Implanted MR coil system for *in vivo* imaging and spectroscopy of a bioartificial pancreas

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Introduction

Diabetes is an incurable disease involving lifetime consequences that can only be postponed by following an adapted lifestyle and taking medications. Alleviating the stress of treatment on patients and restoring independent partial blood glucose control would be a tremendous improvement. The development of a bioartificial pancreas is one possibility being explored to achieve these goals. Therefore monitoring such a macroconstruct non-invasively is a key to understanding functionality and enhancing performance *in vivo*. NMR imaging and spectroscopy shows great promise for non-invasive monitoring of a bioartificial pancreas *in vivo* and has been applied using surface coils at 4.7 T [1]. However sensitivity of these measurements at 4.7 T severely limits the utility of MR at this field strength with surface coils. To overcome these limitations, this presentation describes the first successful step toward developing a non-invasive NMR method for in vivo monitoring of a macroconstruct using implantable coils at 11.1T.

Methods

For non-invasive monitoring of a bioartificial pancreas, we have developed an implanted coil system that consists of an internal (implantable) coil inductively coupled to an external coil [2] (see Fig. 1), for imaging and spectroscopy on an 11.1-T 40-cm clear horizontal bore Magnex magnet equipped with Bruker Biospec Console. The 1.2-cm-diameter 2-turn internal coil will surround the cells in the bioartificial pancreas macroconstruct [1] allowing the direct implantation of the coil inside the macroconstruct. The internal coil includes a single fixed tuning capacitor (0.5 or 0.8 pF, American Technical Ceramics, Hartford, CT). The 2-cm diameter external coil includes one fixed matching capacitor (1 or 0.7 pF), one variable matching capacitor (1-15 pf, Voltronics Corporation, Denville, NJ), one fixed tuning capacitor (4.7 or 5.6 pF), and one variable tuning capacitor (1-15 pf). The coil system functions as both transmitter and receiver at 470 MHz.

In this coupled setting, two configurations are possible: either the current co-rotates in the same direction in both the internal coil and external coil or current counter-rotates in the opposite direction. These two configurations, along with a simple surface coil configuration (SC configuration) were first simulated with GNEC Antenna Analysis software version 1.1 (Nittany, Inc. Riverton, UT) then constructed, tested, and optimized on the bench with a network analyzer HP 8752C. In the co-rotating configuration, the coils were tuned and matched individually at a higher frequency (494 MHz) then tuned and matched at 470 MHz when coupled, whereas in the counter-rotating configuration, the coils were individually tuned and matched at a lower frequency (448 MHz) then tuned and matched to 470 MHz when coupled.

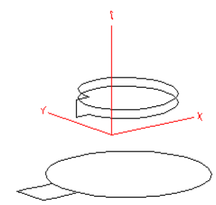

Fig. 1. Coil assembly design

Images were acquired on the 11.1-T magnet using a spin echo (SE) pulse sequence (TR=1000 ms, TE=10 ms, 1-mm slice) on a water sample. The signal-to-noise ratio (SNR) was calculated from the images for each configuration (co-rotating, counter-rotating, and SC), at the implanted coil position, according to the definition given by Henkelman [3]. This allows the determination of the configuration which has the highest sensitivity.

Results and Discussion

The results for each configuration of implanted coil were compared with the SC configuration as a reference. The co-rotating configuration gives an average SNR gain, measured in the three orthogonal directions, of 3.81 over the SC configuration; whereas the counter-rotating configuration gives an average SNR gain of only 2.64 over the SC configuration. Consequently the co-rotating configuration has a better SNR gain than the counter-rotating configuration by a factor of 1.72. This SNR difference can be explained by examining the magnetic fields produced by the co-rotating and counter-rotating currents in the two configurations of the coupled coils. In the co-rotating configuration, the magnetic fields of both coils add as illustrated by simulation (Fig. 2) and displayed in the images (Fig. 5), whereas in the counter-rotating configuration the magnetic fields of the coupled coils subtract showing a null between the two coils, as illustrated by simulation (Fig. 3) and displayed in the images (Fig.6). Fig 4 and 7 are respectively the simulation and the images obtained for a simple surface coil. The near magnetic field produced by the coils was calculated along the axis of symmetry of the coils in the z-direction, with the surface coil positioned at z=0 and the implanted coil centered at 0.01 m (location of bioartificial pancreas). In the figures below, the position of the simulation and images are aligned in the horizontal direction for ease of comparison. The magnitude of the field is highest at the location of the implanted coil in the co-rotating configuration.

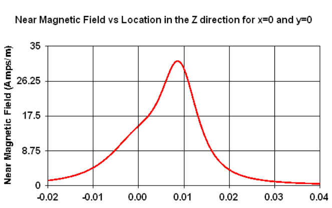

Fig. 2. Simulated co-rotating magnetic field distribution

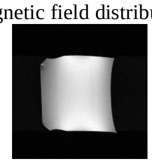

Fig. 5. Co-rotating configuration transversal image

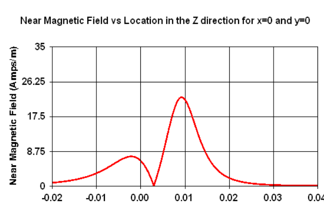

Fig.3. Simulated counter-rotating magnetic field distribution

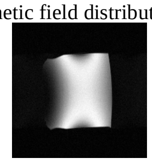

Fig. 6. Counter-rotating configuration transversal image

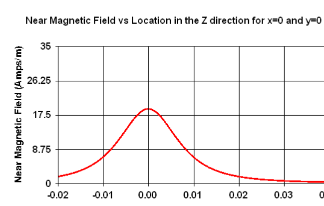

Fig. 4. Simulated SC magnetic field distribution

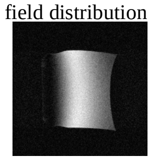

Fig. 7. SC configuration transversal image

Conclusions

Both theoretically and experimentally, implanted coils demonstrate a SNR improvement of a factor of 2-to-4 over single surface coil configurations at the location of the implanted coil (macroconstruct location) and the co-rotating configuration gives a factor of 1.5-to-2 gain in SNR over the counter-rotating configuration. Also we have successfully used the co-rotating coil system to measure localized spectroscopy using phantoms. Since the co-rotating configuration gives the highest sensitivity, this configuration will be developed further as a non-invasive method for monitoring a bioartificial pancreas in vivo. Ongoing work is now focused on selecting the most appropriate material and method for coating the internal coil and embedding the coil in the macroconstruct.

References 1. Constantinidis *et al.* Ann N Y Acad Sci. 961 June 2002. 2. Silver *et al.* Magn Res Med 46. 2001. 3. Henkelman, Med. Phys. 12(2). 1985.