Nature Reviews Chemistry | Published online 20 Dec 2017; doi:10.1038/s41570-017-0106

BIOMIMETIC POWER SOURCES

Electric hydrogels

Biocompatible electric power sources in the form of artificial electric organs would be invaluable in multiple technologies, from *in vivo* sensors to miniature drug delivery pumps. As futuristic as it sounds, electric organs already exist in nature; for example, enabling electric eels to generate a potential difference of more than 600 V. It is precisely this peculiar physiology that inspired a group led by Michael Mayer to design and implement the first artificial electric organ made of biocompatible materials, a finding now disclosed in *Nature*.

Electric eels have evolved predatory and defensive systems based on electrical discharges. Their electric organs receive neurosignals that are translated by cells known as electrocytes, which then trigger the concerted opening of highly selective sodium channels. Each electric organ comprises thousands of electrocytes stacked in series, and these collectively function as a capacitive bio-battery. The extraordinary amplification of the neurosignals results in electric discharges powerful enough to be dangerous to adult humans.

"From first accounts in ancient Egypt to this present day, researchers like us have been fascinated by the ability of the electric fish to generate strong external electric fields", notes Mayer, "we explored several ways to mimic the eel's electric organ, but it became clear to us that even a simple design could allow us to achieve our goal of generating at least 100 V from salt and water." Mayer and colleagues made use of hydrogels to reproduce the four repeating compartments of the eel's electric organ: a high salinity gel, a cation-selective membrane, a low salinity gel and an anion-selective membrane. Reverse electrodialysis enabled the ions to move from the high-salinity gel to the low-salinity gel, generating an ion gradient corresponding to an open circuit voltage of 130–185 mV — values comparable to those attained by a single electrocyte. "In general, hydrogels are ideal materials for biointerfaces because they are robust, transparent, pliant and often biocompatible. These properties see them used, for example, in contact lenses", remarks Thomas Schroeder, a co-author of the article. The artificial electric organ is then assembled by stacking thousands of hydrogels in series to give a voltage of 110 V. "One of the advantages of using hydrogels is that they can be easily manipulated and assembled into any geometry without disrupting the flow of charge", explains Mayer. A 2D array of hydrogels can be folded in order to obtain a 1D sequence in which the contact area between each hydrogel, as well as the current output, is maximized.

The impressive voltages generated by the artificial electric organ engineered by Mayer and co-workers are still six times lower than those achieved by electric eels. "Eels evolved a fascinating approach to using ionic gradients by developing two ion-channel proteins that are supremely selective for one cation each, rather than for a cation and an anion, as we had to do owing to lack of such super-selective membranes", laments Mayer. Also, their use of a solution of low ionic strength increases the overall internal resistance of the artificial electric organ, thus limiting its power. In an eel's electric organs, Na^+ and K^+ gradients are maintained by Na^+/K^+-ATPase proteins, which use ATP as their energy source. Ideally, artificial organs implanted in a living organism would also be recharged using chemical energy derived from food or existing ionic gradients. However, in its present implementation, recharging occurs by connecting an external current source. "A fully metabolically rechargeable artificial electric organ might be used to generate an integrated glucose monitoring and insulin dispensing device, or other implants and low-power prosthetics", notes Mayer. "All these applications are far out in the future and significant hurdles would have to be overcome, but the idea of an electrical power source that is metabolically recharged is supremely intriguing as we see the accelerating fusion of living beings with technological devices and machines", Mayer concludes.

Gabriella Graziano

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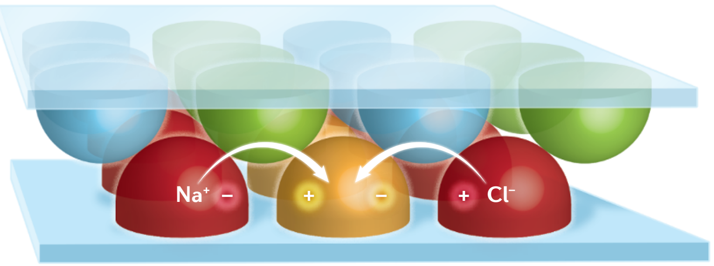
ORIGINAL ARTICLE Schroeder, T. B. H. *et al.* An electric-eel-inspired soft power source from stacked hydrogels. *Nature* **552**, 214–218 (2017)



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