Fat Suppression and Imaging in EPI Time Course Using Modulation with Thresholded Correlation

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INTRODUCTION: Fat suppression is frequently required in studies that use time-course EPI acquisition including fMRI of the brain and flow velocity imaging in muscle tissue (1). At 3 Tesla, the EPI image of fat is shifted by about 18 pixels and overlaps the region of interest. The fat suppression technique CHESS (2) and its derivatives are often used to suppress the unwanted image. The time required for suppression is comparable to the EPI slice acquisition time. When a suppression sequence is applied once every TR, fat magnetization recovers substantially by the time the last slice is acquired. The suppression for every slice works better but reduces the number of slices that can be acquired in a single TR period. Here we introduce a new method of fat suppression that takes advantage of time-course acquisition and also provides a fat image that registers with anatomic images. The technique uses a correlation method of detection introduced in our laboratory primarily for functional brain imaging (3) that was modified for Velocity Encoding Perfusion (VEP) (1). The magnetization component M_z at the fat resonance frequency is subsequently sinusoidally modulated by a series of RF pulses with 200 Hz spectral bandwidth, one pulse per TR, at frequency Ω with a period of 8 acquisitions, for example. The modulation is between 0 and 90 degrees of flip angle to avoid negative components that would show as positive in the image. The pulse amplitude is varied as $\arctan[(1 + \cos(\Omega \cdot t))/2]$ to achieve a sinusoidal time-course modulation of M_z. A simple Fourier Transform (FT) of a time course of images reveals the fat image at the frequency component Ω as is seen in Fig. 1b. Because the phase of oscillations is known, the correlation technique is used, improving the signal-to-noise ratio (SNR) by $2^{1/2}$. In addition, a correlation coefficient threshold is used to remove spurious signals. An algorithm with variable weighting has been developed to subtract the fat image from all images in the series.

METHODS: The study was performed on a Bruker Biospec 30/60 3T MR scanner. A balanced torque three-axis local gradient coil and birdcage RF coil optimized for extremities imaging were used. Image acquisition and RF tagging pulses were done off line on a computer equipped with a DATEL PCI-417G2 card, running Linux OS. Two D/A converters on the PCI card were used to create I and Q signals that were fed to a quadrature modulator to produce fat modulating pulses synchronously with the EPI sequence. These pulses were mixed with standard RF pulses and sent to the transmitter. The fat image was created from the time series of images using correlation techniques. Acquisition parameters were: TE=27.2 ms, resolution 64×64, BW=125 kHz, FOV=16 cm, slice 3 mm, TR 1 s, fat modulating pulse 40.95 ms, time series: 263 images (only 256 were used).

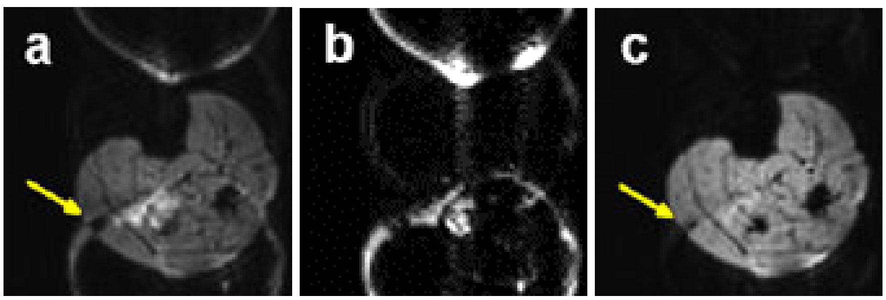

Fig. 1 a) Image with fat b) Extracted fat image c) Image with fat removed

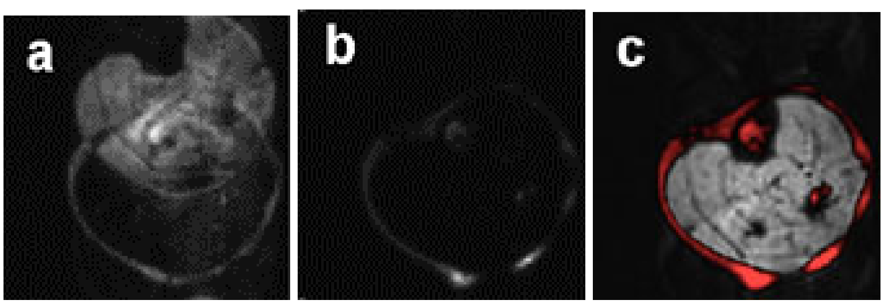

Fig. 2 a) 440 Hz shift b) pure fat image, centered c) superimposed fat image

RESULTS: Fig. 1b shows a correlation image of fat obtained with a correlation coefficient threshold of 0.2. In Fig. 1c, fat was removed from image 1a. The image in Fig. 2a was reconstructed with raw data shifted by 440 Hz. The tissue image shows phase errors but the fat image does not. The fat image, Fig. 2b is at the correct position and was superimposed over the tissue image as shown in Fig. 2c.

DISCUSSION: The method of fat removal described here is equivalent to spectroscopic imaging that discriminates between fat and water. It is robust and oscillations ascribed to fat tissue are visible in a time-course display. There are some areas, shown by arrows in figures 1a and 1c, where fat and tissue signals interfere destructively. The resulting oscillations are around zero level in I and Q space, and are rectified in amplitude images. They contain higher time-course harmonics of the frequency Ω. Several approaches have been developed to address this problem. The method developed here appears to be the first to show pure fat images when using EPI. The thresholded correlation method yields both favorable SNR for fat imaging and improved fat suppression for time-course EPI of water protons.

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