

Simultaneous fat-water separated imaging using dual spatial-spectral RF pulses

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Introduction:

Fat-water separation is important in many clinical applications of MR imaging and a number of different approaches have been developed to achieve it. Conventionally, the fat-water images have been acquired separately employing suppression techniques, or with approaches such as Dixon-type methods that employ multiple scans acquired with different TE's. The former procedure has been widely accepted although, because it requires multiple scans, it increases examination times.

Spatial-spectral (SPSP) RF excitation pulses designed to excite only fat or water have been investigated for over two decades [1] and such RF designs today are widely utilized for many purposes, for example, to excite water-only in echo-planar imaging sequences. In this study, we apply two consecutive SPSP pulses designed to separately excite water and lipid protons. Accompanied with proper pre-phasing gradient pairs, the signal from these two groups of excited protons is temporally separated as two independent echoes are formed. Thus, simultaneous imaging of two contrasts is achieved. A spoiled gradient-echo acquisition scheme was adopted for signal acquisition in this study.

Method and Materials:

Experimental Design

In our RF design, the SPSP pulse composed a sinc-like template for the spatial selection along with a Gaussian-shape template that determines the spectral profile. Ten sinc-like sub-pulses of 520 μ s duration each were played out with the pulse amplitudes weighted by a Gaussian envelope. The bandwidth of the spectral profile was 400 Hz. Meanwhile, in a manner similar to that proposed by Feinberg [2], pre-phasing gradient pairs were set so that echoes from spins excited by the two pulses are well separated in time. The temporal separation between the two SPSP pulses and the two readout gradients was kept equal to ensure identical effective echo times for both fat and water. In our current setting, the passband of the first RF pulse was centered at the water resonance frequency and the second pulse at the fat resonance frequency. A schematic plot of our sequence is illustrated in Fig. 1. For comparison, a spoiled gradient-echo sequence (FLASH, Siemens) with water/fat-suppression was utilized with exactly the same scanning parameters (TE/TR/flip angle = 13 ms/31 ms/10°, matrix size = 160 x 160, FOV = 128 mm x 128 mm, and slice thickness = 10 mm). Fat/water suppression in the FLASH sequence is achieved with a phase modulated RF pulse tuned at either the fat or water resonance frequency, which is then followed by strong spoiling gradients. For a simple demonstration, a glass jar filled with water and vegetable oil served as our fat-water phantom. Phantom images were acquired on a 3.0T system (Verio, Siemens Medical Solution, Erlangen, Germany).

Image processing and quality evaluation

A combined image was synthesized by adding up the two complex images acquired with separate acquisitions in our sequence. In order to compare the image quality of our sequence and of FLASH, a region-of-interest (ROI) analysis was performed. The fat-water-ratio (FWR), defined as the ratio between averaged signal intensity within the defined fat and water ROIs, was used to evaluate image contrast.

Results:

Fig. 2 shows a comparison of phantom images acquired with FLASH and with the proposed dual-excitation sequence. Results of ROI analyses of image intensity are listed in the table. FWRs of fat-suppressed (FS), water-suppressed (WS), and non-suppressed (NS) images by FLASH sequence were 17.6%, 175.9%, and 38.9%, respectively. Meanwhile with our proposed method, the FWRs of the water echo (WE) and fat echo (FE) images are 15.6% and 523.5%, respectively.

Discussions and Conclusions:

Compared with FLASH NS image, the synthesized image showed similar image quality as well as image contrast. Meanwhile, better intensity uniformity can be seen in both WE and FE images as compared to images acquired by FLASH. Image artifacts were observed in the FLASH images, especially in the WS image. Compared with the FS image, the FWR was slightly lower in WE image inferred comparable fat suppression.

