Spinal nerve interfaces for bidirectional communication with prosthetic limbs

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Abstract— **The goal of this work is to develop a high-performance, clinically viable system for interfacing directly with spinal nerve (SN) roots to extract prosthesis-control signals from ventral root (VR) recordings and deliver sensory feedback by microstimulation of primary afferent fibers in the dorsal roots or dorsal root ganglia (DRG).**

I. Overview

Advanced prosthetic limbs are capable of generating dexterous, anthropomorphic movements with speed, power, and grace that rival human capabilities. To realize the full potential of these limbs, users must be able to control and sense actions of the limb's many degrees of freedom (DOF) in parallel and in real-time. While most upper extremity amputees prefer body-powered controls, those generally work well for controlling only a single DOF (e.g. grip aperture). Myoelectric interfaces can provide multi-DOF control that enables multiple grasp and reaching movements, but users cannot directly feel the actions performed by the limb as they can with cable-driven devices.

High-density microelectrode arrays provide a unique opportunity for directly engaging the body's native motor and sensory pathways to achieve high DOF control and sensory feedback for prosthetic limbs. A variety of approaches are being considered to interface with motor and sensory neurons at various levels of the nervous system, from peripheral nerves to cerebral cortex. This work has advanced rapidly to the point that multiple small-scale pilot human trials of intracortical neural interface technologies are being performed in humans [1-2].

The SN roots have thus far received little consideration as a potential target for neural prosthesis applications, despite offering several potential advantages. First, the SNs are the only peripheral location where motor (VR) and sensory (DRG) fibers are segregated, improving isolation and quality of signals recorded from motor neurons. Second, the SNs are compact and mechanically stable, protected by surrounding vertebral bones that shield the implant site from physical disruption. Third, there are several, well-established clinical procedures for accessing the SNs using minimally invasive procedures. Thus, open surgery would not be required to install a SN interface, greatly reducing surgical morbidity and recovery times.

In this study, we investigated the SN as a target for chronic recording of motor signals and sensory nerve stimulation. Adult male cats were used; the University of Pittsburgh Institutional Animal Care and Use Committee approved all procedures. Floating microelectrode arrays (Microprobes) were inserted in the left L6 and L7 SNs using a high-speed inserter (Blackrock Microsystems) and custom holder for the arrays. The lengths of the electrodes were varied to access a range of depths in the SN to access either motor (VR) or sensory (DRG) fibers. Bipolar stainless steel electrodes were placed in 8-10 major hindlimb muscles for electromyography (EMG). A 5-contact spiral nerve cuff was placed on the sciatic nerve for electroneurography (ENG).

Neural recording and stimulation experiments typically began 3-5 days after surgery. Single unit activity (i.e. spikes) were detected and sorted on the VR electrodes to measure motor signals associated with muscle activation (EMG). Results show that large, well-isolated spikes can be recorded from VR fibers for up to 6 weeks post-surgery. DRG microstimulation experiments were performed to evaluate recruitment of primary afferent fibers for delivering sensory feedback. The threshold for evoking activity in the sciatic nerve ENG was measured and found to remain generally stable (typically < ~15 µA) for several months following surgery. Thresholds for evoking behavioral responses by single-channel DRG microstimulation were also assessed and found to be typically < 25 µA per channel. These studies represent the first attempt to create a chronic SN interface for prosthesis control and sensory feedback.

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