Comparison of Phased Array versus Implantable Coil for Rat Spinal Cord MRI

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Introduction

MRI of rat spinal cord has been useful to longitudinally track pathological changes in mechanical spinal cord injury [1]. The small size of the rat spinal cord (typically several millimeters) necessitates high SNR to maintain adequate spatial resolution to resolve structures within the cord. In recent years, two coil strategies have been reported to increase SNR within the cord region of small animals: implantable coils which are surgically placed over the spinal column and inductively coupled to a pickup coil outside the body [2], and the phased array which combines signals from several separate surface coils [3]. Here we describe our preliminary work in comparing the performance of implantable coils versus a phased array for rat spinal cord imaging at 7 Tesla.

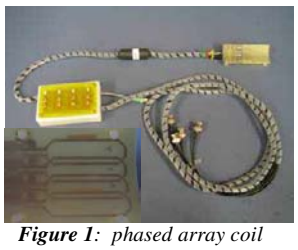

Figure 1*: phased array coil (inset shows coil pattern)*

Figure 2*: implantable coil and pickup coil*

Methods

A receive-only phased array was built (National Research Council, Winnipeg, Canada) with 4 rectangular coil elements (27mm x 8mm), overlapped laterally on a curved shell (Figure 1). PIN diodes detune the array during transmission, which is provided by a 11 cm quadrature volume coil (Bruker, Germany). The phased array signals are combined in a standard sum-of-squares reconstruction. The implantable coil (previously described in [4]) consists of a rectangular copper loop (15x8.5mm) with curved arches, resonated in series with a 8.3 pF chip capacitance, and insulated with polyolefin heatshrink tubing and a biocompatible elastomer (Dow-Corning MDX4-4210). To surgically implant the coil, a midline exposure of the spinal column is made, the implantable coil is placed over the column and secured by suturing each corner to the nearest rib, and the overlying paraspinal muscles and skin are sutured to close the wound. A circular pickup coil (3.4cm diameter) on the dorsal surface of the rat inductively couples to the implantable coil and is used to relay transmit power and received signal.

Imaging experiments were performed on a 7T 30-cm bore MR scanner (Bruker, Germany), focusing on the T9-T11 region of the spinal cord of a 280-gram Sprague-Dawley rat. The rat was implanted with the implantable coil, and then imaged *ex vivo* with an axial T1-weighted gradient-echo FLASH sequence with 100 μm pixel size (TR/TE= 250/8ms, FOV= 2.56cm, 256x256, slice thickness= 1mm, number of slices=12, NA=10). We then removed the implanted coil and surgically closed the wound again, and then imaged with the phased array with the same FLASH sequence. As a preliminary comparison to *in vivo* performance, a separate phased array imaging experiment with the same sequence parameters was performed on a live anesthetized rat, using respiration triggering to reduce motion artifact. SNR was estimated as the signal mean in the spinal cord divided by the standard deviation of a noise region in the image.

Results

Network analyzer measurements indicate an inter-element isolation for the phased array in the range of 16.8 to 29.0 dB, with only one measurement below 20 dB. Q_{air}/Q_{loaded} was 178/84 and 210/112 for the phased array and implantable coil system, respectively. Figure 3 shows axial slices at T9 acquired with the implantable coil (left) and the phased array (right). Both images clearly elucidate structures within the spinal cord, such as the characteristic butterfly pattern of the central gray matter. Cord SNR was 85 for the implantable coil, which is 2.4 times higher than a SNR of 35 for the phased array. Figure 4 shows an *in vivo* phased array image with a cord SNR of 53. It is difficult to make direct comparisons with the *ex vivo* images since the *in vivo* respiration triggering increased the acquisition time by about a factor of 3, which resulted in decreased T1 weighting and subsequent increase in SNR.

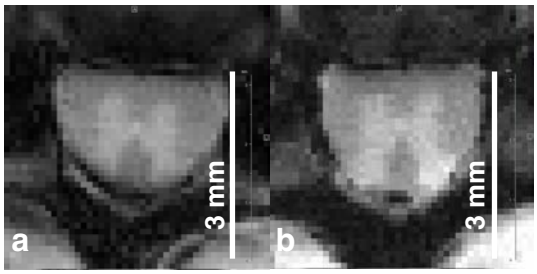

Figure 3*: ex vivo axial FLASH image of spinal cord at T9 using (a) implantable coil and (b) phased array*

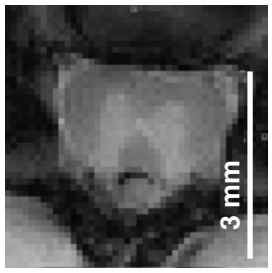

Figure 4*: in vivo axial FLASH image at T9 using phased array*

Discussion & Conclusions

These preliminary results give evidence that both the phased array and implantable coil systems are feasible options for rat spinal cord imaging, with both systems providing adequate SNR for 100 μm spatial resolution at reasonable imaging times. In our study, the implantable coil provided a 2.4x SNR improvement over the phased array. Although the SNR comparison was carried out on *ex vivo* data, the image acquired from a live rat (Fig. 4) suggests that the *in vivo* SNR values will be on the same order of magnitude and suggest that the general trend of higher SNR obtained with the implantable coil will hold in the *in vivo* case as well. The *ex vivo* SNR comparison is somewhat more precise than a comparison in a live rat because differences in breathing rate (and therefore the respiration triggering rate) may cause variations in the total acquisition times.

The phased array in this study was developed to provide an imaging option that may be more practical than the implantable coil in longitudinal studies. Our previous work with implantable coils [4] revealed some reliability problems over a long period of time (such as coil breakage and migration away from cord), which were surmounted after significant effort in technique refinement. The phased array, on the other hand, is simpler to use, much less invasive to the animal, and may be more reliable over the long term, while still providing enough SNR to achieve good spatial resolutions as our preliminary results suggest.

The implantable coil may be used in applications where it is important to maximize SNR. The higher implantable coil SNR highlights the advantage of using a small coil near its region of interest, which limits the volume of reception sensitivity but also decreases the amount of noise detected. The phased array can be further improved by adding more elements and using low-impedance preamplifiers to reduce noise correlation; however this can only improve SNR to a certain extent, particularly for structures deep within the body. The SNR advantage provided by the implantable coil may even increase over the course of a long-term study if the rat grows larger and the cord-skin distance increases.

We have therefore presented two practical coil systems that can feasibly generate high spatial resolution in rat spinal cord: the phased array is a good choice if more noninvasiveness and reliability are desired, whereas the implantable coil can be used if maximal SNR is critical.

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References. [1] Falconer JC et al, Magn Reson Med 1994: 32:484-91. [2] Bilgen M et al, Magn Reson Med 2001: 46:1250-3. [3] Blackband et al, Rev Sci Instrum 2001:4292-94. [4] Yung et al, ISMRM 2004, 1537.