A FLEXIBLE 64 CHANNEL ELECTRODE ARRAY FOR CHRONIC LOCAL FIELD POTENTIAL RECORDING AND MAPPING

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INTRODUCTION

Surface field potentials from cortex are advantageous for mapping electrical activation across large regions of tissue (Jones and Barth, 1999). We have recently tested flex-circuit boards from computer hard drive electronics inserted in a slot between the bone and dura, and shown that very little tissue damage results. We also obtain excellent evoked responses from the cortical surface. Similar procedures are used during human neurosurgical experiments for mapping the brain surface. Unfortunately, the copper metal of the flex-circuit boards is not ideal for long term chronic recordings, and the trace configuration is not mapped in a 2-D array. Thus, we are developing a flexible electrode array which meets the requirements for long term recording with an electrode spacing designed for mapping evoked responses across large regions of the cortex.

MATERIALS AND METHODS

We developed a 64 channel flexible electrode array (Fig.1) which can be inserted through a slot between the skull and dura. An array of finely spaced electrodes was deposited on a flexible substrate to fit underneath the rat's skull and carry out spatially resolved measurements of electrical activity. Using a Kapton polymer substrate, gold thin-films can be sputter deposited in a blanket over the substrate. The gold is then etched using photolithography to pattern an array of 50 - 100 µm spots on a 150 to 500 µm spacing (Fig.2). Traces extend to a commercially available 25 or 64 pin array can also be patterned at this time. To electrically isolate the traces so that the electrical signals are only sensed at the bare metal end, another layer of Kapton was used to cover the electrode layer. This film is then etched using laser cutting tools. Other prototypes have been made using photosensitive polymers as the electrical isolation layer. These early prototype versions suffered from small cracks during implantation. Future efforts may use a more ductile polymer to create a thinner layer than the Kapton. However, we are encouraged because signals can indeed be acquired using these arrays.

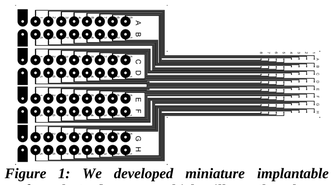


Figure 1: We developed miniature implantable surface electrode arrays, which will greatly enhance our ability to record electrical activity from cortical surfaces. The 5x5 mm electrode array can contain 64 or more channels for high-resolution mapping of evoked responses from the brain surface. Prototypes of the array have been inserted through a slot in the bone between the skull and dura, which greatly reduces the trauma associated with typical electrode arrays.

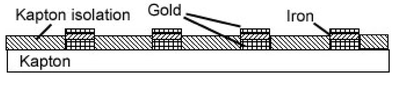
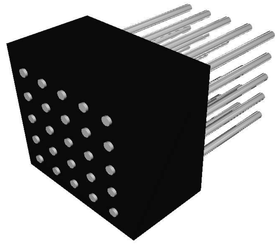


Figure 2: A cross section of flexible electrode array also seen in figure 1 shows the layered structure of the materials used in the construction of the array. Bottom layer Kapton, interlayers of electroplated gold and iron shown in cross section between the insulating top Kapton layer. The iron layer will be used after the experiment to deposit ferro-cyanide staining particles onto the tissue for electrode localization.

RESULTS



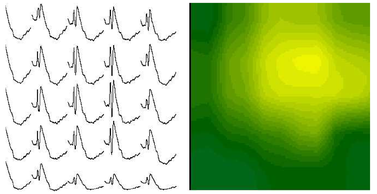
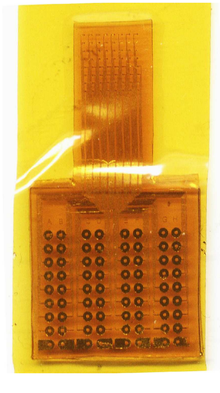


Figure 3: Evoked responses and corresponding graphical image at the peak of P1 from the 25 electrode field potential array after twitching whisker D1. We have implemented 25- and 64-channel electrode arrays in chronic rat preparations for mapping the somatosensory cortex of the rat and have successfully trained rats to tolerate restraint and whisker twitching, which is a critical step in the behavioral component of this proposal. The 25 electrode array diagrammed (left) was constructed from black Delrin using a computer controlled mill and wire drills. The total block size is 4 x 4 mm and 3 mm high. Stainless steel or silver wires inserted in the holes are glued in place with epoxy and polished flat with diamond paste.

