Development of a sensory neuroprosthesis for artificial limbs

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1. Motivation

Trauma, vascular disease, and diabetes are leading causes of limb amputation and sensory deficits in both civilian and military populations. This burden is being offset in part by advances in prosthetic limb technology that extend the usability and capabilities of upper and lower extremity prostheses [1-3]. But, effective strategies for providing amputees with tactile and proprioceptive feedback remain elusive.

Problems associated with absent or impaired somatosensory feedback are evident among users of both upper and lower extremity prostheses, as well as in persons after total joint replacement. Those who wear lower limb prostheses have limited sensation for the limb, due to the natural sensory loss resulting from amputation or neuropathic disability [4]. This population is at higher risk for falling and experiences greater fear of falling than able-bodied individuals [5]. The absence of adequate sensory feedback for the limb results in impaired balance and gait control, slower rates of learning, and increased energy expenditure [6].

2. State of the Art

Although new devices such as the Power Knee (Ossur) and i-Limb (Touch Bionics, Inc.) demonstrate the technology for powered and myoelectrically controlled prostheses is advancing at a high rate, body-powered systems remain better at providing users with a sensory awareness through the body activated cable system [7].

3. Own Approach

The goal of this work is to develop a high performance somatosensory neural prosthesis for providing tactile and proprioceptive sensory inputs after limb loss. Our approach is based on patterned microstimulation of primary afferent neurons in the dorsal root ganglia (DRG) [8]. DRG neurons remain viable even after long-term amputation, electrical stimulation of the residual nerve evokes natural sensations in the phantom limb [9]. The proposed method is unique and uses arrays of microelectrodes to deliver microamp-level pulses of electrical current in the DRG to achieve focal activation of sensory nerve targets, offering advantages over alternative methods, such as epineural stimulation, which is less selective for activating smaller diameter fibers [10]. In principle, our approach would enable a broad range of sensory fibers to be recruited selectively, including afferent neurons that elicit cutaneous, proprioceptive, thermal, and pain sensations.

4. Current Results

To date, we have performed acute and chronic studies in felines to examine the effects of DRG microstimulation on the recruitment of sensory neurons. Patterned microstimulation evokes distinct and reliable responses in primary somatosensory cortex, consistent with the goal of conveying tactile and proprioceptive feedback to the subject. Testing in alert cats shows that stimulation is effective at evoking distinct behavioral responses without causing pain or aversive reactions.

5. Best Possible Outcome

The ultimate goal of this work is to develop a somatosensory neural prosthesis that can target the DRG and be implanted using minimally invasive spine surgery (MISS) methods. Restoration of sensory feedback for the upper and lower extremities would be achieved by targeting DRG in the cervical and lumbar spine, respectively.

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