IN VITRO CHARACTERIZATION OF A PROBE-MOUNTED PARYLENE-BASED PRESSURE SENSOR ARRAY FOR INTRACORTICAL APPLICATIONS

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ABSTRACT

Mechanical interactions at the electrode-tissue interface are postulated to play a role in the steady decline of recording quality from chronic intracortical prosthetics. However, few tools are available to study this interface. A low profile, Parylene microchannel-based force sensor array featuring electrochemical impedance transduction was developed for instrumenting neural probes and can be operated within the body's wet environment without additional hermetic packaging. *In vitro* characterization was performed indicating a linear operational range of 0-1 MPa for each sensor. Agarose insertion of instrumented probes revealed pressure distributions up to 1 MPa along the length of the probe, however the tip experienced pressures beyond the linearly calibrated range of the sensor. Pressures decreased by 75% with faster insertion speeds.

KEYWORDS: Parylene C, Mechanical Pressure Sensor, Intracortical Probe, Insertion Mechanics

INTRODUCTION

The potential of implantable neural prosthetics for alleviating sensory and motor deficits have motivated development of reliable chronic brain machine interfaces [1]. However, mechanical properties at the prosthesis-tissue interface, which may contribute to diminished prosthetic performance and lifetime, are largely overlooked [2]. Understanding biomechanical phenomena at this interface can lead to improve prosthetic designs that possess long term recording capability. To quantitatively characterize the biomechanics of this interface, Parylene-based electrochemical (EC) MEMS sensor technology was developed that integrates with intracortical probe technology and operates within the wet, corrosive environment of the body without requiring bulky, hermetic packaging [3]. Here, we present *in vitro* sensor characterization and preliminary results on interfacial pressure distribution during insertion of instrumented probes into agarose tissue phantoms.

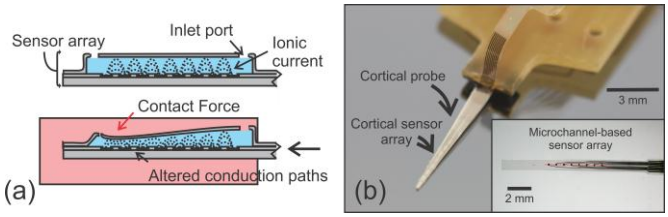

Figure 1: (a) Cartoon of sensor array transduction principle showing insertion into tissue. (b) Image of instrumented cortical probe and Parylene-based sensor array (inset).

The sensor array consists of eight platinum electrodes encased within an electrolyte-filled Parylene microchannel, forming 7 adjacent electrode pairs, or sensors, in a linear array (Figure 1a). As interfacial forces deform the flexible Parylene microchannel above each sensor unit, the volumetric conductive path (and solution resistance) between the pair of electrodes changes as does the measured solution impedance. This change can be correlated to an applied pressure. Sensor arrays easily attach to ceramic-based cortical probes [4] (Figure 1b) and can be tuned to match the anticipated pressure ranges and probe footprint to assess implant mechanics at the electrode-tissue interface.

METHODS

Sensor Characterization

The sensor array was calibrated in an acrylic jig designed to keep the sensing element immersed in an electrolyte (1× PBS). A flat, circular, probe tip (diameter = 630 µm), attached to a motorized Z-axis stage, was displaced in 2 µm increments into the microchannel until reaching the maximum deflection of 20 µm. The probe diameter was chosen to cover the entire surface of a sensor unit (72,665 μm^2). An in-line load cell was used to measure the applied force of the probe during displacement. During this calibration procedure, real-time impedance was measured using LabVIEW software coupled to a LCR meter integrated with a multiplexing PCB that allowed for fast switching between the sensor units. To eliminate fluidic coupling from the shared microchannel, sensors underwent 10 minute relaxation steps prior to calibration to return to the baseline reading (impedance ≤ 0.1% of initial value). Also, to further decouple the sensor units of the array, sensors were calibrated in an order chosen to prevent the sequential testing of two adjacent sensors.

