Lipid Elimination with an Echo-shifting N/2-Ghost Acquisition (LEENA)

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Introduction:

Numerous MRI fat suppression techniques have been developed for a variety of imaging applications. Unfortunately, these techniques require additional acquisition time either for specialized RF excitation pulses (1) or for additional k-space acquisitions (2,3). Longer acquisition times limit the use of these techniques for dynamic or real-time MR applications such as cardiac imaging. The development of parallel acquisition techniques offers an opportunity for faster acquisitions. However, the reduction factors achieved in reduced-FOV parallel imaging results in a relative decrease in SNR (4). Recently, a unique full-FOV parallel imaging algorithm was developed to correct for ghosting artifacts from off-resonance spins in EPI acquisitions (5). In this study, a new pulse sequence and image reconstruction technique, LEENA (Lipid Elimination with an Echo-shifting N/2-ghost Acquisition), expands this ghost cancellation procedure to provide rapid, uniform fat-suppressed images from a single acquisition.

Materials and Methods:

The LEENA acquisition was implemented on a Siemens Sonata 1.5T scanner by modifying a FISP (Fast Imaging with Steady-state free Precession) pulse sequence to vary the echo times between even and odd k-space lines (TR/TE1/TE2=12/4.8/6.0ms). The TE variation was selected to allow the fat magnetization to precess 180° between adjacent k-space lines and results in an N/2-ghost of off-resonance (fat) spins. This method differs from the multi-point Dixon methods where the echo-shifting is applied for multiple acquisitions of the same k-space lines. Acquiring the k-space data with multiple coils allows the fat ghosting artifact to be removed by a ghost cancellation algorithm described by Equation 1 below (5).

$$\mathbf{f_g}(x,y) = [\, \mathbf{S}(x,y)^H \mathbf{R}_n^{-1} \mathbf{S}(x,y) \,]^{-1} \mathbf{S}(x,y)^H \mathbf{R}_n^{-1} \mathbf{G}(x,y) \tag{1}$$

where $\mathbf{S}$ is the sensitivity matrix obtained from a previous acquisition, $\mathbf{G}$ is the matrix of ghosted individual coil image sets, and $\mathbf{R_n}$ is the noise covariance matrix assumed to be identity for this initial study. The superscript $^{\mathbf{H}}$ represents the transpose of the complex conjugate, and the matrix in brackets is inverted by a least-squares, pseudo-inverse operation. The resulting images ($\mathbf{f_g}$) represent the 0th (water image) and 1st ghosts (fat image), respectively. However, these intermediate images can display non-uniform fat suppression and water ghosting caused by B_0 field inhomogeneities. In a second step, these off-resonance artifacts were corrected by first algebraically combining the complex images to produce "Water+Fat" ($\mathbf{I_{W+F}}$) and "Water-Fat" ($\mathbf{I_{W\text{-}F}}$) images. A phase map ($\mathbf{\Phi i}$) was generated from these images, and the final, corrected water and fat images were calculated from Equations 2a and 2b (6).

$$\text{Corrected Water Image} = \mathbf{I_{W\text{-}F}} + \exp(-i \bullet \mathbf{\Phi_i}) \bullet \mathbf{I_{W+F}} \tag{2a}$$

$$\text{Corrected Fat Image} = \mathbf{I_{W\text{-}F}} - \exp(-i \bullet \mathbf{\Phi_i}) \bullet \mathbf{I_{W+F}} \tag{2b}$$

Results:

LEENA images of a volunteer's knees (FOV=350mm, matrix=128x256) were compared with a conventional FISP acquisition to determine the effects on SNR, resolution, and contrast. The TE variation results in the fat-aliased LEENA image (Fig. 1a). This image shows similar SNR, resolution, and contrast as the FISP acquisition (Fig. 1b) but with the majority of the fat signal shifted to the edges of the FOV. Subsequent processing of the LEENA image to separate the fat and water phantoms and remove residual ghosting artifact provides uniform fat suppression and minimal off-resonance artifact in both water (Fig. 1c) and fat (Fig. 1d) images.

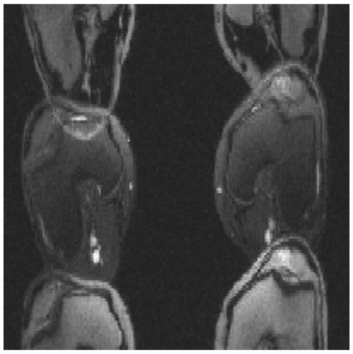

Fig. 1a: Raw LEENA image with N/2-ghosting of fat spins.

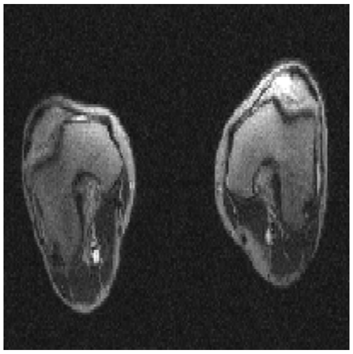

Fig. 1b: Standard FISP image

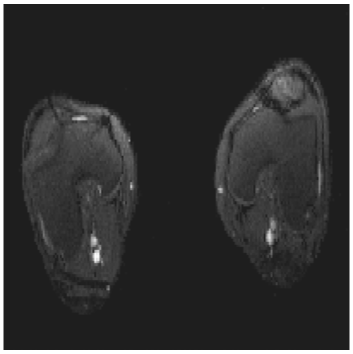

Fig. 1c: Final LEENA image with fat suppression and off-resonance correction

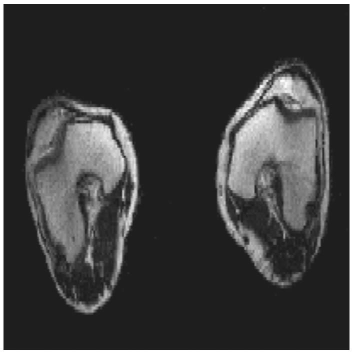

Fig. 1d: Final unghosted fat image with off-resonance correction.

Discussion and Conclusions:

The LEENA method offers more efficient k-space coverage as compared to the repetitive, 2-Point Dixon technique resulting in a 50% reduction in the number of acquired views. Therefore, the resolution and fat-suppression demonstrated in the LEENA images is equivalent to that of the 2-Point Dixon fat suppression methods with half the number of acquired views. This method also improves upon the ghost correction method described by Kellman and McVeigh by using the ghost cancellation procedure to purposely separate the water and fat images. The additional off-resonance correction limits the effects of field inhomogeneities on the uniformity of the fat suppression. The only requirement for the LEENA acquisition is structured echo time variation on sequential views. This could result in increased repetition times for single-echo acquisitions in order to maintain steady-state conditions (2.2ms vs. 5-10ms for binomial or CHESS pulses). However, the LEENA technique is compatible with almost any pulse sequence and could be implemented in multi-echo acquisitions such as EPI with no increase in the acquisition time relative to a standard acquisition with no fat suppression. These improvements make the LEENA acquisition strategy a viable option for current rapid and dynamic imaging applications where fat suppression is beneficial.

References:

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