Intracortical Microsimulation (ICMS) with Microelectrodes

A common request we get from customers is on the parameters of safe microstimulation. The major issues are discussed below:

Back Voltage and Electrolysis

Via Ohm's Law: I =V/R, the amount of current that can be delivered with a given voltage is inversely related to the resistance of the charge-carrying material. Thus, the ideal stimulating electrode would have an infinitely low resistance. If resistance is too high, large voltages will be needed to drive appropriate current, which can result in the electrolysis of cerebrospinal fluid, causing oxygen and hydrogen bubbles to accumulate in the brain. The voltage required for electrolysis of brain fluid is 0.6 V and -0.8 V with our iridium oxide electrodes. We recommend the monitoring of back voltage during stimulation in your experiments to check whether your electrode is exceeding the electrolysis values, and using low impedance probes (50-300 kΩ). The two ways NeuroNexus lowers the impedance of its electrodes are through 1) fabricating probes with larger site sizes (> 1000 $\mu m^{2)}$, and 2) increasing the charge capacity of existing probes by "activating" the electrodes to create an iridium oxide layer.

Capacative/Faradaic Charge Delivery

Ideally, you want microstimulation to be capacitive, that is, you merely want an accumulation of charge on your electrode site, which results in an accumulation of counter ions near the electrode site, a change in the extracellular field potential, and thus depolarization or hyperpolarization of neurons. When charge delivery becomes faradaic, metal species leave the electrode material and may not redeposit back on the electrode during the counter phase. The value where microstimulation becomes faradaic is often called "charge capacity" and varies as a function of metal material. Calculated via cyclic voltrammetry (CV)), the charge capacity of iridium is 100-150 $\mu C/cm^2$, whereas iridium oxide is 1200 $\mu C/cm^2$. Thus, if you have an iridium oxide electrode site with a site size of 1250 μm^2, the maximum current that can be delivered with a 200 µsec phase is:

$$\frac{current \bullet time}{area} \leq capacity \qquad 1200\ \mu C/cm^2 \bullet 1.250E\text{-}5\ cm^2 / 200E\text{-}6\ sec = 75\ \mu A$$

In this case, note that any value higher than 75 µA may damage your electrode over time due to non-reversible faradaic reactions, and cause the charge carrying capacity to drop.

Tissue Damage

Other investigators [1] have empirically determined the relationship between charge delivery and tissue damage, and have developed the equation below:

$$\log\left(\frac{Q}{A}\right) = k - \log(Q) \qquad \text{Which simplifies to:} \qquad Q = \sqrt{A10^k}$$

Where Q is charge per phase in µC, A is surface area in cm^2 , and k is an empirically determined constant. If k exceeds 1.7, then tissue damage can occur. Thus, with a site size of 1250 μm^2 (or 1.250E-5 cm^2), the max charge that can be delivered is 0.025 µC. With a phase of 200 usec, that yields a maximum current of 125 µA, regardless of electrode material.

[1] Merrill DR, Bikson M, Jefferys JG. Electrical stimulation of excitable tissue: design of efficacious and safe protocols. J Neurosci Methods. 2005 Feb 15;141(2):171-98.

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Please reference this document as: Marzullo T, Intracortical Microstimulation with Microelectrodes. Report Briefs. 2008 NeuroNexus Technologies.