RAPID FAST FIELD-CYCLING MRI USING KEYHOLE IMAGING

Peter James Ross[1] and David J. Lurie[1]
[1]*Aberdeen Biomedical Imaging Centre, University of Aberdeen, Aberdeen, Aberdeen City, United Kingdom*

Purpose

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 tissues vary with magnetic field strength - information which can be employed as a useful contrast mechanism. 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 the entirety of k-space is acquired at each field strength. For high-resolution imaging, or where images are collected at multiple evolution fields, scan times can become unacceptably long.

In this work we have made use of the keyhole MRI technique[3] in order to speed up FFC-MRI. By collecting data for the whole of k-space at the beginning of each scan and thereafter only updating the low spatial-frequency region of k-space with each subsequent field-cycling experiment, contrast derived from the FFC technique is maintained while the scan time is dramatically reduced.

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 (MR Solutions, U.K.).

For each experiment, reference saturation-recovery and inversion-recovery images were acquired at the detection field using a conventional spin-echo sequence. Following this, for each magnetic field of interest, the "keyhole" portion of k-space – corresponding to the central 25% of k-space was acquired using a field-cycling inversion-recovery spin-echo sequence. During the inversion recovery period B_0 was rapidly switched to a different field, referred to as the evolution field, and M_z was allowed to relax at that field for an evolution period, typically of the order of T_1. The field was then switched back to the detection field and the imaging sequence was performed.

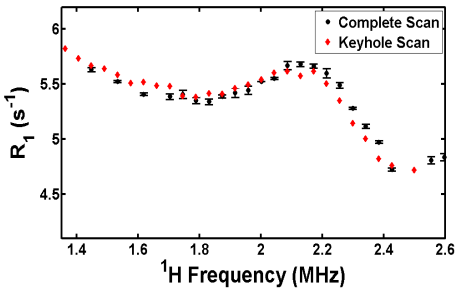

Figure 1: Dispersion curves for a phantom of cross-linked BSA obtained using the keyhole method (red diamonds) show good agreement with results obtained using a conventional field-cycling spin-echo sequence (black circles).

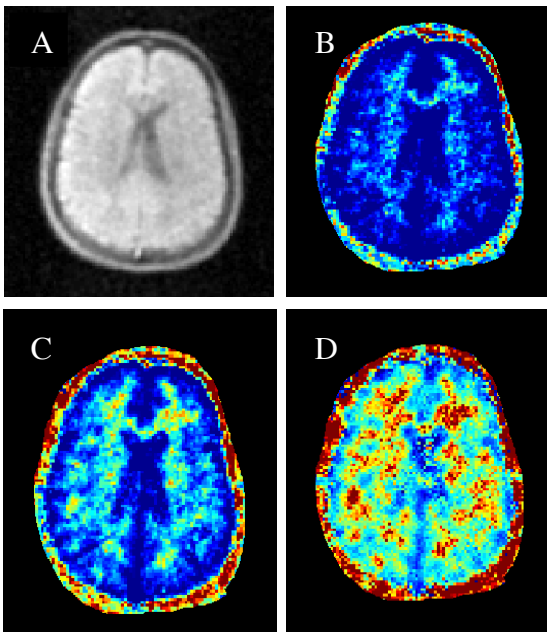

Figure 2. A: Brain image collected from a volunteer at 59 mT
B: Keyhole R_1 map collected at 59 mT
C: Keyhole R_1 map collected at 49 mT
D: ΔR_1 map generated from the subtraction of B from C.
Image parameters were: matrix size = 128x128, FOV = 280 mm, THK = 15 mm, NEX = 6, TE = 30 ms, TR = 1500 ms, evolution time = 200 ms, field-cycling ramp time = 30 ms.

The data were then reconstructed by combining the initially-acquired high spatial-frequency part of k-space with the keyhole central portion of k-space, obtained at each evolution field value. In this way a full-resolution image was constructed at each evolution field value, requiring a scan time of 25% compared to conventional imaging.

The technique was used to derive R_1 dispersion curves (R_1 vs Larmor frequency) from a phantom consisting of cross-linked bovine serum albumin (BSA) across a field range of 1.4 MHz to 2.5 MHz (32 mT to 59 mT).

Brain images were also collected from a volunteer (Fig 2A) in order to validate that the method generated artefact free images *in vivo*. Images were collected for evolution fields of 49 mT and 59 mT (proton Larmor frequencies of 2.1 MHz and 2.5 MHz) and from these images R_1 maps were derived.

All data processing and image reconstruction was performed using in-house software developed using MATLAB R2014a.

Results and Discussion

R_1 dispersion curves derived from BSA using the keyhole technique show excellent agreement with results obtained using a conventional full k-space scan. (Fig.1). The results show a distinct increase in R_1 at close to 2.1 MHz (49 mT). This feature is known as a quadrupole peak, and arises due to ^{1}H-^{14}N cross relaxation effects, which occur at well-known field strengths. The high ^{14}N concentration typically present in protein rich tissue which leads to these peaks can be exploited to generate protein sensitive contrast in FFC-MRI images.

The R_1 maps (Fig. 2B and 2C) generated from brain images show an increase in R_1 at 49 mT, which was used to generate a ΔR_1 map (Fig. 2D) which shows a higher increase in R_1 in predominately white matter regions.

Conclusions

This work has demonstrated that the keyhole technique can readily be applied to FFC-MRI and used to obtain a 4-fold or greater speed up in scan times while still retaining the same contrast as standard FFC-MRI methods. The rich ΔR_1 contrast present in brain images indicates that FFC-MRI has potential application in the characterization of neurodegenerative conditions where subtle changes in R_1, which may not be visible on conventional T_1-weighted imaging, could be used as an early marker of disease.

The reduction in scan time achieved by use of the keyhole technique will significantly improve the applicability of FFC-MRI in volunteer and clinical studies, which we are currently working towards.

Acknowledgements

The author acknowledges funding from the EPSRC through the Centre for Doctoral Training in Integrated Magnetic Resonance.

References

[1] Lurie D.J. *et al*. Fast field-cycling magnetic resonance imaging. Comptes Rendus Phys. 2010;11:136–148.
[2] Pine K.J., Davies G.R., Lurie D.J. Field-cycling NMR relaxometry with spatial selection. Magn. Reson. Med. 2010;63:1698–702
[3] van Vaals J.J. *et al.* "Keyhole" method for accelerating imaging of contrast agent uptake. J. Magn. Reson. Imaging 3:671–5.
[4] Lurie D.J., Foster M.A., Yeung D., Hutchison J.M. Design, construction and use of a large-sample field-cycled PEDRI imager. Phys. Med. Biol. 1998;43:1877–86.