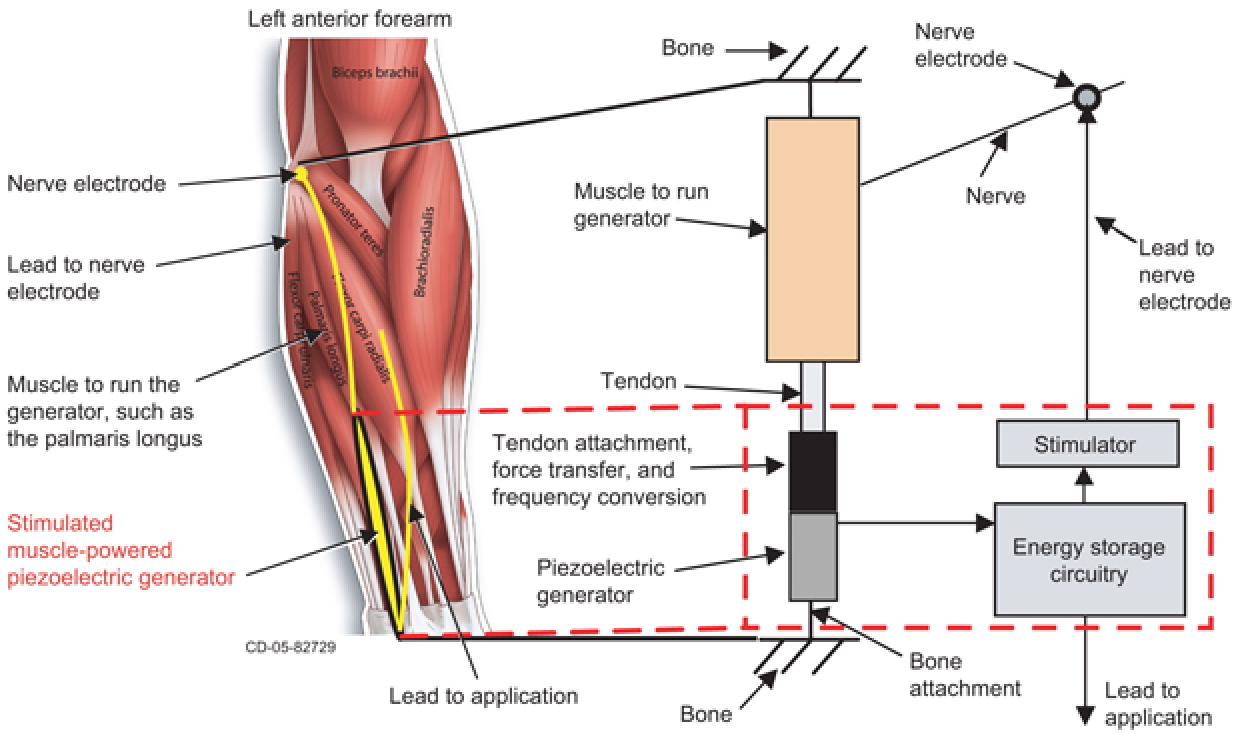
Concept Developed for an Implanted Stimulated Muscle-Powered Piezoelectric Generator

