A field offset coil for spatially localised in vivo field-cycling relaxometry

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Introduction
Field-cycling MR systems differ from conventional MR systems in their ability to rapidly switch the main magnetic field strength \( B_0 \) during a pulse sequence. Because it is possible to change the magnetic field experienced by the subject, one can study the complex variation of relaxation times with field strength (\( T_1 \) dispersion). For example, reductions in \( T_1 \) (‘quadrupole dips’) at well-known frequencies are observed in samples containing protein due to interactions with the quadrupolar nucleus \(^{14}\)N, an effect we have previously demonstrated in vivo [1].

Hardware for in vivo field-cycling has to date been limited to a handful of home-built systems [2,3]. One recent development that could facilitate more widespread research is the concept of an ‘insert coil’ [4]: a removable electromagnetic field offset coil intended to provide a field-cycling capability to existing systems. In this abstract we describe the design & integration of such a coil, and its use to aid spatially resolved relaxometry measurements with a human subject.

Methods
An insertable field-cycling coil was designed to suit an existing whole-body permanent magnet-based imager with 59 mT vertical field [2]. Parameters considered included: cooling, magnetic field efficiency, mass, physical dimensions and rise time. The coil (Figure 1) was constructed (Tesla Engineering Ltd., UK) and is comprised of multiple windings (not all visible) to generate a projected homogeneous region (+/- 5% over a 50 mm DSV) centered 50 mm from the coil’s front face. Due to the imager’s construction from ferrite and fiberglass, no active shielding is required as would be the case with a cryogenic system. It is portable and easily installed in the imager by one person in around 15 minutes. The main properties are summarised in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Cooling</td>
<td>Direct water cooling through coil conductors</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Ø 38 cm, 6 cm thick</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>Up to 100% (DC)</td>
</tr>
<tr>
<td>Field strength</td>
<td>56 mT @ 187 A typical</td>
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<tr>
<td>Inductance</td>
<td>10 mH</td>
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<tr>
<td>Mass</td>
<td>~30 kg</td>
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<tr>
<td>Resistance</td>
<td>335 mΩ</td>
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</tbody>
</table>

Table 1: Properties of the insert coil

Electrical current for the coil is delivered by a high-power amplifier (Copley 266, Analogic Corporation, MA, USA) and high-voltage DC power supplies (TDK Lambda, NJ, USA) in a custom configuration allowing for ramp times of 10 ms. Field control is automatic and performed within the pulse programming environment (SMIS Ltd., UK). A hand-held gaussmeter was used first to calibrate field strength and then to measure the insert coil’s ability to offset the magnetic field of the imager (probe 52 mm from coil surface).

An interleaved saturation-recovery / inversion-recovery pulse sequence with PRESS for localisation [1] was used to measure \( T_1 \) of a volume marked on a pilot image. The RF coil used was a solenoid with 15 turns and a diameter of 7 cm.

Results
Figure 2 shows a graph of net field strength (i.e. the static field of 59 mT minus the offset coil’s field) versus electrical current for the insert coil. The steady state temperature of the coil is also shown.

Figure 3 is a dispersion curve of a voxel centered over the PIP joints of the fingers of a human volunteer, with measurements of \( T_1 \) at 1 mT intervals between 20 - 80 mT. Quadrupole dips are observed at points corresponding to well-known NMR frequencies, due to the presence of immobilised protein.

Conclusions
A compact and portable insert coil was used to offset the magnetic field of a body-sized imager, allowing the in vivo study of relaxation dispersion. The target area of the scan is currently restricted by the geometry of the solenoidal RF coil. A surface RF coil would enable more flexibility.

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References