

# Development of a Receive-Only Inductively-Coupled RF Coil System to Enhance $^1\text{H}$ NMR Localized Spectroscopy to Monitor an Implantable Bioartificial Construct at 11.1T

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## Introduction

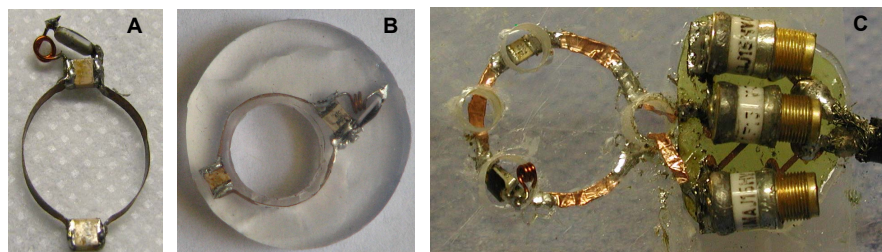
One promising approach to treat diabetes is to implant insulin-secreting cells within a tissue-engineered bioartificial pancreatic construct (Fig. 1). Non-invasive monitoring of such constructs is of primary importance in optimizing their design and assessing cellular viability and function during its life span *in vivo*.

Recent studies have shown that using NMR with a transmit-receive inductively-coupled coil system at high field allows such monitoring with high sensitivity [1]. Furthermore, magnetic resonance spectroscopy is of particular interest in monitoring implanted constructs as it allows the detection of a choline signal, which can be linked to the number of viable cells within the area of detection. To optimize MR spectroscopy, a uniform excitation and highly sensitive signal detection is required. Towards achieving this goal, a receive-only (RX) inductively-coupled, implanted coil system has been developed and implemented at 11.1 T. Its specific requirements for monitoring a bioartificial construct *in vitro* have also been investigated.

## Methods

The RX inductively-coupled implantable coil systems consisted of an implantable loop-gap resonator coil (IC) inductively-overcoupled (co-rotating mode) to a surface coil (SC) [1]. Both coils were constructed using a passive decoupling circuit [2,3], composed of anti-parallel diode pair in series with a small solenoid inductor and placed in parallel to one of the tuning capacitors on the resonant circuit. The system was tested on an 11.1 T horizontal 40-cm clear-bore Magnex magnet equipped with a Bruker Biospec console using a transmit-only homebuilt bird-cage volume coil to provide a uniform excitation for  $^1\text{H}$  NMR. The system was compared to an inductively-coupled system functioning as both transmitter and receiver (TRX) [1].

Different system layouts were built and tested to optimize the design for both the implantable coil and the surface coil (Fig. 2). These layouts differed by the type of diode used (Schottky or PIN diodes) and the number of capacitors implemented (from 1 to 4). The effects of the decoupling circuit were also tested by determining changes in the resonant frequency and Q for all coils and systems after insertion into the coil main circuit. The efficacy of the decoupling was also verified. To determine the system with the best *in vitro* (and presumably *in vivo*) characteristics, the implantable coil was coated (Fig. 2) using polydimethylsiloxane (PDMS, Medical Grade Silicone Elastomer, Factor II, Lakeside, AZ) as described in [1]. The quality factor (Q) of each coil taken individually and of the whole system was recorded after construction with and without coating and loading (either a gel phantom mimicking the characteristics of a mouse abdomen or culture media used for *in vitro* studies).



**Figure 2:** Photographs of some of the coils comprising the RX systems tested. A) a loop-gap resonator coil; B) a loop-gap resonator implantable coil coated with PDMS; and C) a surface coil. Each coil contains two tuning capacitors and a decoupling circuit that includes a hand-wound inductor and Schottky anti-parallel diodes.

## Results and Discussion

Adding the decoupling circuit to the coil circuit resulted in the resonant frequency of the coil shifting down by 27 % when only 1 tuning capacitor was used in the circuit of either the implantable or the surface coil and their Q decreased by at least 5-fold. These changes were attributed to the diode characteristics. The coils constructed with two and four tuning capacitors in their loop were less influenced by the insertion of the decoupling circuit, as were coils with PIN diodes. However, coils with the PIN diodes were eliminated from the study as they required an external DC bias source to turn the diodes ON, which is not suitable for the implantable coil. Also only coils with two capacitors in their inductive loop (Fig. 2) were kept and the Schottky diodes were found to be the best compromise between ease of construction and utilization. The PDMS coating of the RX implantable coils was easily achieved using a coil coating technique [1]. After the coating and loading of the RX implantable coils, a resonant frequency shift and a Q decrease similar to that previously observed for TRX implantable coils was obtained [1].

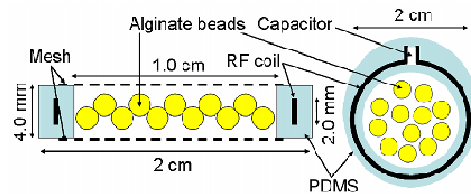
Then the uncoated and coated RX systems were tested in an 11.1 T magnet under unloaded conditions and compared to results obtained with the TRX system. When the unloaded IC was placed approximately 1 cm away from the SC [ $0.87 \pm 0.08$  cm], the SNR of the images acquired with the RX inductively-coupled implantable coil systems was approximately 25% below the SNR from images acquired with the TRX system [ $0.77 \pm 0.18$ ,  $p < 0.001$ ]. This SNR reduction of the RX system is believed to be due to the effects of the decoupling circuit on the Q, since the diode capacitance is on same order as the capacitors of the coils. Loading largely affected both systems, and under loaded conditions, the RX systems performed better than the TRX systems, with a SNR 13% higher [ $1.13 \pm 0.19$ ,  $p < 0.001$ ]. Furthermore compared to the TRX system, the signal profile throughout the construct was much more uniform with the RX system.

## Conclusions

The receive-only implantable inductively-coupled coil system was successfully constructed, coated, integrated with the bioartificial construct, and used to image the construct *in vitro*. Under *in vitro* and *in vivo* conditions, where loading becomes an unavoidable factor, the coated RX system is as good as, and may exceed the performance obtained by a TRX system. Additionally, this coil system provides greater signal uniformity and therefore, a better means by which to analyze the function of implanted bioartificial organs quantitatively using choline NMR detection. Ongoing work is now focused on: 1) improving the localized spectroscopy techniques; 2) calibrating the NMR localized spectroscopy method to correlate the choline NMR signal to the number of viable cells within the construct; and 3) studying the construct function *in vitro* over time using localized spectroscopy.

**References** [1]. Volland NA, *et al.* MRM (accepted). [2] Edelstein WA, *et al.* JMR 67: 156-161 (1986). [3] Hyde JS, *et al.* JMR 89:485-495 (1990).

Supported by NIH RO1 DK47858



**Figure 1:** Coil-construct assembly scheme: A) transverse view; B) coronal view. The macroconstruct consists of a coil surrounded by PDMS and containing alginate beads.