In Vitro Testing

In vitro testing was carried out by implanting instrumented probes via insertion into 0.5% agarose, a commonly used cortical tissue phantom, immersed in a 1× PBS solution to assess the effects of insertion speed. Following integration of the sensor array with the ceramic cortical probe and subsequent sensor array filling, the instrumented probe was inserted into

agarose at various speeds (0.01, 0.03, and 0.1 mm/s), while array impedances were measured in real time (via LabVIEW interface) to compare the effects of insertion speed on the interfacial pressures generated.

RESULTS AND DISCUSSION

Sensor Characterization

Sensors demonstrated operational uniformity despite their differing locations along the fluidically coupled channel. The Parylene microchannel was found to deform uniformly along the length of the channel, as the displacement per applied force was similar across runs for each sensor (Figure 2a). This trend was also present in the normalized impedance vs. force results (Figure 2b). A calibration constant of 1417.89 ± 13.56 (mN/normalized impedance; Mean ± SE, n = 4) was found for each sensor unit in its linear operating range between 0-80 mN (0-1.101 MPa).

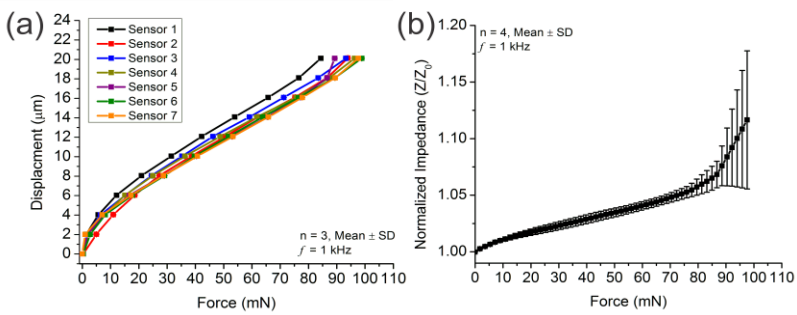

Figure 2: (a) Measured displacement as a function of force applied during sensor calibration. (b) Representative plot of normalized impedance measured vs. force applied to obtain calibration constant.

Table 1: Measured interfacial pressures for insertion experiment into agarose at different speeds.

Speed (mm/s)	Maximum ΔZ%: Sensor 1 (shank tip)	Average ΔZ%: Sensors 2-7 (n=6, Mean ± SE)
0.01	102%	20 ± 1.9%
0.03	70%	7 ± 0.8%
0.1	26%	4 ± 0.4%

In Vitro Testing

In preliminary results for insertion experiments (Table 1), some of the observed normalized impedance values (and thus pressures) greatly exceeded the calibrated linear range of the sensor, suggesting variability in sensor response ranges resulting from fabrication inconsistencies across the wafer. However, the percentage change in impedance suggests a trend in interfacial pressures experienced as a function of insertion speed. Thus it was observed that maximum pressures were located within the first 1 mm of the probe tip (Sensor 1), and were found to decrease by 75% for a 10× increase in speed.

CONCLUSION

Parylene-based mechanical pressure sensor arrays were characterized and used to assess effects of insertion speed on insertion mechanics *in vitro*. Despite the fluidically coupled sensing element, each sensor functioned similarly and had a calibration constant of 1417.89 ± 13.56 (mN/normalized impedance; Mean ± SE, n = 4) regardless of its position along the microchannel. *In vitro* insertion in agarose using the instrumented cortical probes indicated that the tip 1 mm of the probe encountered the highest pressures (102% impedance change) and decreased by 75% with a 10× increase in speed. As observed from our preliminary testing, Parylene-based EC-MEMS sensor arrays are an enabling technology to provide the first quantitative measurements of forces at the prosthesis-tissue interface during implantation. Currently further sensor characterization, and *ex vivo* and *in vivo* studies are planned to generate data and knowledge leading to improved surgical implantation techniques and mechanical design of neural implants towards realizing reliable chronic neural prosthetics.

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