For mapping evoked responses across the cortical columns of the somatosensory and auditory cortex, we have initially relied on flat, high-density electrode arrays made from Delrin blocks and placed directly on the dural surface.

We have used both silver and stainless steel wire in these measurements. Silver has the advantage of a low resistance pathway for the electrical recordings, whereas stainless steel exhibits better longevity in chronic preparations. Additionally, stainless steel electrodes can be used to deposit iron into the tissue by passing a current, which can be subsequently used to identify the locations of columns that were mapped using evoked response characteristics with histological techniques.



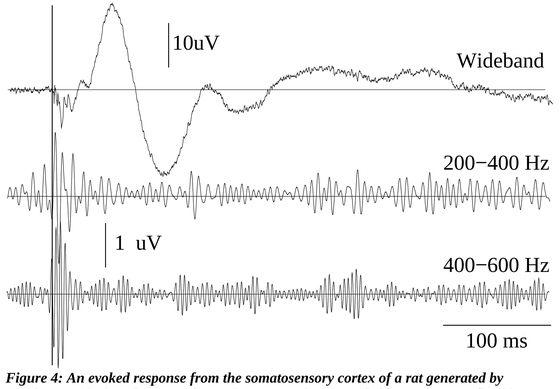


Figure 4: An evoked response from the somatosensory cortex of a rat generated by twitching a whisker shows good signal-to-noise when recorded by a prototype flexible electrode array inserted through a slot in the skull between the bone and dura. With as few as 20 averages in this example, the wideband response as well as the 200-400 and 400-600 Hz components are clearly visible.

We have collected data from a 3x3 mm 25 electrode array and have successfully mapped the spatial location of cortical whisker barrels during individual and multiple whisker stimulation (Fig. 3). By employing flat and flexible substrates when constructing such electrode arrays, it is possible to insert the array under the skull through a slot, rather than removing all of the bone that covers the cortex of interest, similar to those used for chronic implantation of electrode arrays during pre-surgical assessments in human subjects. Initially, we will use gold for the electrode array because of its stability in tissue and ease of manufacturing. We obtained excellent evoked responses from the cortical surface using a prototype device with one electrode (Fig. 4).

Figure 5: Wires in our electrode array can be constructed from stainless steel, thus allowing iron to be deposited onto the brain surface. A subsequent ferro-cyanide stain during perfusion can mark the location of the electrodes.

In order to mark the location of each electrode, a small deposit of iron can be embedded at the tip of each electrode which can be released into the tissue at the end of the experiment by passing current, then identified by staining with a standard ferro-cyanide stain (Fig. 5).

CONCLUSIONS

In both animal and human paradigms, removal of the skull bone is traditionally required for mapping large areas of the brain surface. High density electrode arrays inserted into the tissue for unit recordings typically do much tissue damage, and are short lived.

This new technique alleviates such trauma, and allows much higher resolution, limited only by lithography, and allows a wider mapping region covering up to one hemisphere with minimal additional effort. The special activation maps (Fig. 6) obtained by the surface array are comparable to those we obtain with optical imaging procedures (Rector et al., 2001). We are also developing a 16 to 256 channel preamplifier and digitizer on a 3x3 mm chip using mixed signal ASIC (Application Specific Integrated Circuit) technology.

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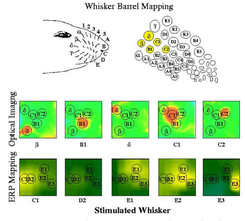

Fig 6: Stimulating particular whiskers produced early response images using optical and electrical techniques with discrete regions that were localized in space to regions corresponding to cortical columns. The five images were collected after stimulating the whisker indicated below the image. For spatial comparison, circles that show the activated regions were drawn on all images.

REFERENCES:
Jones, M.S. and D.S. Barth. Spatiotemporal organization of fast (>200 Hz) electrical oscillations in rat Vibrissa/Barrel cortex. J Neurophysiol, 82(3):1599-609, 1999.
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