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Impedance, Histology, Stability and Longevity of the Neurotrophic Electrode in Rats, Monkeys and Humans

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Abstract. This paper describes the important characeristics of the Neurotrophic Electrode. It has a radical design difference from tine type electrodes and wires because it encourages growth of neural tissue into and through a hollow glass tip where the ingrown neuropil is held securely and thus produces enduring, stable units.

Keywords: Single-Unit Activity, Multi-Unit Activity, longevity, impedance, histology, signal stability, speech prosthesis

1. Introduction

The Neurotrophic Electrode's radical design encourages neural tissue to grow into its hollow glass tip where the tissue is held while in-situ micro-wires record the electrical activity of the ingrown tissue over periods of years. These design aims have been achieved in rats, monkeys and humans with the longest recording period being over 5 years in humans with recordings still continuing until breakdown of the implanted electronics. The electrode has some disadvantages such as destruction of surrounding tissue so that accurate histological reconstruction of the surrounding neurons is not feasible. Also, there is a delay of three to four months until growth is complete and multi-units can be recorded which then have to be separated into single units. However, stability of continuously recorded multi/single units and persistence of local field potentials over years make it more advantageous than any other electrode today for long-term prosthetic use as a BCI. To provide for a wider understanding of its potential, this presentation will provide data on impedances, histology, stability, longevity and numbers of units recorded over years in rats, monkeys and humans over the past quarter century.

2. Material and Methods

Unlike other electrodes, the Neurotrophic Electrode induces neurites to grow into and through its hollow glass tip that contains two to eight, 1 or 2 mil teflon-insulated gold (or occasionally platinum) wires for bipolar recording of the ingrown tissue [Bartels et al., 2008]. It contains proprietary growth factors when implanted into the human cerebral cortex. In rats and monkeys, NGF was commonly used [Kennedy, 1989]. The gold wires are coiled for their full length from the skull. This reduces strain and is very important for longevity. Identification of the site for implantation is achieved using functional MRI with the mute subject making silent (not imagined) vocalizations on an object naming task while in the MRI scanner. Implantation is performed under fully sterile conditions with a Stealth 3D localization system to determine the implant target matched to the fMRI. Following craniotomy and electrode implantation, insulated amplifiers and FM transmitters are plugged into the electrodes, sealed and covered with acrylic cement before scalp closure. Separation of single units from multi-units is achieved using the exclusionary convex hull technique (Neuralynx Inc. Boise, Montana) whereby dissimilar units are excluded from the main group on the basis of outlying height, peak, valley, width and energy. Inter spike interval histogram analyses indicate single units and thus provide criteria for rejection of multi-units. ISIHs, PETH, cross correlations and auto correlations are performed to strengthen the identification of single units across sessions. Multiple functional relationships have been established in rats, monkeys and humans.

3. Results

Impedances were measured at 1 kHz in all electrodes before and after implantation in all rats and monkeys. Impedance initially fell before stabilizing around 100 Hz, sometimes as high as 400 Hz or as low as 20 Hz.

Histological analyses included light and electron microscopy. Normal neuropil (excluding neurons) was found inside the glass cone at 3 weeks to 16 months. Oligodendroglia were found along with myelinated axons, blood vessels, axo-dentritic synapses. No scavenger microglia were found and no gliosis [Kennedy et al., 1992].

Single units stabilized at three to four months when functional studies began. Fig. 1 shows an example of human multi-unit recordings on two channels. Note the similar unit peaks or valleys. Using +/- voltage thresholds, units are separated as shown on the right. Confirmatory evidence was sought as described in methods using ISIHs, PETH, cross correlations and auto correlations.

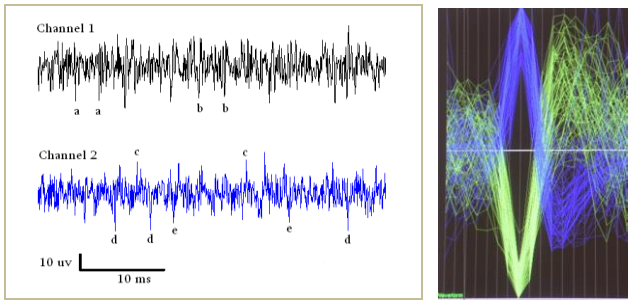

Figure 1. *Left panel: Two channels of human multi-unit data recorded years after the tissue has grown into the electrode tip. Right panel: Two single units separated by using a threshold above and below the data.*

Cluster cut parameter files were used from one recording session to the next. Stable units were found over 16 months in rats and 15 months in monkeys before experiment termination. Human recordings for over five years have been achieved with cluster parameter changes being necessitated only by damage to the electronics when the new electronics had different amplifier gains. Other human recordings included 4.5 and 4 years, and 76 days (all died from underlying diseases) and 89 days (removed deliberately). Functional studies have provided data that will likely produce a speech prosthetic [Guenther et al., 2009].

About 10 to 15 single units can be separated from multi-units recorded from each channel. Thus for the latest monkey implant (Shane @ MIT), 95 units were recorded from 12 mono-polar wires. ISIH indicated single units. PETHs indicated relationship to licking. In humans, 15 to 20 units per channel have been used in speech studies.

4. Discussion

These data detail the impedances, histology, unit numbers, stability and longevity of the Neurotrophic Electrode. The data provide evidence that the principle of growing the brain into the electrode and holding the neuropil within the electrode tip is the key to long-term stability of recorded single units [Kennedy et al., 2011]. Its usefulness as an important component of a speech BCI has been demonstrated [Guenther et al., 2009].

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