Principles and Applications of Magnetic Field Cycling in MRI

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Purpose: Fast field-cycling (FFC) relaxometry of small samples has been in use for several decades, using custom-built and commercially-available equipment. In contrast, the use of field-cycling in magnetic resonance imaging (MRI) experiments has been limited to a few laboratories. In FFC the field is switched rapidly, so that the nuclear spins can "evolve" at a chosen magnetic field strength, with signal detection at a different, fixed field. In this way, a single instrument can be used to measure a sample's NMR parameters over a wide range of field strengths.
Methods: Earth's Magnetic Field MRI: Since the Boltzmann magnetisation is naturally very small, field-cycling is used to boost the initial magnetisation using an inhomogeneous magnet coil, for subsequent detection in the Earth's field. Pre-Polarised MRI uses a strong, inhomogeneous magnetic field which is pulsed to boost the initial magnetisation, and hence improve the SNR. Detection occurs at an intermediate homogeneous magnetic field, produced by a second magnet. Relaxometric MRI is the imaging equivalent of FFC relaxometry, used to obtain spatially-resolved T1-dispersion data by collecting images at a range of evolution field strengths. Field-Cycled PEDRI free radical imaging uses the Overhauser effect: irradiation of the free radical's ESR (at low magnetic field) causes a transfer of polarisation from electron spins to coupled nuclear spins, resulting in a change in image intensity (detected at a higher field).
Results: We are engaged in a project to develop new FFC-MRI hardware and to optimise the pulse sequences and data analysis. In particular, information on protein concentration can be obtained non-invasively, by virtue of the "quadrupole dip" effect, whereby the proton T1 is reduced significantly at field strengths where resonance crossings of the proton NMR and N14 nuclear quadrupole resonance (NQR) occur (16, 49 and 65 mT).
Conclusions: Field-cycling MRI is a developing area, which offers significant extra information, compared to conventional MRI. Due to the necessity to switch the magnetic field rapidly (in a few tens of milliseconds), it requires special magnets, power supplies, control hardware and software. All of these present significant technical challenges, which are currently being addressed.