An Actin-Myosin Machine

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The Problem: A long standing goal in engineering is to exploit the unique designs of biological systems to guide the development of autonomous biomimetic machines that exhibit agility, strength and speed in a variety of natural environments. Most critical to this effort is the development of an actuator that behaves like muscle. Although important research has been conducted to advance actuator function, engineering science has not yet produced an effective artificial muscle. Polymer gels provide stresses and displacements comparable to muscle, but their contractile velocity is far too slow for many applications[4]. The goal of our work is to investigate the feasibility of using animal-derived muscle as an actuator for robotic applications in the millimeter to centimeter size scale.

Motivation: Muscle is employed almost exclusively by animals for actuation, from sub-millimeter organisms to blue whales. Using muscle to power movement has certain advantages. Muscle generates force quietly, allowing predators to move within close proximity of prey. Muscle is also adaptive and responds to varying work loads by modulating its structure to meet specific tasks demands. Still further, muscle is efficient. Working aerobically, muscle can generate up to 4000 kJ of work from just 1 Kg of glucose. And for its size, muscle can generate a large isometric force, enabling the extremities of organisms to be lightweight but strong.

Approach: In our work we are specifically engineering muscle tissue for machine actuation. Genetic, chemical, and electromechanical interventions are being employed to enhance muscle robustness and contractile function in vitro. Two types of muscle tissue are examined: native and cultured tissues from genetically-modified mice (Figure 1) and native whole muscle from non-mammalian sources such as frog and crab. Once engineered, the contractility and robustness of these tissues are characterized and comparisons are made to current artificial muscle technologies.

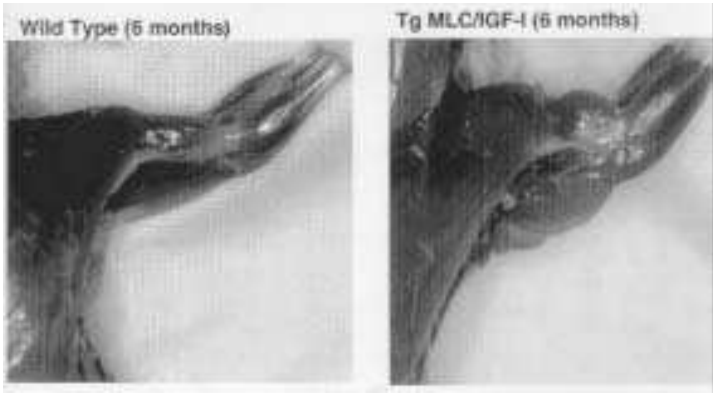

Figure 1: The forelimb of a wildtype mouse (left) and a genetically-modified mouse (right) are shown. The pronounced muscular hypertrophy in the transgenic animal is the result of locally-acting IGF-I

Difficulty: Perhaps researchers in the past did not consider muscle a viable actuator because of tissue robustness problems. It is true that native whole muscle, once extracted from an animal, only retains contractility for several days using standard organ culture techniques[2, 3]. However, recent advances in biology suggest that enhancing

tissue robustness in vitro may now be an achievable goal. Preliminary experiments conducted by Nadia Rosenthal at MGH suggest that IGF-I transgenic native whole muscle is more robustness with an enhanced contractility compared to wildtype tissues. IGF-I genetic manipulations have been shown to enhance the tetanic force of native wildtype muscle by as much as 25 percent[1]. We also have preliminary evidence from experiments conducted in our lab that these interventions promote cell differentiation and robustness in cultured tissues grown from transgenic mice.

Impact: A muscle actuator may offer certain advantages over contemporary motor technologies. As with real muscle, an engineered muscle could offer a transduction efficiency far superior to that of electric motors, or shape memory alloys, powered by battery or fuel cell. Although high efficiencies can be achieved from gasoline engines, stealth quietness cannot; gas powered autonomous robots are noisy and produce environmentally unfriendly bi-products. In distinction, engineered muscle would generate force quietly with biodegradable bi-products. Finally, there remains the possibility of manufacturing engineered muscle at low cost. Starting from the cells of an animal, it may be possible to grow hundreds of muscle actuators.

Future Work: Once we have successfully engineered a muscle actuator, we will then build a morphologically and dynamically realistic robotic fish that is capable of achieving steady-state swimming speeds comparable to living organisms. We hypothesize that biological steady-state swimming speeds and propulsive efficiencies can be achieved through the application of a hybrid-robot design in which the engineered muscle actuator is used to power undulating movements across a synthetic vertebral column. Machine architecture will be modeled after the shape, compliance and flexibilities of small rainbow trout (Oncorhynchus mykiss), a common animal model used in many previous experimental investigations on swimming dynamics. To achieve fish-like movements, we propose to use kinematic data from real swimming trout to train the robotic swimmer using a supervised learning strategy. A robotic fish platform has been chosen for this Program because it offers a sufficiently complex locomotory model where control issues in robotic locomotion can be readily addressed while using a biologically-based actuator system.

Research Support: Funding for this research is provided by the Controlled Biological and Biomimetic Systems Program within DARPA.

References:

[1] H. Sweeney E. Barton-Davis, D. Shoturma. Viral mediated expression of igf-i blocks the aging-related loss of skeletal muscle function. *Proc. Natl. Acad. Sci., USA*, pages 15603–15607, 1998.

[2] A. Harris and R. Miledi. A study of frog muscle maintained in organ culture. *J. Physiol.*, pages 207–226, 1972.

[3] M. McDonagh. Mechanical properties of muscles from xenopus borealis following maintenance in organ culture. *Comp. Biochem. Physiol.*, pages 377–382, 1984.

[4] Y. Tatara. Mechanochemical actuators. *Advanced Robotics*, pages 69–85, 1987.