


(h) separation using proposed method with original FOV results in fold-over


(i) fold-over resolved by in-plane SENSE

Conclusion: The proposed technique yields in-phase water/fat separated images at arbitrary echo times that requires only one measurement. In future work the technique may be extended to a multi-band water/fat separation sequence that is able to achieve single point water/fat separation in multiple slices at once.

References: [1] Dixon Radiology 1984 153:189-194; [2] Eggers et al. MRM 201165(1):96-107; [3] Helle et al. Proc ISMRM 2013 p768;[4] Schick MRM 1998 40(2):194-202; [5] Breuer et al.MRM 2005 53(3):684-91; [6] Sbrizzi et al. MRM 2011 66(3):879-85; [7] Hore JMR 1983 54:539-542; [8] Stab et al. MRM 2011 65(1):157-6