One important feature of this proposed sequence is that both fat and water signals are acquired within a single TR, and with identical TEs. Temporal information of both signal sources can therefore be simultaneously collected. In the meantime, identical TEs are also valuable since quantification error occurs due to different T2* weighting on signals, when Dixon-type method is applied for fat-water separation. One potential application of our method is the temperature estimation using MR. In the case of MR thermometry, the presence of fat affects the measurement of temperature changes such that it is normally suppressed or excluded [3, 4]. However, fat signal can be valuable as a reference due to low sensitivity of its resonance frequency to temperature changes. Consequently, an inclusion of fat signal could be used for absolute temperature estimation. Our proposed sequence may serve to simultaneously acquire temporal phase variation of both water and fat signals, for dynamic absolute temperature monitoring.

This technique can be regarded as a magnetization preparation method, and is thus compatible with different kinds of fast acquisition approaches such as echo-planar and spiral imaging. By employing acceleration strategies, this SPSP pulse and the corresponding gradient scheme is suitable for dynamic imaging applications.

Reference:

[1] Meyer, CH., et al. Magn Reson Med, 1990. [2] Feinberg, DA., et al. Magn Reson Med, 2002. [3] Rieke V., Pauly KB, J Magn Reson Imag. 2008. [4] de Zwart, J., et al. Magn Reson Med, 1999.

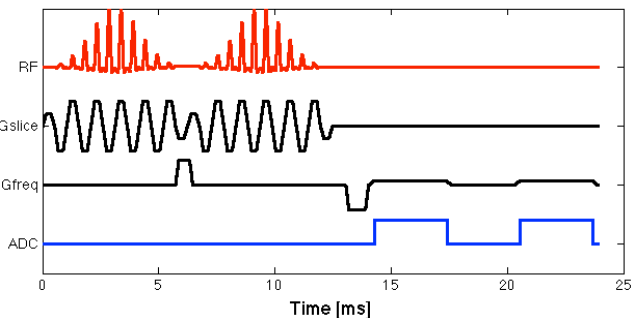


Fig. 1 A sketch plot of our pulse diagram. Phase encoding gradients and spoil gradients are not drawn for simplicity. The pre-phasing gradient pairs were properly designed so that the 1st ADC window acquired the signal excited by the 1st RF.

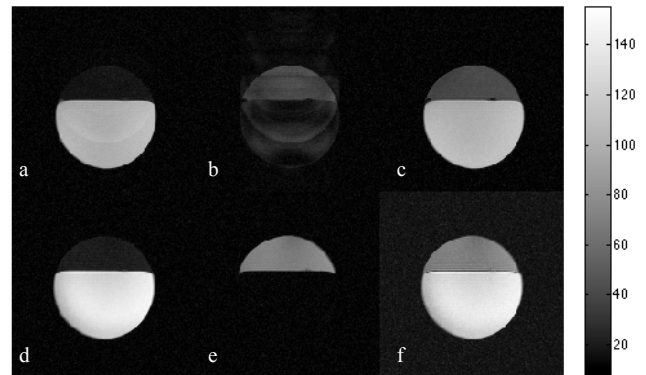


Fig. 2 Upper three: Phantom images acquired using FLASH sequence with (a) fat-suppression, (b) water-suppression, and (c) no suppression; Lower three: (d) water echo image, (e) fat echo images, and (f) the synthesized image acquired with our proposed sequence. Less severe artifact could be easily observed in the water echo image, compared with the water-suppressed FLASH image.

Signal Intensity (au)	FLASH (FS)	FLASH (WS)	FLASH (NS)	Water Echo (WE)	Fat Echo (FE)
Fat ROI	18.0±1.7	38.4±4.1	40.7±2.4	20.7±1.8	69.6±6.4
Water ROI	101.9±4.4	21.8±5.6	104.8±4.9	132.6±11.9	13.3±3.7

Table 1 Results of ROI analysis. (mean ± S.D.)

Abbreviations: NS, non-suppressed; FS, fat-suppressed; WS, water-suppressed; WE, water echo; FE, fat echo.