# Rapid Field-Cycling Relaxometric Imaging using Fast Spin-Echo

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## Introduction

Fast Field-Cycling MRI (FFC-MRI)[1] is an emerging technique that adds a new dimension to conventional MRI by making it possible to rapidly vary $B_0$ during a pulse sequence. By doing this it is possible to observe how the NMR relaxation rates of biological tissue vary with magnetic field strength. To date we have used FFC-MRI to perform spatially-selective relaxometry using an adapted PRESS sequence[2] and also relaxometric imaging (a set of $R_1$ images at a range of field strengths) using a gradient echo sequence. Relaxometric imaging collects more information than selected-volume relaxometry but its application is limited by lengthy scan times, since to estimate $R_1$ at least two images (e.g. IR and SR) must be acquired at each field strength. For high resolution imaging, or where images are collected for multiple evolution fields, scan times can become unacceptably long.

In this abstract we describe an adaptation of the well known Fast Spin-Echo pulse sequence[3] for FFC-MRI, named Field-Cycling Fast Spin Echo (FC-FSE). Combining this with a two-point method developed for FFC-MRI that only requires a single image to be collected at each field to estimate $R_1$, we have achieved relaxometric imaging in a fraction of the time that would otherwise be required .

## Methods

Imaging was carried out on a home-built whole-body field-cycling imager with a 59 mT detection field and a coaxial resistive offset magnet which provides field-cycling capabilities[4]. The system uses a commercial console (SMIS Ltd., U.K.).

For each experiment a reference saturation recovery and inversion recovery image are acquired at the detection field. Following this, a field-cycled inversion recovery image is acquired for every evolution field of interest. During the inversion recovery period $B_0$ is rapidly switched to a different evolution field and $M_z$ is allowed to relax at that field for an evolution period, which is typically of the order of $T_1$. The field is then switched back to the detection field and the imaging sequence is performed. $R_1$ is estimated at each field step by measuring image intensity and comparing it against the reference saturation recovery image using a two-point algorithm developed specifically for field-cycling MRI. Image reconstruction and analysis were performed using code written in MATLAB 2012a.

Relaxometry was also performed on small samples using a commercial bench-top field-cycling relaxometer (SMARtracer, Stelar s.r.l., Italy).

## Results

FC-FSE imaging was performed on a phantom containing cross-linked bovine serum albumin (BSA) and the $R_1$ dispersion results were compared against those obtained using multipoint curve-fitting relaxometry performed on the same sample using the commercial bench-top relaxometer. Figure 1 shows that there was good agreement between these measurements. A small positive bias is observed in $R_1$ measurements at low field which can be attributed to the effects of $B_0$ ramps.

FC-FSE images from a volunteer's thighs using an echo train length of 4 (Figure 2) exhibit virtually no artifacts from either field-instability or phase errors. 22 evolution field strengths were covered in the set of images, ranging from 22 mT to 40 mT. A dispersion curve (Figure 3) obtained from the outlined region-of-interest in muscle shows enhanced relaxation at specific frequencies, known as quadrupole peaks, arising due to $^1$H-$^{14}$N cross-relaxation in immobile protein molecules within the muscle. Dispersion curves from the bone/fat region show no quadrupole peaks (data not shown), indicating that there is little protein in those regions. The total scan time was ~30 minutes. In contrast, the same experiment performed using conventional gradient echo relaxometric imaging without the use of our field-cycled two-point algorithm would have required around 4 hours.

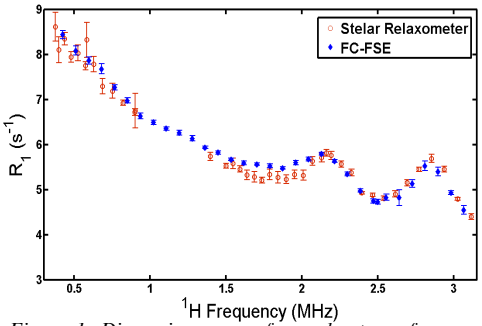


*Figure 1: Dispersion curves for a phantom of cross-linked BSA obtained using the FC-FSE sequence (solid dots) show good agreement with results from a commercial relaxometer (open circles).*

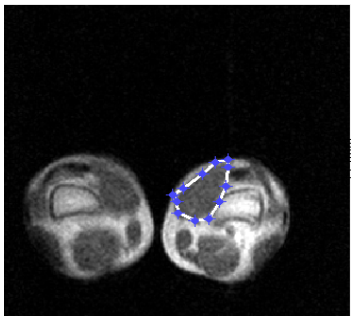

*Figure 2: Image of a volunteer's thighs obtained using the FC-FSE sequence with a speed up factor of 4. RoI delineates muscle, from which a dispersion curve was obtained.*

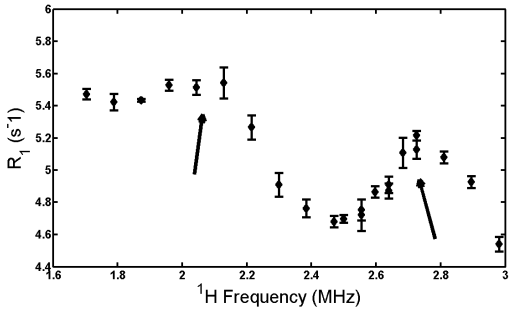


*Figure 3: $R_1$ dispersion curve for the RoI shown in Figure 2. The quadrupole peaks arising due to immobile proteins in muscle are clearly visible (see arrows).*

## Conclusions

This work has demonstrated that relaxometric imaging can be performed up to 8 times faster relative to the basic procedure, with virtually no sacrifice in the accuracy of $R_1$ determination. This paves the way for clinical relaxometric studies with acceptable scan times.

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## References

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