Neural Prostheses

Brain Behav Evol 1977;14:158–160

Overview

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The present symposium deals with the materials, electrophysiology, and histopathology of stimulation of the nervous system with emphasis on the electrodes for neural prosthetics. If there is a central theme to be derived from this collection of papers it is the fact that 'safe' electrical stimulation of the central nervous system is feasible over long periods of time and electrical stimulation by chronic surface electrodes is an efficacious method of developing human neural prosthetics.

The data reported here are obtained from *in vitro* and *in vivo* studies of simulated human conditions and are derived from several areas of brain, sampling a variety of animals and utilizing a variety of experimental methods. Although this may cause initial bewilderment, the data obtained from the various modes of stimulation are in remarkable agreement.

The objective of any neural prosthetic is to produce return of function in a mode that is 'safe' and will not result in tissue damage. In the case of a cortical visual or auditory prosthetic, values of 0.3 or 0.6 A/ cm² of stimulation at 50 Hz and 0.5 msec duration are required to produce a phosphene or audene. It appears that these high current densities result in tissue damage in some experiments and not others. The papers by PUDENZ *et al.* and BERNSTEIN *et al.* in the symposium will show that the former research group can safely stimulate at high current densities whereas the latter group cannot. Careful examination of the electrodes shows that PUDENZ *et al.* utilized roughened (25%) surfaces on noble metal electrodes and BERNSTEIN *et al.* utilized polished surfaces. Since the charge density of roughened surface electrodes is orders of magnitude less than the same current density on polished surfaces, it appears that one of the major sources of tissue damage iKcharge density.

Another major cause of tissue damage is the hydrolysis commonly associated with low level stimulation of metal electrodes. The hydrolytic effect can be avoided by controlling biphasic electrode polarization or by utilizing capacitively coupled stimulating electrodes. Controlling the polarization of the biphasic pulse still often results in increased thresholds for stimulation after protracted periods of stimulation.

One of the results of surface stimulation is after-discharges of cortical neurons following excitation. The after-discharge of stimulated neurons should be avoided because of the possibility of the development of primary and/or secondary epileptic foci. The threshold for producing neuronal after-discharges following surface stimulation can be increased dramatically by manipulating the parameters of stimulation or administering Dilantin. Thus, the deleterious effects that can possibly result from after-discharge can be controlled.

In the past there has been a 'digital' mode of stimulation of neural electrodes for prosthetic purposes. That is, the electrodes are unstimulated initially (off) and the surface electrode is then stimulated (on) to produce the desired neuronal discharge. The paper of BARTLETT *et al.* in the present symposium shows an intriguing and physiologically sound method of stimulation. In essence this system mimics the neuronal membrane generator potential by constantly stimulating surface electrodes at given electrical and polarization parameters. The stimulus is then slightly altered in current density. This method of stimulation results in altered stimulus parameters of an artificially electrically charged neuronal membrane and the neuronal response may be considered an 'analog' type of stimulation (more-or-less). Using this stimulation paradigm, a blind macaque can be maintained on stimulation 2–10 times threshold indefinitely without apparent tissue damage. The animal with a threshold of 290 μA could respond to a 80 μA diminution in 580 μA and 0.2 msec pulses constantly applied for 1 h. at 50 Hz. This method of altering stimulation can be controlled within ranges that will not result in tissue damage for periods of years.

The electrode material presents a problem. The noble metals have been extensively utilized with platinum as the best electrode material. Although platinum can be stimulated 'safely' at low current densities and surface roughening does protect the brain from pathologies, the current densities needed to reliably produce phosphenes or audenes will result in electrode corrosion of the noble metals with *in vitro* stimulation over long periods of time. Therefore, the noble metals rhodium (which

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is toxic), gold, and platinum are not suitable for chronic, long-term, high current density stimulation of the brain. Recently, new materials have been produced that will have the characteristics that are required of neural prosthetic electrodes, that is, tissue compatibility and resistance to corrosion when utilized as chronic, high current density, stimulating electrode. The electrode material tantalum pentoxide (Ta_2O_5) is proving to be such a material. Electrodes made from this material are monophasically stimulated utilize capacitive coupling in the stimulation mode and are extremely stable when stimulated. Ta_2O_5 electrodes are in a series of new generation electrode materials under development.

T. There is a very exciting conclusion that can be drawn for the visual prosthetic or any cortical neural prosthetic. The stimulation parameters to reliably produce a visual phosphene (3.0 mA

0.5 msec

50 Hz) is well within the limits of stimulation that result in electrode corrosion and cortical pathologies as well as increased threshold for stimulation

neuronal after-discharges and hydrolysis. However the visual and other cortical prostheses were initially based on the premise that should stimulation produce the psychophysical sensation of light or sound. The present papers have shown that the deleterious effects of stimulation can be avoided by low levels of stimulation. Since these levels ^m not produce a visual phosphene we appear to have an insoluble dilemma. However

[BMhe emphas^mn thought is shifted to perceived differences which are not related to the psychophysical phenomenon of 'light' or a phosphene [Bartlett et al.]

then the problem takes on new perspectives. The association of a perceived difference in stimulation within the cortex by integrative centers within various cortical areas may well be the key to the production of a useful visual prosthetic. The interpretation of these perceived differences (which may not necessarily be 'light') from alterations of constantly applied current from an external source (intraorbital camera) by the person wj^Sihe implant will determine the efficacy of this type of stimulation as a msual prosthetic.