Immobilized Liquid Coatings for Implantable Neural Electronics

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Statement of Purpose: Implantable neural electronics are clinically important in many treatments such as deep brain stimulation for Parkinson's disease, mapping of epileptic foci for surgical resection of the zone as well as in the development of brain-machine interfaces (BMI) for paralyzed individuals. Traditionally, implantable electronics much more resemble the electronics that are used in our everyday technology (computers, phones) than the tissue that surrounds such devices. For this reason, implantable electronics suffer from many limitations that prevent them from realizing full clinical impact. Such limitations include chronic biocompatibility, chronic electronic performance (e.g. biofouling, dielectric degradation) and significant surgical trauma from their implantation. Here, we have investigated immobilized liquid coatings on implantable electronics. Such coatings consist of a water-immiscible liquids (oil) that are anchored to the implant surface by being infused within an elastomer network to shield neural probes from surrounding tissue. Immobilized liquid coatings are slippery (ultralow sliding angles); others have been shown these coatings resist blood cell adhesion and bacterial biofouling. We investigate how such liquid coatings can benefit neural probe applications.

Methods: Immobilized liquid coatings were synthesized with silicone elastomers (PDMS) and silicone oils to generate both PDMS and oil-infused PDMS. Coatings were applied to metal wires via dip coating. Biocompatibility studies consisted of subcutaneous implantation of elastomer disks in C57BL/6J mice for one month. Tissue was histological processed and stained with H&E as well as Masson's Trichrome. Masson's Trichrome was used for collagen capsule quantification. Subcutaneous explants were immunofluorescently stained and imaged with confocal microscopy. Cell coverage on explants was determined by percentage blue pixels (DAPI/cell nuclei) relative to explant area. Coated metal wires were inserted into agarose hydrogels (brain models) for insertion force characterization with a mechanical tester. Coated needles were also inserted into freshly extracted brains of mice for investigation of insertion trauma.

Results: After subcutaneous implantation for one month in mice, elastomer alone and oil-infused elastomer (liquid coated) discs as well as surrounding tissue were removed. Using confocal microscopy, cell coverage on the explants was analyzed and revealed that oil-coated samples led to a greater than 3X reduction in cell adhesion to the implant (Fig.B-C). For the tissue surrounding the implants, the collagen capsule, a measure of the foreign body response, was measured. This histological analysis revealed that there was not a significant difference between elastomer and oil-coated elastomer (Fig.A). Metal wires, those used for implantable electrophysiology (recording and stimulation), were coated with either the elastomer or the oil-infused elastomer. Insertion into agarose hydrogels revealed a reduction in the sample average magnitude of insertion forces (Fig.D). The minimum force during insertion is mostly attributed to the friction force, and therefore, oil coatings likely reduce friction upon insertion. When implanted into a mouse brain, oil coated implants display less tissue damage (Fig.E-F) than oil-coated implants. The tissue border of insertion does not show signs of tearing, blood vessel shearing as well as extravascular blood cells, as are evident in the elastomer alone.

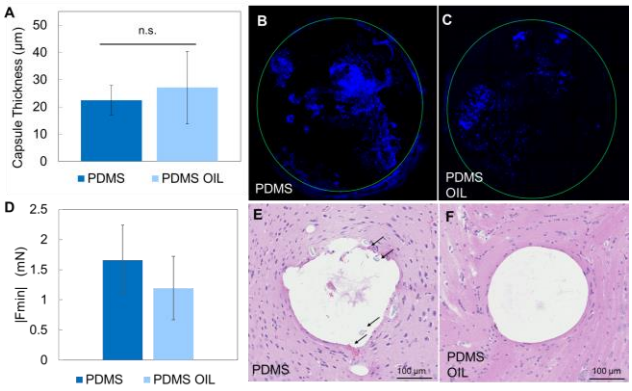

Figure 1. A) Collagen capsule thickness quantification. Oil-infused elastomers are likely just as biocompatible as elastomers alone. Means not significantly different, one-way ANOVA. B-C) DAPI staining of 5 mm diameter explant (green circle). ~3X less cell adhesion on oil-infused elastomer. D) Insertion force studies. Oil coating reduces force. E-F) H&E staining of a mouse brain inserted with coated metal needles. Oil-infused elastomer shows less traumatic insertion, less tissue tearing on insertion edge and no evident vascular damage.

Conclusions: Oil-infused elastomers appear to be just as biocompatible as their elastomer counter-parts, which are already regarded as biocompatible and are used as the packaging and dielectric material in many implantable bioelectronic devices like neural probes. Oil-infused elastomers lead to a great reduction in cells bound to the implant; therefore, this reduces biofouling that may contribute to a degradation in device performance. Finally, oil-infused elastomers reduce friction against tissue when inserted and lead to less insertion trauma. Less insertion trauma could improve acute and chronic outcomes of the surgery and device performance, and this will be an area of future investigation. Other future studies include further analysis of the site-specific foreign body response in the brain relevant to neural probes as well as electrophysiology studies to see if these coatings improve chronic tissue compatibility and electronic device performance.