T_1 Mapping for Breast DCE-MRI Using Inversion Recovery TrueFISP: Assessment of Phantom and *in vivo* Data

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Introduction

This work assessed the use of a 3D inversion recovery (IR) steady-state free precession sequence (True Fast Imaging with Steady State Precession, TrueFISP) for pre-contrast longitudinal relaxation time (T_1) mapping in dynamic contrast enhanced (DCE) MRI of the breast. Results are presented for a phantom and patients with malignant primary breast tumours.

Method

Scanning was performed on a MAGNETOM Avanto 1.5T scanner (Siemens, Erlangen, Germany) using a 3D IR-TrueFISP to image a phantom filled with gadolinium doped water, which supported twelve cylinders, with varying concentrations of doped polysaccharide gels to give different T_1 values. Images were acquired with a 128x128x16 acquisition matrix (frequency-encoding x phase-encoding 1 x phase-encoding 2) and 200x200x32mm field of view (FOV). Non-slice-selective inversion pulses were used with delays between inversion pulses (inter-shot delay,ISD) of 2120ms and 5000ms used with four inversion times (TI) used for each (in the range 270-2000ms for the shorter ISD and 270-3100ms for the longer ISD). The repetition time of the read-out pulses within each echo-train was 4.44ms, and the echo-time (TE) 2.22ms. The length of the train of read-out pulses was proportional to the number of in-plane phase-encoding steps, with the number of inversions, and consequently the imaging time, proportional to the number of through-plane phase encoding steps. In addition to the IR-TrueFISP acquisitions images were acquired using a reference standard sequence (single slice IR spin-echo, IR-SE) with a 10s ISD to allow near complete recovery of longitudinal magnetisation between inversion pulses (for substances with a clinically relevant T_1 (<2s)). Ten TI values (in the range 80-3080ms) and a 128x128 acquisition matrix were used with 5mm slice thickness and a 200x200mm FOV. As this sequence acquired a single line of data following each inversion pulse the disturbance to the longitudinal magnetisation recovery between inversion and read-out was minimised.

Pre-contrast IR-TrueFISP images for T_1 mapping were acquired for seven patients with primary breast tumours who were subsequently treated with neo-adjuvant chemotherapy. A flexible coil was used on the patients' backs in addition to dedicated breast coils to increase signal from the aorta. IR-TrueFISP images were acquired with four inversion times (in the range 400-2000ms), which was found to be the minimum number required to reliably perform polarity restoration when attempting to produce maps using a sub-set of the TIs. Images were acquired with a 3000ms ISD, 128x128x30 acquisition matrix, FOV of 300x300x150mm, TE in the range 1.1-2.1ms and total acquisition time of six minutes.

T_1 maps were produced by fitting signal intensities from images with a range of inversion times (TI) to the model described in equation 1, using a least-squares curve fitting algorithm in Matlab 2009b (Mathworks Inc., Mattick, MA). Fitting was performed on a voxel-by-voxel basis with polarity restoration integrated into the mapping program using a technique based on that described by Bakker *et al*[i]. Typical fits can be seen in ***figure 1*** showing the polarity restored signal intensities from voxels in lesion, aorta and fat, along with the fitted curve.

$$S = kM_0\left[1-\left(1-\cos\theta\right)\exp\left(-\left(TI/T_1\right)\right)\right]$$

Equation 1 - signal intensity in IR images: S=signal intensity, k=constant of proportionality, M_0=equilibrium longitudinal magnetisation, θ=inversion flip angle.

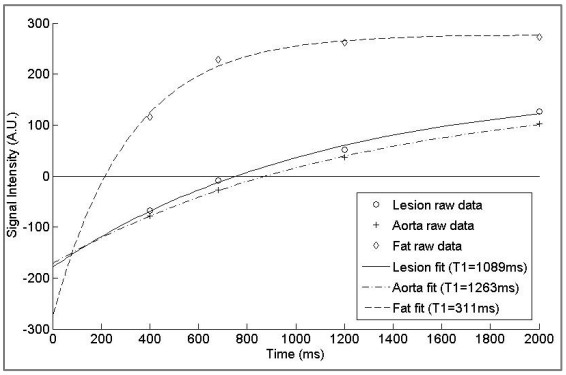

Figure 1 - plots of polarity restored signal intensities and fitted relaxation curves for lesion, blood in the aorta and fat.

