Partial Skeletal Muscle Grafts for Prosthetic Control

Shoshana L. Woo, MD; Melanie G. Urbanchek, PhD; Xin Zheng, BS; Michelle K. Leach, PhD; Jana D. Moon, BS; Paul S. Cederna, MD; Nicholas B. Langhals, PhD

Abstract

Background: Nonvascularized partial skeletal muscle grafts are notorious for their limited force-generating capacity and tendency to degenerate in the absence of reinnervation [1-3]. Accompanied by peripheral nerve implantation, however, partial muscle grafts can survive and transmit detectable electromyographic (EMG) signals capable of prosthetic control [4]. Our study investigated partial muscle graft survival in the construction of regenerative peripheral nerve interfaces (RPNIs) and further characterized their electrophysiological properties across various muscle donor sites.

Methods: Twenty F344 rats were assigned to 1 of 5 groups based on muscle graft type used for RPNI construction: 1) control-whole extensor digitorum longus; 2) partial biceps femoris; 3) partial rectus femoris; 4) partial lateral gastrocnemius; and 5) partial vastus medialis. Each graft of approximately 140-mg was transferred to the femur, wrapped in small intestinal submucosa for tissue isolation, and implanted with the transected common peroneal nerve. After 4 months of RPNI recovery, *in situ* EMG (Figure 1) and force testing were performed.

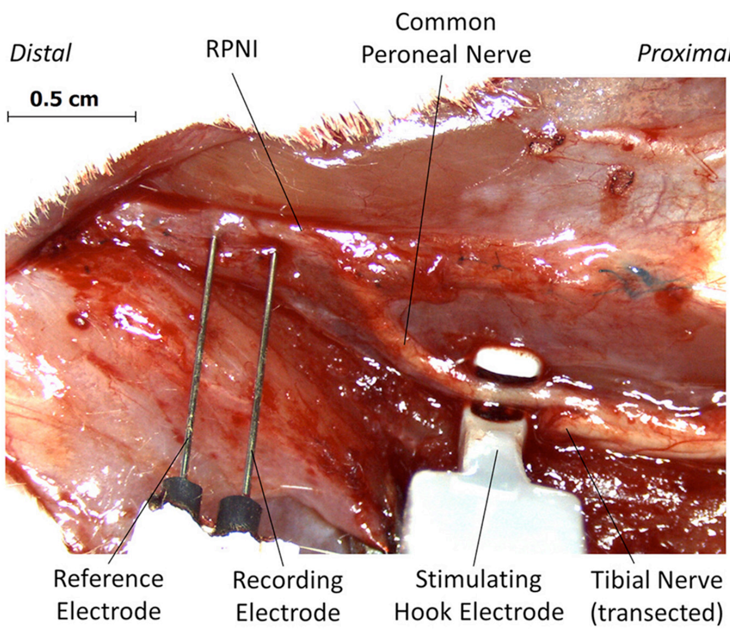

Figure 1. Example of a regenerative peripheral nerve interface (RPNI) at 4 months, constructed with a partial lateral gastrocnemius muscle graft implanted with the common peroneal nerve in the thigh. Bipolar needle electromyography (EMG) was performed using direct stimulation of the common peroneal nerve. The tibial nerve was transected just prior to testing in order to minimize signal interference.

Results: Twelve of 16 partial muscle RPNIs demonstrated detectable EMG function at 4 months. Significant differences between control RPNIs (n=4) and functional partial muscle RPNIs (n=12) included average mass (118±42 mg vs. 66±25 mg), EMG peak-to-peak amplitude (6.7±2.3 mV vs. 1.5±1.6 mV), and maximum tetanic force (729±666 mN vs. 175±154 mN). Outcomes by group for all RPNIs (n=20) are depicted in Figure 2. RPNI mass was the overriding significant predictor of EMG peak-to-peak amplitude ($p<0.001$). After adjusting for RPNI mass, donor muscle type showed no correlation with partial muscle EMG signal strength.

