Implantable Biofuel Cells Operating In Vivo – Towards Biomedical Devices Powered with Electricity Harvested Inside the Body

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Biofuel cells converting chemical energy into electricity upon biocatalyzed chemical reactions have recently emerged as promising alternative sources of sustainable electrical energy. Implantable biofuel cells suggested as sustainable micro-power sources operating in living organisms are still exotic and very challenging to design bioelectronic systems. Very few examples of abiotic and enzyme-based biofuel cells operating in animals in vivo have been reported. Implantation of biocatalytic electrodes and extraction of electrical power from small living creatures is even more difficult and has not been achieved yet. Despite the long-term research (over 20 years) in the area of biofuel cells, very little progress has been achieved yet. Many researchers aiming at ultimate application of biofuel cells as implantable devices operating in vivo have demonstrated only model systems working for limited time in vitro. Revolutionary step in this research was recently achieved in our laboratory upon implanting biocatalytic electrodes in living animals: snails [1], clams [2] and lobsters [3], producing electrical power over long period of time using physiologically produced glucose as a fuel. Using novel approaches based on bionanotechnology we extracted sustainable electrical power from living organisms in a natural environment for a long time-period. We are reporting on the first implanted biofuel cell continuously operating in a living body and producing electrical power over long period of time using physiologically produced glucose as a fuel. The “electrified” snails, clams and lobsters being biotechnological living “devices” were able to regenerate glucose consumed by biocatalytic electrodes, upon appropriate feeding and relaxing, and then produce a new “portion” of electrical energy. The animals with the implanted biofuel cell will be able to operate in a natural environment producing sustainable electrical micro-power for activating various bioelectronic devices. Small biocatalytic electrodes were implanted in live clams resulting in enzyme-catalyzed oxidation of glucose and reduction of oxygen in the bio-fluid inside the mollusks and producing electrical power from the biological source. Integration of the implanted biofuel cells in serial or parallel batteries allowed significant increase of the generated electrical power, thus allowing its use for potential activation of electrical devices. Still even the batteries composed of 3 biofuel cells produced electrical power which is in the range of tens of microwatts. In order to accumulate the released electrical energy, the biological battery was connected to a capacitor collecting the energy produced by the bio-battery to be later released on a rotating motor used as an example device. The present study is the first step in the long way to the design of bioelectronic self-powered cyborgs which can autonomously operate using power from biological sources. Enzyme-modified electrodes were implanted in living lobsters resulting in biocatalytic oxidation of glucose and reduction of oxygen in the bio-fluid inside the lobster’s body thus producing electrical power from the biological source. Integration of the “electrified” lobsters with the biofuel cells connected in series allowed for the activation of a digital watch as a model electronic device. Various sensing, information processing and wireless transmission devices for future military, homeland security and environmental monitoring applications are feasible based on the present example-device with the power produced by a “cyborg” creature. Another fluidic device with implanted bioelectrodes assembled in series and mimicking the human blood circulatory system was used to activate a pacemaker [3]. Currently, implantable devices (including pacemakers) are powered by batteries, which provide reliable power, but must be changed every few years. This results in a significant number of surgeries that could be avoided by using in vivo power generation. The project is aiming at biomedical applications of the implanted biofuel cells for activating pacemakers, insulin injectors and other implantable bioelectronic/biomedical devices getting electrical power directly from physiological sources. Integration of bioelectronic devices and living systems could be considered as the first step in creation of “cyborgs” described in science fiction but never attempted in scientific/engineering research. Future implantable medical devices, such as cardiac defibrillators/pacemakers, deep brain neurostimulators, spinal cord stimulators, gastric stimulators, foot drop implants, cochlear implants, insulin pumps, etc. powered by implanted biofuel cells extracting electrical energy directly from a human body are possible, resulting in bionic human hybrids. The present study is a step on the long path to the design of bioelectronic self-powered “cyborgs” which can autonomously operate using power from biological sources. However, the major future applications of this novel technology are in medicine for activating implanted bioelectronic devices. It should be clearly understood that the achieved results are only the first steps to the future work where the expertise in electrochemistry, materials science, biology, medicine and electrical engineering will be integrated.

References:

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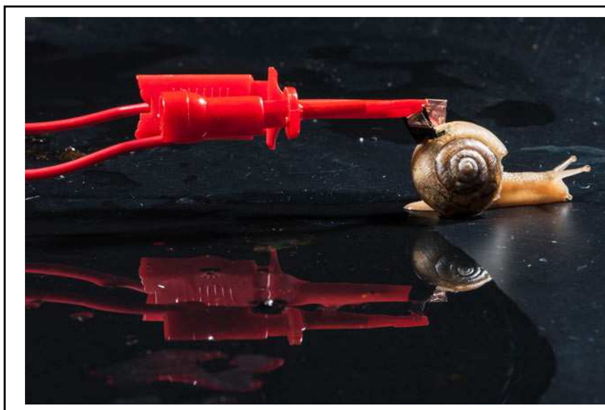

Snail with implanted bioelectrodes producing electricity.