Field-cycling MRI - from free radicals to protein dynamics

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Fast field-cycling (FFC) relaxometry is used in many laboratories, to study the variation of a sample's T_1 relaxation time with magnetic field (known as a T_1-dispersion plot). In FFC the magnetic field is switched during the pulse sequence, so that the nuclear spins can "evolve" at a chosen magnetic field strength. Following the evolution period, the magnetic field is switched to the "detection" magnetic field, which is the same for every repetition of the pulse sequence; this is a key aspect, since it means that no re-tuning of the radiofrequency coil(s) is needed. In this way, a single instrument can be used to measure a sample's T_1 over a wide range of magnetic field strengths (e.g. proton Larmor frequencies of 10 kHz to 40 MHz).

While relaxometry of small samples using FFC has been used for several decades, the combination of FFC with magnetic resonance imaging (MRI) remains relatively uncommon, but has been increasing in recent years [1]. This presentation will review the techniques and applications of FFC-MRI, from our own laboratory and from others.

One application is in imaging free radicals using Field-Cycled Proton-Electron Double-Resonance Imaging (FC-PEDRI), developed in our laboratory. This uses the Overhauser effect: irradiation of the free radical's ESR causes a transfer of polarisation from electron spins to coupled nuclear spins, resulting in a change in image intensity. Field-cycling allows the ESR irradiation to be carried out at low field (hence relatively low frequency, and low non-resonant absorption), while NMR signal detection and imaging is done at higher field, to preserve SNR. We have constructed two FC-PEDRI scanners, both of which can also be used for FFC-MRI [2,3].

Relaxometric MRI is the imaging equivalent of field-cycling relaxometry. The aim is to obtain spatially-resolved T_1-dispersion data, by collecting images at a variety of evolution field strengths [1,4,5,6]. We have recently demonstrated methods for implementing relaxometry on localised regions defined from a pilot image [7]. We have also shown that FFC relaxometry can detect the formation of cross-linked fibrin protein from fibrinogen *in vitro*, in a model of the blood clotting process [1,8]. This relies on ^{14}N-^{1}H cross-relaxation phenomena, also known as "quadrupole dips" in the T_1-dispersion plot [9]. These reductions in T_1, occurring at Larmor frequencies equal to the ^{14}N nuclear quadrupole resonances, reveal information about the concentration and conformation of immobilised protein molecules. In other recent work we have demonstrated that FFC-MRI can be used with tailored contrast agents which exhibit significantly different relaxivity over the range of field strengths accessible to an FFC-MRI scanner; in this way, the sensitivity of the experiment can be enhanced [10].

In summary, developments in FFC-MRI have demonstrated this technique's ability to extract extra information that is not obtainable from conventional, fixed-field techniques. In addition to bio-medical applications, field-cycling magnetic resonance may have applications in the characterisation and monitoring of industrial processes, for example in the preparation of foodstuffs.

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