Results

In the phantom T_1 values measured with the IR-SE sequence ranged from 216-1755ms. T_1 values from the IR-TrueFISP sequences were compared to those from the IR-SE sequence. The mean difference between results from the IR-TrueFISP sequence and the IR-SE sequence was 1.0% (max=5.1%) for the shorter ISD and 0.8% (max=5.0%) for the longer ISD. T_1 maps from IR-TrueFISP data had more noise than those from the IR-SE sequence with the mean of the standard deviations (as a percentage of the mean T_1) across the twelve cylinders was 9.0% for the short ISD IR-TrueFISP sequence, 6.6% for the long ISD IR-TrueFISP sequence and 1.8% for the IR-SE T_1 map.

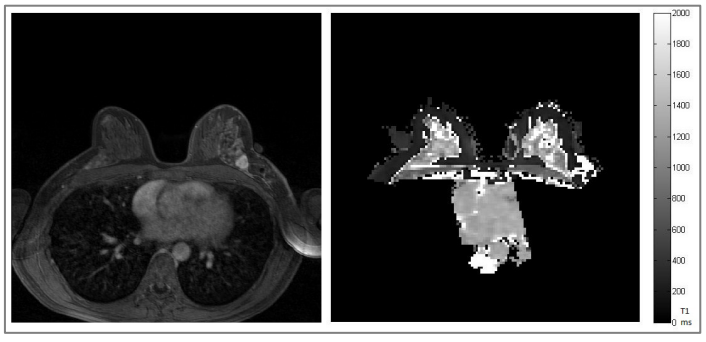

Figure 2 - Left: post-contrast image used for contouring - enhancing lesion in left breast, near chest wall. Right: corresponding T_1 map with 128x128 matrix. Grey scale shows T_1 in ms (0-2000ms). Images were masked (to include breasts and aorta) prior to mapping to reduce computational times.

Visual assessment of the patient T_1 maps (e.g. ***figure 2***, right) revealed unrealistically high T_1 values (typically >5s) in voxels at fat/tumour interfaces. Mean T_1 values for blood in the aorta, lesion and fat were calculated using regions of interest drawn on a 384x384 post-contrast 3D spoiled gradient echo image with fat saturation (***figure 2***, left), acquired as part of the routine clinical protocol, and re-scaled to the appropriate matrix size. Mean pre-chemotherapy T_1 values were (mean ± standard deviation) 1092±104ms for tumour, 1364±97ms for blood and 315±33ms for fat which are consistent with published values[ii,iii,iv] using other IR sequences.

Conclusions

T_1 maps in close agreement with a reference standard sequence have been produced using IR-TrueFISP images of a phantom. This work has demonstrated that accurate T_1 maps can be acquired using a TrueFISP sequence in a clinically acceptable time. T_1 measurements were not reliable at fat/tumour interfaces but it is likely that the extent of the effect could be reduced by using a higher in-plane resolution while maintaining the same scan duration or modifying the sequence to use a TE for which fat and water are in-phase.

[i] Bakker C. G., De Graaf C. N. and Van Dijk P. 1984. *Restoration of signal polarity in a set of inversion recovery NMR images*. IEEE transactions on medical imaging. **3**(4), pp. 197-202
[ii] Cron G.O., Kelcz F. and Santyr G.E. 2004. *Improvement in breast lesion characterization with dynamic contrast-enhanced MRI using pharmacokinetic modeling and bookend T1 measurements*. Magn. Reson. Med **51**(5), pp. 1066-70
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[iv] Rakow-Penner R., et al. 2006. *Relaxation times of breast tissue at 1.5T and 3T measured using IDEAL*. J. Magn. Reson. Imaging **23**(1), pp.87-91