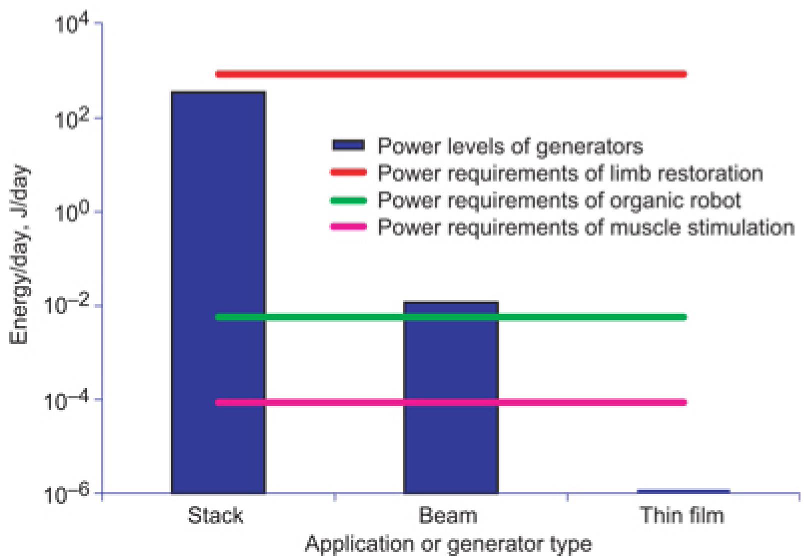


Concept for an implanted, stimulated muscle-powered generator. The tendon of a muscle, such as the palmaris longus, is detached from its distal bone. Piezoelectric material is attached in series between the tendon and bone. Electrically stimulated muscle contractions exert force on the piezoelectric material, producing a charge across the material. The generated energy is stored in a battery or capacitor and used to power the stimulator and other loads.

Implanted electronic devices are typically powered by batteries or transcutaneous power transmission. Batteries must be replaced or recharged, and transcutaneous power sources burden the patient or subject with external equipment prone to failure. A completely self-sustaining implanted power source would alleviate these limitations. Skeletal muscle provides an available autologous power source containing native chemical energy that produces power in excess of the requirements for muscle activation by motor nerve stimulation. A concept has been developed to convert stimulated skeletal muscle power into electrical energy (see the preceding illustration). We propose to connect a piezoelectric generator between a muscle tendon and bone. Electrically stimulated muscle contractions would exert force on the piezoelectric generator, charging a storage circuit that would be used to power the stimulator and other devices.

Software circuit models are being used to evaluate the fundamental design considerations for the muscle-powered piezoelectric generator. We are evaluating the most effective size, shape, and material for the piezoelectric generator, given the physiological constraints imposed by the biological system. Piezoelectric generator shapes include stacks, beams, and thin film; and piezoelectric materials include ceramics and polymers. A piezoelectric generator can be electrically represented as a voltage source in series with a capacitor. The voltage depends on the magnitude, frequency, and direction of the force application; the piezoelectric constant; and the dimensions of the material. The capacitance depends on the dielectric constant and the dimensions of the material. The input to the piezoelectric generator is the tension developed by the muscle. For simulation purposes, this input was modeled as a 10-N, 1-Hz sinusoid.

Piezoelectric stack generators were found to produce more power than beam or thin-film generators for this application. These stacks are composed of many layers of thin lead zirconate titanate plates. The most sensitive parameter to output power generation was the overall thickness, indicating that the number of layers should be maximized. Increasing the number of layers increases the capacitance of the generator, allowing impedance matching with a higher capacity capacitor in the storage circuit.



Summary of the power-generation levels of the three generators compared with the power-consumption levels of two applications and the power-consumption level of the muscle stimulator required to run the generator. The stack generator theoretically produces more power than is needed to power the organic robot; therefore, a self-supporting system may be feasible.

The theoretical output power of the piezoelectric stack generator was significantly higher than the anticipated power requirements for muscle stimulation or organic robot operation, indicating that a stimulated muscle-powered generator may be feasible (see the preceding bar chart). The generator may be feasible for totally powering some applications and for augmenting external power sources or implanted, limited-life power sources of high-power-consuming applications. Additional modifications, such as frequency tuning and optimization of the system, may be required to increase the output power of the generator enough to power applications such as neuroprostheses for restoring limb function. The results support the continued development of an implanted, stimulated muscle-powered piezoelectric generator.

This project is funded by NASA Glenn Research Center's Alternate Energy Foundational Technologies Project, which is part of the NASA Vehicle System Program of the Aeronautics Research Enterprise. The project is a collaboration between investigators at NASA, Case Western Reserve University, and MetroHealth Medical Center.

Find out more about this research at http://www.grc.nasa.gov/WWW/AERO/base/rac.htm

Glenn contacts: Beth Lewandowski, 216-433-8873, Beth.E.Lewandowski@nasa.gov; and David Ercegovic, 216-977-7009, David.B.Ercegovic@nasa.gov
Case Western Reserve University contacts: Kevin Kilgore, 216-778-3801, klk4@po.cwru.edu; and Kenneth Gustafson, 216-368-8626, kjg@po.cwru.edu
Authors: Beth Lewandowski, Kevin Kilgore, David Ercegovic, and Kenneth Gustafson
Headquarters program office: Aeronautics Research
Programs/Projects: VSP, AEFT