

## Fast field-cycling magnetic resonance imaging

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### Introduction

Most contrast in conventional MRI arises from differences in  $T_1$  between normal and diseased tissues. Several studies on small tissue samples have shown that extra information could be obtained from  $T_1$ -dispersion measurements (plots of  $T_1$  versus magnetic field), but this information is invisible to standard MRI scanners, which operate only at fixed magnetic field (e.g. 1.5 T, 3.0 T). We have developed Fast Field-Cycling Magnetic Resonance Imaging (FFC-MRI) to exploit  $T_1$ -dispersion as a potential biomarker, with the aim of increasing diagnostic potential [1].

### Methods

$T_1$ -dispersion is typically measured using FFC, by switching the magnetic field rapidly between levels during the pulse sequence [2]. In this way, a single instrument can be used to measure  $T_1$  over a wide range of magnetic field strengths. FFC-MRI obtains spatially-resolved  $T_1$ -dispersion data, by collecting images at a range of evolution fields [3].

In our lab we have built a range of FFC-MRI equipment, including two whole-body human sized scanners, operating at detection fields of 0.06 T [4] and 0.2 T [5]. The 0.06 T device uses a double magnet, with field-cycling being accomplished by switching on and off a resistive magnet inside the bore of a permanent magnet; this has the benefit of inherently high field stability during the detection period. The 0.2 T FFC-MRI system (Fig. 1) uses a single resistive magnet which has the advantage of increased flexibility in pulse sequence programming, at the expense of lower field stability during the detection period, necessitating more complex instrumentation.



Figure 1. 0.2 T FFC-MRI scanner at the University of Aberdeen

## Results

Our laboratory is investigating a range of applications of FFC relaxometry and FFC-MRI. We have demonstrated that FFC relaxometry can detect the formation of cross-linked fibrin protein from fibrinogen *in vitro*, via the measurement of  $^{14}\text{N}$ - $^1\text{H}$  cross-relaxation phenomena [6]. We have also shown that FFC-MRI can detect changes in human cartilage induced by osteoarthritis [7]. Experiments on resected tissues from breast cancer patients have demonstrated significant differences in the dispersion curves between normal and diseased tissues [8]. We have performed *in vivo* studies on patients with acute ischaemic stroke; FFC-MRI images exhibited increased intensity in stroke-affected regions, with maximum contrast typically at the lowest field used (0.2 mT) [9]. We have also begun studies on patients with brain cancer and patients with breast cancer. All human studies were conducted following approval of the relevant Research Ethics Committees and with the informed consent of patients.

Other work has focused on speeding up the collection of FFC-MRI images by incorporating rapid MRI scanning methods along with the use of improved pulse sequences and algorithms [10, 11]. Work to improve the hardware and software is ongoing, including the implementation of improved radiofrequency coils [12].

## Conclusions

Our work has shown that FFC-MRI has significant potential for the generation and use of novel biomarkers arising from ultra-low field MRI contrast and from low- and ultra-low field  $T_1$ -dispersion phenomena.

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