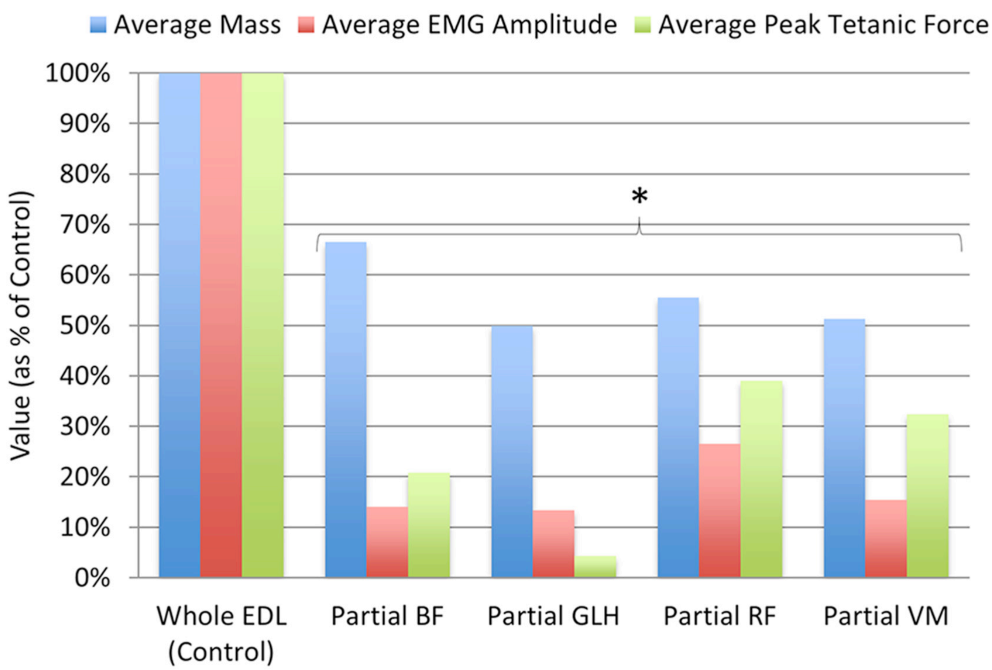

Figure 2. Comparison of control versus partial muscle RPNI mass, EMG peak-to-peak amplitude, and peak tetanic force at 4 months. Values for partial muscle RPNI groups are expressed as percentages of control group values, with n=4 per group. All values for partial muscle RPNI groups were significantly lower than their control group counterparts (*, $p < 0.05$). *EDL, extensor digitorum longus; BF, biceps femoris; GLH, gastrocnemius, lateral head; RF, rectus femoris; VM, vastus medialis.*

Conclusions: Partial muscle graft RPNIs transmit detectable EMG signals with a 75% success rate at 4 months. This proof of concept feasibility underscores the potential to develop and refine partial muscle graft-based interfaces to harness peripheral nerve signals for high-fidelity prosthetic control in amputees. While signal size remains favorable (i.e. 10-50 times larger than signals recorded directly from peripheral nerves) [5], further studies are warranted for optimization of partial muscle graft regeneration and methods of signal acquisition.

References

1. Boyce, R.G., Nuss, D.W. & Kluka, E.A. The use of autogenous fat, fascia, and nonvascularized muscle grafts in the head and neck. *Otolaryngologic clinics of North America* **27**, 39-68 (1994).
2. Mong, F.F. Histological and histochemical studies on the nervous influence on minced muscle regeneration of triceps surae of the rat. *Journal of morphology* **151**, 451-462 (1977).
3. Carlson, B.M. & Gutmann, E. Contractile and histochemical properties of sliced muscle grafts regenerating in normal and denervated rat limbs. *Experimental neurology* **50**, 319-329 (1976).
4. Woo SL, U.M., Cederna PS, Langhals NB. Revisiting Nonvascularized Partial Muscle Grafts: A Novel Use for Prosthetic Control. *Plast Reconstr Surg* (Accepted 03 February 2014. In press.).
5. Clark, G.A., Ledbetter, N.M., Warren, D.J. & Harrison, R.R. Recording sensory and motor information from peripheral nerves with Utah Slanted Electrode Arrays. *Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference* **2011**, 4641-4644 (2011).

Disclosure/Financial Support

Supported by DARPA (N66001-11-C-4190), the Plastic Surgery Foundation, and the Frederick A. Coller Surgical Society.

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