A Hybrid T1/T2*/PRF Pulse Sequence with Improved Spectral Resolution

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Purpose

Real-time multi-parametric MR temperature imaging using a multi-echo gradient-echo (MGE) can simultaneously provide temperature information from proton resonance frequency (PRF) as well as information on tissue damage via dynamic R2* or T1-weighted signal changes from each chemical species [1,2]. Recently, an alternating flip angle was added to the multi-echo acquisition as well to demonstrate similar results in dynamic T1 measurements [3,4]. This work is focused on an MGE sequence which facilitates higher spectral resolution and un-aliasing capabilities along with dynamic PRF, R2* and T1 mapping for interventions.

Methods

Pulse Sequence. The pulse sequence was implemented on 1.5 T & 3 T MRI (Signa Excite HDxt and Discovery MR750 respectively, GE Healthcare, Waukesha, WI). A basic 2D gradient echo sequence (2DFAST) was modified (Fig 1). Variable flip angles for dynamic T1 mapping were attained by modifying the pulse amplitude after the acquisition of each temporal phase. A readout echo train ($n \leq 16$) was added to the sequence with positive readout polarity and a flyback pulse to minimize artifacts. The sequence allows for shifted echo trains with each temporal phase to attain higher spectral resolution of the PRF and T2* decay when combined. E.g., for a total number of four echo trains, the echo trains were shifted by 0, 1/4, 2/4, and 3/4 times the inter-echo spacing. The following pulse sequence parameters were used: $TE_1 = 2.6$ ms, inter-echo spacing = 1.5 ms, TR = 31 ms, matrix = 128×128, field of view = 256×256 mm^2, bandwidth = 1116 Hz/px, acquisition time = 4.0 s · number of flip angles · number of shifted echo trains.

Phantoms. Multiple flip angle measurements were performed using an in-house built relaxation phantom. The phantom was placed in an 8-channel head coil at 1.5 T and measurements for nominal flip angles from 1° to 180° were performed. The T1 values of the phantom were measured with an inversion recovery pulse sequence (TR = 4 s, TI = 50 - 2000 ms). An in-house built fat water phantom was used to demonstrate the spectral PRF and T2* resolution. The solid phantom was made with 1.5% agarose and contained three inclusions made up of equal parts water and lard by volume emulsified with lecithin [5].

Processing. Autoregressive moving average (ARMA) processing [2] was performed separately on each acquisition with low resolution of the echo train to maintain temporal resolution for online monitoring. The results were compared to the high resolution data (shifted echo trains combined).

Results

Signal evolution for multiple flip angles is shown in Fig. 2. Figure 3 presents the signal evolutions of agarose gel and the fat/water emulsion after excitation with a 20° nominal flip angle sampled with 47 ms between echoes (32 shifted echo trains). R2*/ΔPRF were 109 ± 17 1/s / 0.36 ± 0.04 ppm (water) and 107 ± 21 1/s / -3.19 ± 0.04 ppm (fat) for the low resolution data and 103.7 1/s / 0.4 ppm (water) and 105.7 1/s / -3.2 ppm (fat) for the high resolution data. No wrapping of the peaks was observed in the high resolution data.

Discussion

During MR temperature imaging, fast and accurate PRF mapping for each chemical species can be obtained at each time point from ARMA processing of the echo train [2]. By using echo-shifting, higher spectral resolution data can be accumulated over multiple time points. Benefits are higher resolution PRF and R2* measurements that can be used for more accurate measurement of the background temperatures over time. This information could be used for long term temperature and drift correction and combined with similar information from T1 mapping. Additionally, the R2* and T1 maps can be analyzed to assess tissue damage [1,3].

In conclusion, the pulse sequence provides multi parametric information with good temporal resolution and high spectral resolution for real-time MR temperature imaging.

References

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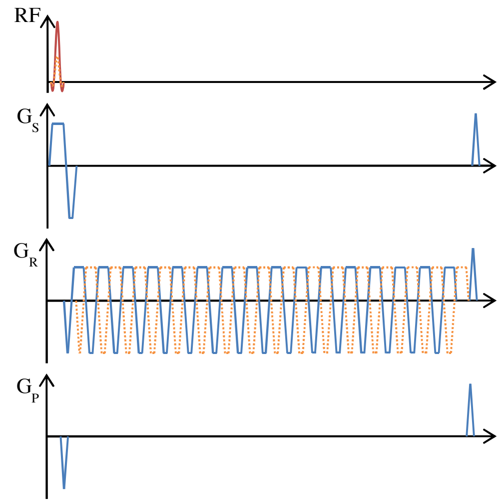

Fig. 1: Pulse sequence diagram. After slice excitation with a variable flip angle (red/orange) an echo train with 16 echoes is acquired. The echo train is shifted (orange) for the same k-space line to attain higher spectral resolution of the T2* decay.

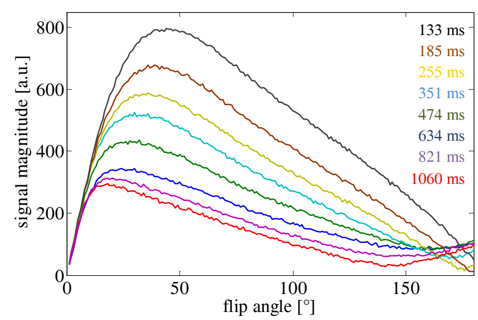

Fig. 2: Variable flip angle measurements over a range of nominal excitation angles from 1° to 180° for 8 tubes with different T1 values.

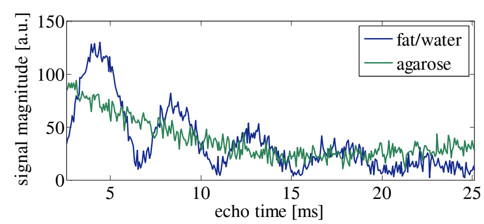

Fig. 3: Signal evolution of T2* decay acquired with 32 shifted echo trains of 16 echoes.

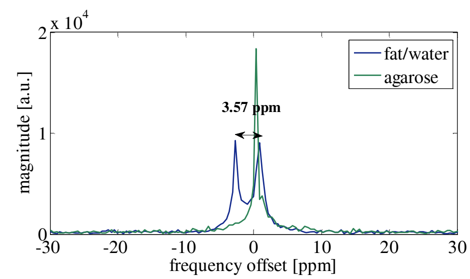

Fig. 4: Spectrum of measured signal shown in Fig. 3.