NOBLE METAL PENETRATING CORTICAL STIMULATING ELECTRODE ARRAY: PRELIMINARY RESULTS

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ABSTRACT

Electrical stimulation of the visual cortex causes subjects to see spots of light (phosphenes) in their visual fields. We have developed arrays of penetrating electrodes which may form the basis of a visual prosthesis centered around electrical stimulation of the visual cortex. These arrays have been constructed of inert materials, and have been implanted into cats to test array insertability and biocompatibility. Tests to determine electrode wire insertion force have also been performed. Preliminary acute histological results have shown little cortical damage due to the implants.

INTRODUCTION

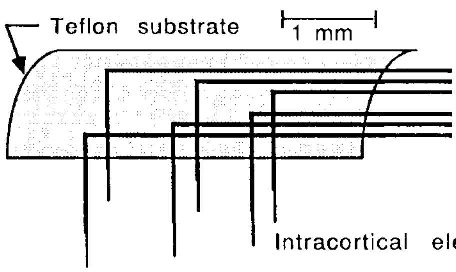
Electrical currents, when passed into the visual cortex from an external source, cause both blind and normally sighted subjects to perceive spots of light (called "phosphenes") in their visual fields. Electrical stimulation of the visual cortex thus has been proposed as a means of providing a limited restoration of vision to the blind. However, previous attempts at providing a functional visual prosthesis [1-2] using electrodes on the surface of the visual cortex have not been successful. The disk surface electrodes used in these studies had areas in the order of 1 square millimeter, and required currents in the milliampere range to activate neurons within the visual cortex. With such surface stimulation, "large" regions of cortex are excited. This becomes a detriment to phosphene two point discrimination and phosphene localization since a large amount of visual space can be represented in a small patch of visual cortex.

In contrast, electrode arrays which penetrate into the visual cortex could have small stimulating regions located near the tips of each electrode. Current passed into the cortex by these electrodes would stimulate a much more localized region of tissue, and therefore evoke phosphenes with electrode current in the microamp region. This localized stimulation should also allow for the use of more electrodes per unit area of cortical tissue, and more phosphenes per degree of visual space. This would result in a higher resolution "visual sense".

However, penetrating electrodes create a new set of problems. For instance, what is the effect of impaling a cortical blood vessel by a penetrating electrode? Since intracortical electrodes will be in intimate contact with deep neural tissues, the use of penetrating electrodes places a greater concern on material biocompatibility in the cortex and the effects of electrochemical by-products on cortical tissue. Other basic questions to be answered include: what is the minimal size and optimal tip geometry of a penetrating electrode that can mechanically withstand cortical penetration, while maintaining enough surface area for the passage of safe electrical currents? What should the shape and density of the array be to insure no movement in the cortex after implantation? Can electrode arrays with reasonable geometries penetrate the visual cortex without causing excessive irreversible cortical deformation?

MATERIALS AND METHODS

We believe that the optimal depth that such intracortical electrodes should penetrate into the visual cortex is at the level of the "normal" neural input to this region. To accomplish this, we chose a "hair brush" type array, with multiple penetrating individual electrodes, each 1.5 mm in length. Such an array would ideally have the same density as the cortex, and would essentially float after implantation with the array substrate sitting on the surface. We also decided to use small diameter wire for the electrodes to minimize the displaced cortical volume, and to reduce the residual torque in the lead wires leading to the array. A diagram of such an array is shown below.



The electrode arrays consisted of six penetrating electrodes fabricated of Teflon insulated 25 μm diameter, 80% Pt - 20% Ir wires. The insulation on the penetrating electrode wire tips was removed and the metal sharpened to facilitate cortical penetration. The penetrating electrode wires were 1.5 mm long, and were held parallel to each other by a molded 125 μm thick FEP and PTFE Teflon substrate. This substrate sat on the surface of the cortex and held the inter-electrode spacings to distances ranging from 0.35 mm to 1.25 mm.

The animals to be implanted were anesthetized, and the arrays sterilized by steam autoclave. The bone over the visual cortex was removed with the use of a round burr. The dura over the implantation site was reflected. The array was positioned and implanted, and the dura closed with 8-0 monofilament nylon sutures. The burr hole was filled with Silastic 382 and acrylic. The electrode lead wires were brought to a seven pin percutaneous feedthrough which was attached to the cats skull.

RESULTS AND DISCUSSION

Initial tests involved the implantation of individual 25 μm diameter sharpened and blunt (cut orthogonally at the end) wires into the striate cortex of a rat. While blunt wires occasionally bent prior to penetration, sharpened wires penetrated the cortex with smaller forces and with less surface depression. During the implantations in four acute and four chronic cats, the 25 μm diameter wires used in the arrays never buckled due to excessive insertion forces.

We often noted dimpling of the cortex under the implanted array. The consequences of this problem will be much more severe as the number of penetrating electrodes increase.

Little or no bleeding was noted on the surface of the cortex as a result of the implantation of our arrays. Preliminary acute histological studies on passive electrode arrays indicate that penetrating electrodes push the cortical tissue out of the way during penetration, and cause only a minimal amount of damage to the surrounding neural tissue. It was also found that the materials used to construct the penetrating electrodes did not elicit an acute foreign body reaction. The electrode arrays have also been used to record cortical visually evoked responses. Psychophysical experiments are being performed on cats chronically implanted with the electrode arrays to determine phosphene threshold currents and the extent of electrode current interactions.

CONCLUSIONS

Even with sharp electrode wires, the cortex dimpled slightly under the substrate due to the penetrating electrodes. This could become an important factor when trying to implant a "hair brush" type array with many electrodes. Smaller, more flexible lead wires are important to avoid undesirable array movement after implantation. Preliminary acute histological results suggest that only minor hemorrhaging occurs with blood vessel impalement and that penetrating electrodes seem to push the tissue out of the way with little neural damage. Finally, the materials used in our electrode arrays appear to be compatible with neural tissue.

REFERENCES

[1] G.S. Brindley, W.S. Lewin, "The Sensations Produced by Electrical Stimulation of the Visual Cortex." J. Physiol., Vol. 196, pp. 479-493: 1968.

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