Isolation of Electrophysiological Biosignal Utilizing Silicone and Xenogeneic Extracellular Matrix

John V. Larson, Theodore A. Kung, Melanie G. Urbanchek, Paul S. Cederna, Nicholas B. Langhals.
University of Michigan.

Statement of Purpose: The Regenerative Peripheral Nerve Interface (RPNI) is a biologic construct which is surgically fabricated using a piece of free muscle, a residual nerve of an amputated limb and an implanted epimysial electrode in order to achieve volitional control of bioengineered neuroprostheses. However, independently controlling the multiaxial functions of advanced prosthetic limbs requires implantation of multiple proximate RPNIs. Differentiating the independent signals relies on effective signal isolation techniques, necessitating the addition of a biologically compatible insulating substrate in conjunction with the RPNI. We therefore investigated the *in vivo* insulating properties of silicone elastomer (Dow Corning Corp., Midland, MI) and xenogeneic small intestinal submucosa (SIS, Cook Biotech Inc., West Lafayette, IN) in conjunction with the RPNI.

Methods: In a rat hindlimb model, four groups (N=6/group) were randomly tested using a repeated measures design. To minimize signal interference from adjacent musculature, a medial gastrocnemius muscle flap was elevated from the posterior compartment while leaving the neurovascular pedicle intact. The flap was rotated into a chamber containing mineral oil and secured to the base. A stainless steel electrode (Plastics One Inc., Roanoke, VA) was affixed to the surface of the gastrocnemius. The muscle was then encircled with either 1-layer SIS, 4-layer SIS, silicone elastomer, or no covering (control). A second stainless steel electrode was placed over the experimental material. Finally, an external silicone layer was used to encircle the entire construct. The tibial nerve was exposed proximally and a stainless steel hook electrode (Harvard Apparatus, Holliston, MA) was placed around it for electrical stimulation. Current applied to the hook electrode was varied from 10 uA - 208uA over 100 pulses, at a repetition rate of 0.5 Hz. Electromyographic (EMG) studies were performed to evaluate the degree of signal isolation between the two electrodes, defined as the proportion of recorded signal from the electrode placed superficial to the signal insulator divided by the recorded signal from the electrode placed immediately on the surface of the muscle. Data were analyzed using ANOVA and Bonferroni post-test, with significance set at $p<0.05$.

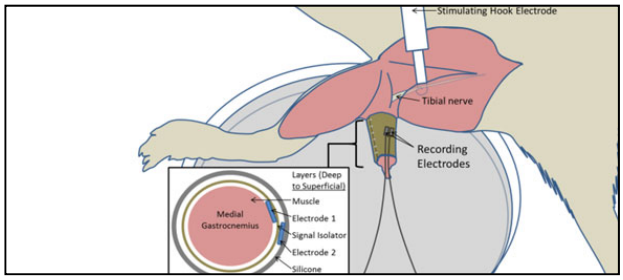

Figure 1. Experimental Setup

Results: There were no differences in stimulation threshold or muscle latency between the groups. Signal isolation of the Compound Muscle Action Potential (CMAP) amplitude at stimulation threshold was significantly greater using silicone (60.0%, Standard Deviation (SD) 24.7%) compared with 1-layer Surgisis (3.0%, SD 5.2%), 4-layer Surgisis (5.9%, SD 6.5%), or control (1.0%, SD 1.5%) ($p=<0.001$). Isolation of the CMAP peak-to-peak amplitude at maximal stimulation was also greater with silicone (57.0%, SD 31.1%) versus 1-layer Surgisis (4.1%, SD 5.1%), 4-layer Surgisis (0.0%, SD 2.6%), or control (0.0%, SD 1.3%) ($p=<0.001$).

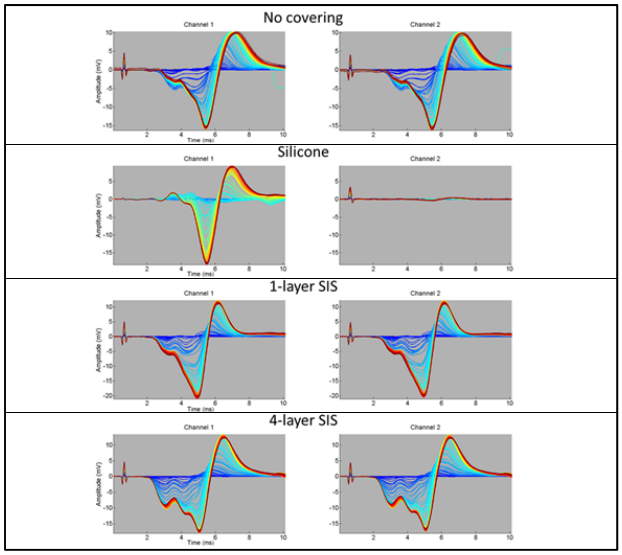

Figure 2. Time synced EMG recordings. Left column - Channel 1(Control electrode), Right column - Channel 2 (Experimental electrode).

Conclusions: Silicone provides superior signal isolation, making it an effective material for biosignal insulation for the RPNI. However, use of a silicone layer will likely inhibit muscle revascularization and viability, and must therefore be restricted to a limited amount of muscle surface area. SIS provides minimal signal isolation acutely, yet functions to secure the electrode and provides an advantageous tissue scaffold for the RPNI by facilitating biological integration. Future efforts will evaluate the effects of chronic implantation on signal isolation levels in RPNIs and explore the effects of utilizing different combinations of biotic and abiotic materials to optimize biosignal insulation while maintaining tissue viability.

Acknowledgements: This work was sponsored by the Defense Advanced Research Projects Agency (DARPA) MTO under the auspices of Dr. Jack Judy through the Space and Naval Warfare Systems Center, Pacific Grant/Contract No. N66001-11-C-4190 and the Plastic Surgery Foundation.