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Scanning electron microscopy data of 980 intracortical microelectrodes, implanted in three humans for recording and stimulation of cortical networks

D. A. Bjånes*[1], L. Rieth[4], S. Kellis[3], R. Nickl[2], B. Baker[5], T. Aflalo[1], L. Bashford[1], S. Chivukula[1], M. S. Fifer[2], L. E. Osborn[2], B. Christie[2], B. A. Wester[2], P. A. Celnik[2], N. E. Crone[2], W. S. Anderson[2], K. Pejsa[1], N. Pouratian[6], B. Lee[7], C. Y. Lu[7], F. Tenore[2], R. A. Andersen[1]

[1]T&C Chen Brain-Machine Interface Center, California Institute of Technology, Pasadena, CA, USA; [2]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA [3]Blackrock Neurotech, Salt Lake City, UT, USA; [4]Mechanical and Aerospace Engineering, West Virginia University, Morgantown, WV; [5]Electrical and Computer Engin. Univ. of Utah, Salt Lake City, UT; [6]UCLA Brain Research Institute, University of California, Los Angeles, Los Angeles, CA 90095, USA; [7]Department of Neurological Surgery, Keck School of Medicine of USC; Los Angeles, California 90033, USA

**** California Institute of Technology, 1200 E California Blvd, Pasadena, CA, USA. E-mail: dbjanes@caltech.edu***

Introduction: Long-term stability of the microelectrode arrays is a fundamental requirement for the viability of brain-machine interfaces (BMIs) as therapeutic devices. These BMI devices hold significant promise to accomplish a variety of clinical outcomes, by capturing neural activity and using signal processing to decode an extraordinary amount of detailed information: motor planning and intent, high-level cognitive goals, speech and language, and dysregulated neural activity. Furthermore, they can inject information into cortical networks via electrical stimulation, creating novel sensory percepts, visual stimuli and stabilizing dysregulated neural networks.

Material, Methods and Results: Using scanning electron microscopy (SEM), we performed physical characterization of changes in the electrode metallization and insulation after long-term implantation in the human cortex. We imaged 980 electrodes, across eleven arrays (NeuroPort, Blackrock Microsystems, Salt Lake City, UT): eight arrays with platinum (Pt) electrode tips and three with sputtered-iridium oxide (SIROF) tips. Ten of these arrays were implanted across three human participants with tetraplegia. Two participants were implanted in anterior intraparietal area (AIP) and Brodmann's area 5 (BA5) for a duration of 5 yrs, 5 months and 5 yrs, 10 months. Another participant was implanted in primary motor (M1) and sensory (S1 area 1) cortices, bilaterally, for 2 years, 7 months. Three different clinical sites performed the implant and explant surgeries (Caltech - UCLA/USC and Johns Hopkins).

We found the physical state of the electrodes significantly correlated with measured noise, signal-to-noise ratio (SNR) and impedance (as measured *in vivo* prior to explant). We also categorized degradation outcomes ("pockmarked" vs. "cracked") for stimulating and non-stimulating electrodes as a step in the process of evaluating mechanisms for these effects. Physical damage was significantly spatially auto-correlated, suggesting biological degradation. From our data, we hypothesize erosion of the silicon shank often precedes damage to the tip metal, accelerating damage to the electrode / tissue interface.

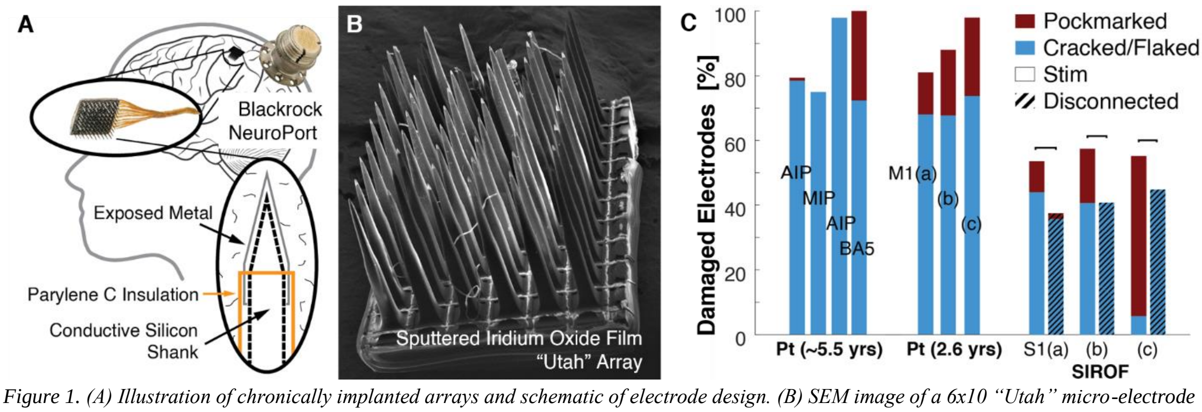

Figure 1. (A) Illustration of chronically implanted arrays and schematic of electrode design. (B) SEM image of a 6x10 "Utah" micro-electrode array after 2.6 years in-dwelling, tipped with iridium oxide electrodes. This 20-80kOhm impedance interface allows for recording and stimulation on each electrode. (C) Two unique tip degradation types were identified ("pockmarked" and "cracked"). The "pockmarked" degradation significantly occurred on stimulation electrodes while rarely occurred on non-stimulation electrodes.

Discussion and Significance: These findings link quantitative measurements, such as 1 kHz impedance, signal-to-noise ratio and RMS noise, to the physical condition of the microelectrodes and their capacity to record and stimulate. They provide researchers useful information and actionable insights for the day-to-day experimental process. These data are vitally important as multi-year clinical trials of BMIs are becoming more common and could lead to improved manufacturing or novel electrode designs to improve long-term performance of BMIs.

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