A practical insert design for dreMR imaging in the human torso

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Introduction: Delta relaxation enhanced magnetic resonance ("dreMR") imaging allows for enhanced signal specificity when using targeted MR contrast agents. By utilizing a "B_0 insert" coil to modulate the main magnetic field as a function of time during the longitudinal relaxation phase of a pulse sequence, signal from unbound agent and background tissues can be separated from that of bound agent. The dreMR effect is present whenever the bound-state relaxivity of a targeted contrast agent is strongly dependent on field-strength [1]. The method has recently been demonstrated in vivo for both mice and humans using FDA approved contrast agents [2, 3]. Because the time-varying field modulation is not applied during the signal detection or selective excitation phases of the pulse sequence, the field is not required to be particularly uniform, with variations of tens of percent allowable.

DreMR insert systems have been constructed for small-animal experiments [4] and more recently, we have proposed a practical design for imaging of the human head [5]. In this study, we propose an open-geometry dreMR system for imaging focused areas within the torso. The proposed coil is intended for use in dreMR imaging of the prostate, breast, or spine, with the subject lying prone or supine above the coil (Fig. 1). The field shifts need only be applied over the limited anatomical area of interest. The actively-shielded coil conforms to the geometry of the tray upon which the patient bed runs within a clinical whole-body scanner.

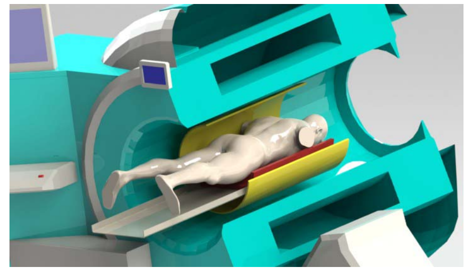

Figure 1. DreMR insert system shown within MR system bore. Primary coil is shown in red, shielding coil (partially cut away) in yellow.

Methods: The primary coil was modeled as six pseudo-planar layers to allow access into the system. Figure 2 displays the shape and dimensions of the first primary layer (closest to the imaging region). Each successive layer was sized and positioned to have a 5 mm gap between itself and the previous layer and allowed a maximum length (z-direction) of 80 cm. The primary coil set was designed so as to create a high field-shift 10 cm above the 1st primary layer (corresponding to isocenter in the main magnet) while minimizing power using the boundary element method [6]. The primary wire pattern was constrained to have wire spacing between 4 and 5 mm. Field homogeneity was not emphasized in the primary coil design, as noted above. The active shielding layer was designed over a cylinder of diameter 60 cm and total length 1.0 m using the minimum energy method [7].

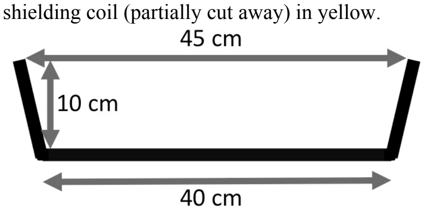

Figure 2. Cross-sectional view of first layer of primary coil. Additional layers were scaled so as to have a 5mm gap between layers.

Coil efficiency, power, inductance, and shielding proficiency were compared against a previously proposed dreMR coil designed for imaging of the human head [5]. This coil was chosen as a comparison because it is of similar design scale and has been successfully evaluated for use in Siemens 1.5 T clinical systems.

Results and Discussion: The wire patterns for the primary and shield coils are shown in figure 3. Only one layer of the primary coil is shown and both wire patterns are shown with reduced winding density in order to aid visualization. The insert coil produces a field efficiency (at isocenter) of 0.27 mTA^{-1}, resistance of 390 mΩ, and inductance of 13.5 mH. Due to the long rise times (10 – 20 ms) allowed in the dreMR method, the relatively high inductance value is acceptable. The field efficiency translates to a 0.1 T field shift when driven with 376 A, easily achievable with current power amplifier systems. The peak power dissipation associated with this field shift is approximately 55 kW, and the average power is 27 kW and 14 kW for 50% and 25% duty cycles respectively. Both of these latter values are manageable with relatively standard water-cooling systems. The performance values are summarized and compared to the previously designed and evaluated head dreMR system in table 1.

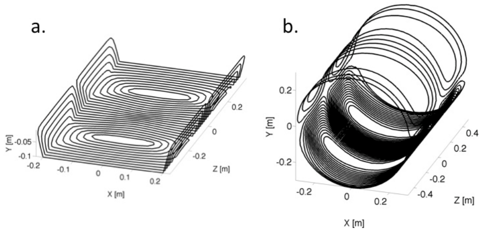

Figure 3. (a) Wire pattern for a single layer of the primary coil. (b) Wire pattern for active shield coil. Both wire patterns are scaled down 2.5 times.

The maximum eddy-current-induced field (generated on a copper cylinder, radius = 50 cm) produced at iso-center for a typical dreMR pulse (rise time = 10 ms) was simulated to be less than 0.07% of the applied field-shift. The field-shift homogeneity with respect to the field at magnet isocenter is shown over the xy-plane in figure 4. Because field-shift inhomogeneity results only in variation of the contrast-to-noise-ratio in the resulting image, the relative inhomogeneity in the y-direction results in an increase in CNR for regions closer to the coil and a corresponding drop in CNR for regions further away. The extent of the region within which the CNR would be within 50% of the value at isocenter is approximately 16 cm in the y-direction (larger in both x and z), and therefore sufficiently large to allow investigation of localized areas such as the breast or prostate.

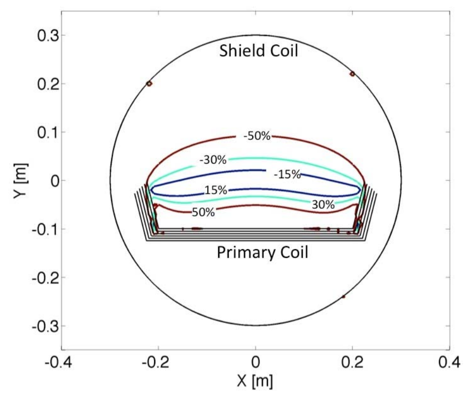

Figure 4. Field-shift homogeneity with respect to iso-center of MR system. Positive percentages correspond to field-shifts larger than that at iso-center, negative percentages correspond to smaller field-shifts.

Table 1. Performance values for the proposed body dreMR coil and previously presented head dreMR coil.

		Head Coil	Body Coil
Field Efficiency (mT/A)		0.30	0.26
Resistance (mΩ)		413	386
Inductance (mH)		8.40	13.5
Power for 0.1 T Field-shift (kW)	25% Duty Cycle	11	14
	50% Duty Cycle	22	27
	100% Duty Cycle	44	55

Conclusion: A feasible, actively-shielded, open-geometry dreMR coil design has been presented which allows access to focused areas within the human torso (although the extremities could clearly be positioned within the coil equally easily). The proposed design is capable of producing +/- 0.1 T field shifts with currently available power amplifiers. The coil has been designed such that it could be fabricated using our current techniques. Previous results [1,4], using field shifts of this size in phantoms and small animals, indicate that the proposed system will be capable of demonstrating significant dreMR contrast over focused regions of interest in the human body.

References and Acknowledgements:

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