Lasting Quality of Regenerative Peripheral Nerve Interface Signals throughout a Fatigue Protocol

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Abstract

Background: Regenerative Peripheral Nerve Interfaces (RPNIs) transfer signals between an amputee's residual limb and motorized prostheses. RPNIs are surgically transferred autologous muscle neurotized by residual nerve fascicles. Implanted electrodes transduce electromyographic signals from the RPNIs. RPNI signals have been shown to control brief prosthetic movements, but RPNI use during prolonged activity has not been demonstrated. Our purpose was to measure both RPNI maximal signaling capacity and signaling during continuous, repetitive, submaximal use.

Methods: Rats were assigned to either RPNI (n=4) or Control (n=7) groups. For the RPNI group, the extensor digitorum longus (EDL) muscle was transferred to the thigh and neurotized by the transected peroneal nerve. Bipolar electrodes were secured to the EDL muscles in each group. Five months post-surgery, maximal compound muscle action potential (CMAP) and maximal contractile force were measured following peroneal nerve stimulation. A 20-minute intermittent activation protocol that fatigues normal muscle was administered. This submaximal force protocol totaled 720 repeats of muscle excitation, contraction, and relaxation (Figure 1). Short excitations were evoked by 300 milliseconds of stimulation each second and repeated for 360 contractions. This was followed by long excitations evoked by 600 milliseconds of stimulation per second for another 360 contractions. After five minutes of rest, maximal excitation was again measured.

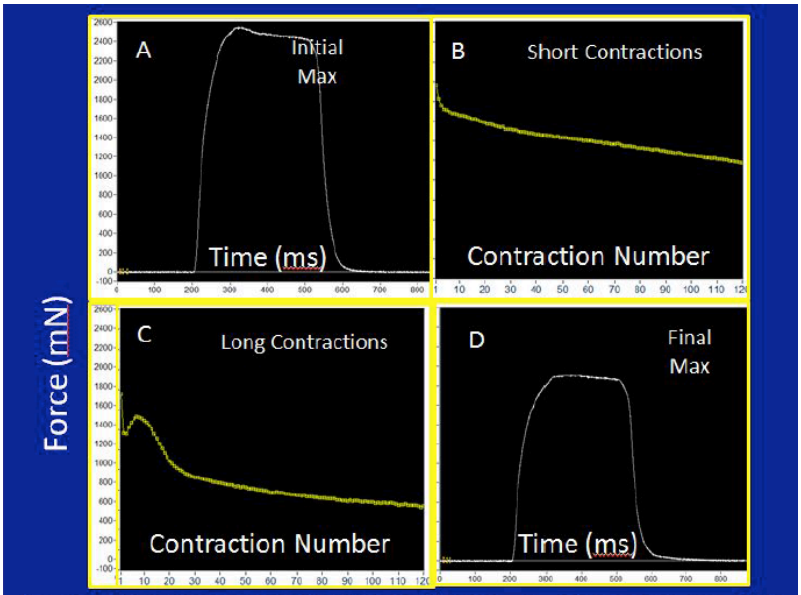

Figure 1. Fatigue Protocol. (A) Maximal force, rest 5 minutes, (B) Short contractions, 360 contractions, 1 every second, 300 milliseconds in length, 40 hertz stimulation, (C) Long contractions, 360 contractions, 1 every second, 600 milliseconds in length, 40 hertz stimulation, (D) Rest five minutes and repeat maximal contraction.

Results: A high correlation was verified between maximal CMAP and maximal contractile force ($r=0.81$, $p < 0.01$) indicating RPNI signaling. RPNI group CMAP was 32% and maximal force was 23% of Control group amplitudes. The RPNI group averaged 26% of maximal force during shorter contractions and 10% during longer contractions (Figure 2). The Control group maintained 28% and 23% of maximal force during short and long contractions. Following repetitive activations and a five minute rest, RPNIs recovered maximal contractile signaling on average equaling 72% of their individual initial maximal force, while Controls recovered 87% of their initial maximal force production.

Figure 2: All forces are shown as a percentage of the initial maximum force. Bars indicate maximal contractile force before the repeated submaximal contraction series: Pre Fatigue Max, and after two series: Post Fatigue Max. Circles indicate the submaximal contractile force as a percentage of group maximal contractile force. During Series One, peroneal nerve was stimulated at 40 HZ, for 300 ms duration, with a train rate of one train per second, for six minutes. Series Two was the same except stimulation duration was raised to 600 ms. A total 720 contractions were evoked. The negative slopes indicate the rate of signal fatigue for each group. The slopes did not differ significantly. It is interesting that RPNI Device was not able to achieve the same percentage of maximal force as the Control group.

Conclusions: Though signals produced by the RPNIs were not as large as Controls, signaling from the RPNIs resisted fatigue during repetitive activation similar to Control muscle. RPNIs also showed recovery of maximal signaling within five minutes of repeated contractions. All RPNI signals were in the millivolt or milliNewton range with sufficient information to control prostheses.

Financial Support: Defense Advanced Research Projects Agency (DARPA) MTO Contract No. N66001-11-C-4190.

None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.