Signal polarity restoration in IR sequence for T1-mapping in the DGEMRIC technique.

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Introduction:

Loss of glycosaminoglycan (GAG) in cartilage is typically an initiating event in osteoarthritis and non-invasive assessment of GAG concentration could become a biomarker for cartilage degeneration, regeneration, adaptation, and repair [1]. Delayed gadolinium-enhanced MRI contrast (dGEMRIC) is an emerging technique that has shown the promise to assess (GAG) concentration in the cartilage in vivo [2].

Typical implementation of dGEMRIC technique involves application of some sort of inversion-recovery sequence. A series of image acquisitions with varying inversion-times (TI) allows to probe T1 relaxation recovery curve and various 2D and 3D IR sequences variants were proposed to be used in conjunction with dGEMRIC technique. All these methods use one common reconstruction algorithm where modulus of image data for each pixel is fitted to the theoretical T1 recovery curve. This approach effectively halves the original dynamic range of IR signal which in turn can contribute to errors in T1 value estimates.

In this study we present a simple reconstruction algorithm that restores signal polarity in IR sequence for dGEMRIC technique. We applied this reconstruction algorithm with 3D IR gradient-echo sequence for T1 mapping and validated the technique in a phantom study. In addition, we performed T1-map calculations in post osteochondral allograft transplant (OAT) patients and non-symptomatic volunteers using this novel reconstruction method

Methods and Results:

T1 mapping uses a series of 3D IR image data sets with N (N>3) different TI times. T1 relaxation times are typically extracted from a 3-parameter fit using equation for signal Z in IR sequence, where $Z \propto Z_0 \cdot [1-Ae^{-(TI/T1)}+e^{-(TR/T1)}]$ and Z_0, A and T1 are parameters to be fitted. Currently used reconstruction methods use modulus of the available signal Z.

Lets $Z_{lk}(x,y)$ annotates a complex signal in (x,y) pixel of l^{th} slice in the k^{th} 3D data set where (k=1,N).

$$Z_{lk}(x,y) = M_{lk}(x,y)\exp[\Theta_{lk}(x,y) + \Phi_{lk}(x,y)] \quad [1]$$

M_{lk} is a magnitude of a complex signal Z_{lk}

Θ_{lk} is a phase component of the signal that depends on multiple factors such as B_0 and B1 field inhomogeneity, signal delays, etc

Φ_{lk} is a phase factor related to a state of an initial magnetization being positive or negative along z-axis. Note that Φ_{lk} assumes only two phase values 0 or π

In this algorithm the last (N-th) 3D image data set is intentionally acquired with a long enough TI_N value to guarantee that all spins have positive initial magnetization along z-axis. With this assumption the signal for the last 3D set can be written:

$$Z_{lN} = M_{lN}(x,y)\exp(\Theta_{lN}(x,y)) \quad [2]$$

A phase of Z_{lk} signal can be phase corrected using phase information in Z_{lN}. For simplicity we will drop indexes annotating a slice and a pixel coordinates.

$$Z_k Z^*_N = M_k M_N \exp(\Phi_{lk}) \quad [3]$$

Where Z^*_N is a complex conjugate of Z_N, and M_N and M_k are magnitude of signal Z_N and Z_k respectively. A phase corrected Z'_k can then be written as:

$$Z'_k = M_k \exp(\Phi_{lk}) = (Z_k Z^*_N) / M_N \quad [4]$$

This allows us to restore signal polarity using a substitute:

$M_k = M_k$ if $\Phi_k = 0$

$M_k = -M_k$ if $\Phi_k = \pi$

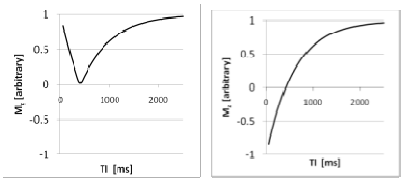

Fig. 1. Currently used (left) and proposed (right) recovery curves for T1-map calculations. T1 relaxation times are typically extracted from a 3-parameter fit using equation for signal Z in IR sequence [1]. Proposed method restores the polarity of the signal which doubles the dynamic range of the signal and decreases a number of faulty fits. The proposed algorithm was implemented in Matlab and results were validated using a phantom consisting of nine saline-filled plastic tubes with various concentration of Gd.

Subjects enrolled in this study were injected with 0.2mmol/kg Gd contrast (Magnavist) and allowed to exercise following the protocol outlined previously by Burstein et al [3]. Imaging studies on Philips 3T MRI scanner using 8-channel knee coil were started 60-80 minutes post Gd injection. Standard T1 and T2 with fat suppression series were acquired in axial, coronal and sagittal planes. For T1-mapping 3D IR FFE sequence was used with TR/TE 5.1/2.6, 52 shots, shot interval 2800, flip 15, FOV 180x160, matrix 256x200, recon voxel 0.5x0.5x1.5, 62mm slab, bandwidth 434 Hz/pixel, resulting in scanning time of 2:26 min per inversion time TI. TI series included 40, 100, 300, 600, 1000, 1500, 2200 ms. To assure consistency of the data sequence tuning was turned off between the series. Magnitude, real, imaginary, and phase images were reconstructed and used in the proposed algorithm to calculate T1-maps.

Fig. 2. Examples of color coded T1-maps in dGEMRIC technique calculated with the proposed reconstruction algorithm.
(A) Post osteochondral allograft transplant (OAT)
(B) Normal volunteer
(C) Asymptomatic volunteer with decreased GAG in the cartilage (red).

Conclusions and Discussion:

We introduced a novel reconstruction algorithm for T1 mapping in dGEMRIC technique. The method restores signal polarity in IR sequence and therefore doubles the dynamic range of data to be used in T1 curve fitting. The algorithm significantly improves reliability of T1 relaxation time fits to an inversion-recovery function and can be applied to any 2D or 3D IR acquisition sequence used in conjunction with the dGEMRIC technique. Proposed image reconstruction method will allow for a decrease of a number of inversion recovery TI points resulting in substantially shorter acquisition times.

References: (1) Gray M.L. et al. J. Ortho. Res. 2008; 3-281-291. (2) McKenzie C.A. et al: JMRI 2006; 24:928-933. (3) Burnstein D. et al: MRM 2001, 45:36-41.