Monitoring brain dimpling and intracortical micro-electrode arrays with high resolution MRI in rats

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Introduction

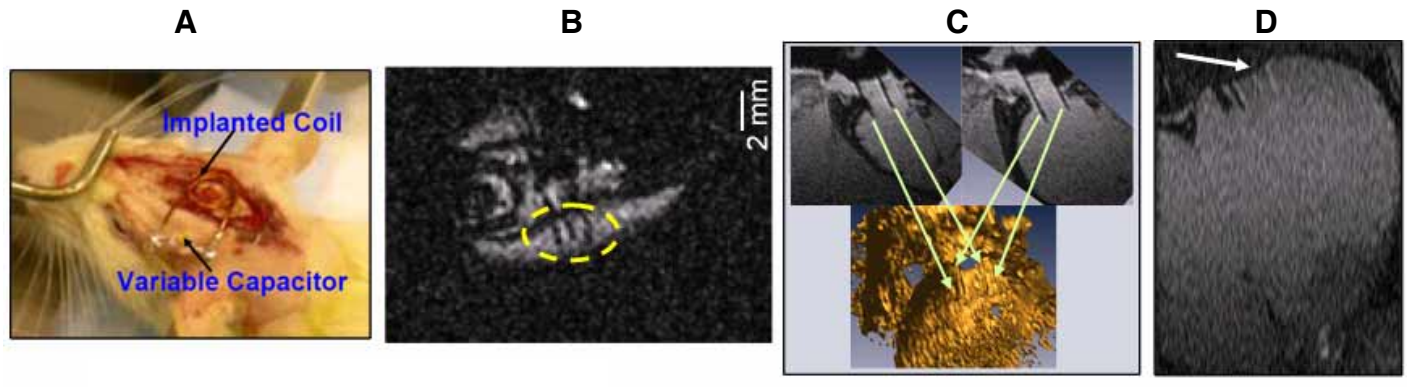
Long-term failure of chronic neural implants to record unit activity can be attributed to many factors including initial insertion trauma (i.e., micro-hemorrhaging and dimpling of the brain), neuronal cell loss, and scarring due to active gliosis around the implant. Actual data required to elucidate the relative contributions of these factors in loss of neural recordings is scarce due in part to the lack of effective real-time implant monitoring techniques. Currently, the overall implant system represents a "black-box", in which the state of the neural interface can only be hypothesized from electrophysiological recordings and electrode impedance. Questions concerning the time course of brain compression (dimpling) as observed during electrode implants, orientation of the pliable electrodes inside the brain, and formation of encapsulation sheath and their effect on recording performance are not clearly understood. Here we present preliminary data showing the feasibility of using high resolution in vivo MRI to detect brain dimpling and also to image the location, geometry and integrity of implanted microelectrode arrays.

Materials and Methods

Male Sprague Dawley rats (400-500g) were implanted with 50µm tungsten microwire arrays (16 closely spaced or 4 sparsely space): implants were either in primary sensory or motor cortical areas. Post-surgical MRI was performed on a horizontal bore 7 tesla magnet, with a 12 cm diameter gradient set and a Varian Direct Drive console. Two different RF coil setups have been used. In the first, a rectangular surface coil (2.5 x 2 cm) is placed around the micro-electrode array and is used in transmit-receive mode. The second arrangement uses a self-resonant coil which is implanted on to the skull surrounding the craniotomy during surgery (Fig 1A), forms part of the acrylic head cap used for stabilization of the electrode array, and is then coupled to the transmit/receive coil by mutual inductance. Reduction of magnetic susceptibility-induced artifacts in the frequency dimension was achieved using the method of Chang and Fitzpatrick [1] with reversal of the polarity of the frequency encoding gradient for successive transients.

Results

Figure B shows one image acquired using the implanted coil, the high signal-to-noise of the small coil results in a very short data acquisition time. Figure 1C shows two-dimensional slices and a three-dimensional reconstruction of an implanted four-microelectrode array, in which the position, relative orientation and depth of insertion of the microelectrodes can easily be seen. No dimpling of the brain is seen, and there is also no evidence of trauma or swelling in the brain. Figure 1D shows that dimpling of the brain can also be detected soon after insertion of a large, 16-channel microelectrode array.



A. Placement of a self-resonant coil around the craniotomy before electrode insertion. **B**. In-vivo visualization of implanted micro-electrodes. TR = 1 s, TE=8.65 ms, FOV=20x20 mm^2, matrix=128x128, in-plane resolution=156x156 µm^2, slice thickness=500 µm, data acquisition time 2 min 8 sec. **C**. Two slices from a spin echo data set showing the positions of all four microelectrodes in a sparse array. An external transmit/receive surface coil was used. Data acquisition parameters: TR=2 s, TE=16.2 ms, 16 signal averages, 256x128 data matrix, in-plane resolution 75x125 µm^2, slice thickness 200 µm. **D**. One slice from a multi-slice data set showing dimpling of the brain associated with recent implantation of a 16-electrode micro array. Data acquisition parameters: TR=1 s, TE=17.6 ms, in-plane resolution 50x150 µm^2, slice thickness 200 µm.

Conclusion

The results show that it is possible to visualize the locations of implanted micro-electrodes in vivo as well as to see subtle effects such as brain dimpling. For short-term studies, implanted RF coils give very high signal-to-noise: for chronic studies external surface coils must be used, but still give high quality images. Currently, we are studying the correlation between changes in the relaxation properties of tissue between and surrounding the electrodes and the quality of electrical measurements.

References. 1. Chang H, Fitzpatrick J.M. IEEE Trans.Med.Imag. 1992, 11, 319.