Using Multiple High-Count Electrode Arrays in Human Median and Ulnar Nerves to Restore Sensorimotor Function after Previous Transradial Amputation of the Hand

Gregory A. Clark, Suzanne Wendelken, David M. Page, Tyler Davis, Heather A. C. Wark, Richard A. Normann, David J. Warren-*IEEE member*, and Douglas T. Hutchinson

Abstract—**Peripheral nerve interfaces that can record from and stimulate large numbers of different nerve fibers selectively and independently may help restore intuitive and effective motor and sensory function after hand amputation. To this end, and extending previous work in two subjects, two 100-electrode Utah Slanted Electrode Arrays (USEAs) were implanted for four weeks in the residual ulnar and median nerves of a 50-year-old male whose left, dominant hand had been amputated 21 years previously. Subsequent experiments involved 1) recording from USEAs for real-time control of a virtual prosthetic hand; 2) stimulation to evoke somatosensory percepts; and 3) closed-loop sensorimotor control. Overall, partial motor control and sensation were achieved using USEAs. 1) Isolated action potentials recorded from nerve motor fibers, although sparse at these distal implant sites, were activated during fictive movements of the phantom hand. Unlike in our previous two subjects, electromyographic (EMG) activity contributed to most online recordings and decodes, but was reduced in offline analyses using common average referencing. Online and offline Kalman-filter decodes of thresholded neural or EMG spikes independently controlled different digits of the virtual hand with one or two degrees of freedom. 2) Microstimulation through individual electrodes of the two USEAs evoked up to 106 different percepts, covering much of the phantom hand. The subject discriminated among five perceived stimulus locations, and between two somatosensory submodalities at a single location. 3) USEA-evoked percepts, mimicking contact with either a near or distal virtual target, were used to terminate movements of the virtual hand controlled with USEA recordings comprised wholly or mostly of EMG. These results further indicate that USEAs can help restore sensory and motor function after hand loss.**

I. Introduction

Limb amputation profoundly affects the activities of daily living (ADL), involving ~1.6 million people in the U.S. alone [1]. Advanced prosthetic arms and hands exist with up to 26 degrees of freedom (DOF) [2], but lack intuitive, dexterous control signals and most sensory feedback.

Peripheral nerve interfaces may help overcome these limitations. The Utah Slanted Electrode Array (USEA) [3] has 100 independent electrodes that penetrate into peripheral nerve fascicles. USEA electrodes allow selective recordings from motor fibers to obtain control signals, and stimulation of sensory nerve fibers to provide cutaneous and proprioceptive feedback. A non-slanted version has been used successfully in human cortex [4]. The flat interface nerve electrode FINE [5], a cuff electrode, provides long-term stimulation, but selectivity at the subfascicular level is limited, and extraneural electrodes are not well suited for recording individual neural discharges. Longitudinal intrafascicular electrodes (LIFEs) [6, 7] and transversal intrafascicular multichannel electrodes (TIMEs) [8] record motor control signals and evoke stimulus percepts, but have relatively few channels. Electromyographic (EMG) activity recorded with surface electrodes or implantable myoelectric sensors (IMES) provides useful control signals, particularly in targeted reinnervation [9], but these sensors do not provide neural stimulation.

We recently demonstrated that single USEAs, implanted in residual arm nerves of two humans after hand loss, can provide offline control of a virtual hand for up to 13 types of digit movements, and activate a greater number of sensory percepts than previously achieved [10]. We now extend this work by using USEAs in two nerves of the same residual arm, so as to provide greater coverage for motor commands and sensory percepts. Further, simultaneous recording and stimulation provided bidirectional sensorimotor control.

II. Methods

A. Subject

The subject was an active 50-year-old male who had his left, dominant hand amputated at the wrist 21 years previously, after a crush injury. The study was approved by the University of Utah Institutional Review Board, the Salt Lake City Veterans Affairs Hospital Research and Development Service Center, and the Department of the Navy Human Research Protection Program.

978-1-4244-7929-0/14/$26.00 ©2014 IEEE