Biomaterials and Electrode Strategies in Regenerative Peripheral Nerve Interfaces

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Statement of Purpose: Loss of an upper limb results in considerable physical and often psychological impairment, with the majority occurring in young, healthy and productive members of society. To restore natural function after amputation, a reliable and biologically compatible neural interface is needed to transfer efferent motor signals between peripheral nerves and micro-processors controlling advanced neuroprostheses. Our lab has developed a Regenerative Peripheral Nerve Interface (RPNI), a surgically implantable device that achieves a robust connection with the distal ends of divided nerves in an amputated limb. This offers the potential for both high-fidelity motor function and sensory feedback without the need for relearning previously automatic extremity functions. We are currently investigating the biological and electrical properties of RPNIs in both the acute and chronic setting to enhance the fidelity and long-term stability of both motor and sensory signals.

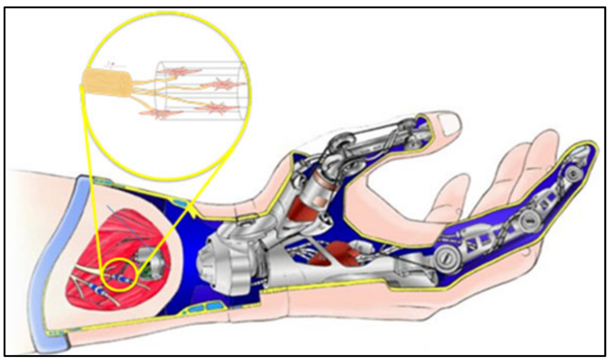

Figure 1. Schematic of Prosthetic Hand- The RPNI can be integrated into the residual limb for reliable, high fidelity connections between the biotic and abiotic interfaces.

Methods: The study population includes adult, male, specific pathogen-free Fisher 344 rats (Harlan Laboratories Inc., Haslett, MI). In a rat hindlimb model, extensor digitorum longus muscle is transferred proximally to the site of peripheral nerve transection and the residual proximal nerve segment is used to neurotize the muscle. Electrodes utilized in the RPNI include stainless steel (PlasticsOne, Roanoke, VA) and polyimide 32-channel electrode arrays (NeuroNexus, Ann Arbor, MI). These electrodes are coated with electroconductive polymer poly(3,4-ethylenedioxythiophene) (PEDOT), affixed to the epimysial surface of the transferred muscle, and the entire construct is wrapped in xenogeneic small intestinal submucosa extracellular matrix (Cook Biotech Inc., West Lafayette, IN).

Results: The use of free muscle prevents the development of painful neuromas, amplifies electrophysiological signals, and protects the delicate nervous tissue from the rigid electrode by functioning as a biologic shock-absorber. Xenogeneic small intestinal submucosa extracellular matrix provides a porous outer layer which serves to contain the interface while also allowing transferred muscle revascularization. Nerve regeneration and successful neuromuscular junction formation demonstrate electrical continuity between the host tissue and implanted electrodes. PEDOT facilitates charge exchange between the ionic biological tissue and electronic abiotic electrodes. Serial percutaneous electromyographic studies demonstrate evidence of reinnervation of the RPNI and signal transduction through the interface. Histology and muscle force testing also provide evidence of biological integration including revascularization, viability, reinnervation, and minimal scar deposition.

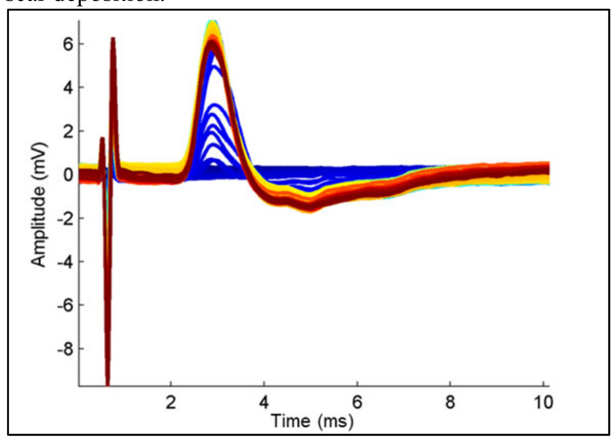

Figure 2. Time synchronized EMG traces recorded from RPNI. Stimulation varied 10 uA-2010 uA over 200 pulses at a rate of 0.5 Hz. Threshold electrical stimulation for eliciting a Compound Muscle Action Potential (CMAP) was 150 uA. Stimulation at 670 uA resulted in a max CMAP peak-to-peak amplitude of 8.31 mV (at 2.89 ms).

Conclusions: Regenerative peripheral nerve interfaces (RPNIs) have potential as biocompatible, lifelong signal interfaces for control of robotic prosthetic devices in amputees. Acquisition of the data necessary to enable the recording of high quality signals for extended periods is currently underway. Future work is focused on developing strategies for optimizing information extraction from these interfaces and enhancing signal isolation using advanced biomaterials. Continued refinement of RPNI technology will facilitate use in humans by improving their overall quality of life.

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