Mechanical Evaluation of an Ultrafast Degrading Polymer as a Temporary Coating for Neural Probes

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Statement of Purpose: Implanted neural probes typically induce a high level of gliosis, thereby insulating them from neurons and significantly limiting their long-term recording capacity. Recent developments suggest that the use of smaller and more flexible probes can limit brain tissue damage and thus the development of gliosis. However, small and flexible probes (e.g., polyimide-based probes) are often too flexible to be inserted into the brain tissue. We have designed a novel, tyrosine-derived polycarbonate based copolymer that serves as a sacrificial coating to temporarily stiffen a flexible probe and facilitate implantation. The ultrafast degrading polymer coating erodes within hours after implantation, and thus limits the chronic inflammation that leads to the development of gliosis. In this study, we fabricated small flexible probe prototypes, developed a coating process for the probe with the ultrafast degrading polymer, and further evaluated the feasibility of using an ultrafast degrading polymer (E5005(2K)) as a temporary carrier for neural probes from the perspective of mechanical properties.

Methods: Terpolymer poly(45%DTE-co-50%DT-co-5% PEG2000 carbonate) (E5005(2K)) was synthesized using previously described procedures [1]. A series of non-electrical functional, SU-8 based probes were fabricated using a standard photolithography process. They were made with an anchor area for outer instrumentation integration and handling. Micromolding in capillaries (MiMiC) was designed to coat the small flexible probes. A master mold was used to prepare a replica molding channel made of polydimethylsiloxane (PDMS). The PDMS molding channel was carefully aligned with the small flexible probe under a microscope, and the polymer solutions were then used to fill the molding channel. Devices were baked in a vacuum oven at various temperatures for at least 24 hours to produce uniform coatings. Young's modulus was measured using a MTS Sintech Universal Testing Machine (Eden Praire, MN) equipped with a 100 N load cell. The insertion force of the probe into a 1% agarose gel was tested using a Kinexus rheometer (Malvern Instruments, United Kingdom) by compressing the probe at a rate of 0.5 mm/min against the agarose gel.

Results: Prototype SU-8 based, thin, flexible neural probes (20 μm thick) with different widths (5-50 μm) were fabricated. A micromolding procedure was then developed to produce a polymer coating that encapsulates the probe with smooth morphology and definite shape (Figure 1). 1% agarose gel was used as a phantom brain model to measure the force barrier during probe insertion. A linear increase in force barrier was measured as the cross-sectional area of the probe was increased. Further, the effect of the probe's tip on the force required for insertion into the 1% agarose gel was determined; sharp-tip probes had a significantly reduced barrier to overcome as compared to flat-tip probes. Next, the Young's modulus of the polymer probe was measured, which allowed us to estimate the buckling strength of the polymer using Euler's equation. Our preliminary results indicate that the force barrier for probe insertion is within 7mN, and the polymer coating necessary for gel insertion is within the specifications required for the probe's buckling strength. Proof-of-concept studies demonstrate that the polymer-coated neural probe prototype penetrates the 1% agarose gel without bending.

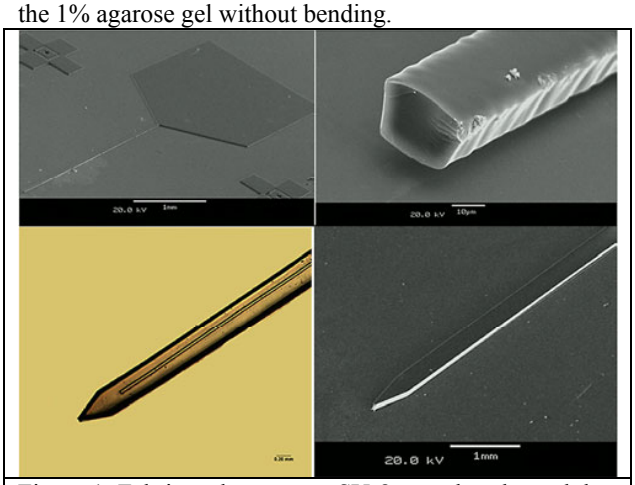

Figure 1. Fabricated prototype SU-8 neural probe and the coating of the probe with an ultrafast degrading tyrosine-based polycarbonate. The probe was fabricated using a photolithography on the surface of glass (A, B). The coating on the probe was made with a custom-made PDMS mold with polymer solution. The coating completely encapsulated the probe (C) and had a smooth morphology and definite shape (D).

Conclusions: A MiMiC based process was developed to coat small flexible probe prototypes with a smooth, uniform layer of ultrafast degrading polymer. Probe insertion mechanics were studied with a Kinexus system that allowed for sensitive detection of the probe's force barrier into a simulated brain tissue model (1% agarose gel). The thickness of the polymer coating required for probe insertion into the brain was estimated based on a combination of force measurements and the polymer's mechanical properties. The coated probe was successfully inserted into the 1% agarose gel, consistent with the force barrier measurements. These promising results demonstrate the feasibility of using an ultrafast degrading polymer as a temporary, sacrificial coating for small flexible neural probes, with the goal to obtain long-term neuronal signal acquisition.

References:

[1] D. Lewitus D et al. Acta Biomater. 2011; 7(6):2483-91.