Journal of Bacteriology and Parasitology
ISSN: 2155-9597
Franks, J Bacteriol Parasitol 2012, 3:9
DOI: 10.4172/2155-9597.1000e116

Editorial
Open Access

What's Current with Electric Microbes?

Ashley Franks*
Department of Microbiology, La Trobe University, Melbourne, Victoria, 3086, Australia

Microbes capable of interacting with insoluble electron acceptors and/or donors have broad implications, ranging from geomicrobiological processes, alternative energy production, bioproduction of commodity chemicals, and an understanding energy flow in anaerobic environments. Electromicrobiologists investigate bacteria capable of transferring electrons extracellularly to and/or from insoluble surfaces, driving internal metabolic processes. Electromicrobiology is a cross-disciplinary field that covers the processes, mechanisms and applications of electric bacteria.

A wide range of microbes have been discovered that are capable of electrically interacting with their environment. Dissimilatory metal reducing bacteria are among the most studied, being capable of "breathing metals" in anaerobic environments. Derek Lovley isolated the first dissimilatory metal reducing microbe, Geobacter metallireducens, from sediment in the Potomac River in 1987 [1]. This microbe is capable of the complete oxidation of organic carbon to carbon dioxide, while utilising an insoluble electron acceptor to support growth. Geobacter species are able to reduce a wide range of mineral and metalloids, including iron, manganese and uranium. Utilising metal oxides in anaerobic environments for respiration; dissimilatory metal reduction plays an important role in carbon and geochemical cycles. An understanding of their function can be applied to the bioremediation of organic pollutants, heavy metals and radio nuclides in anaerobic environments [2].

An interesting aspect of the Geobacter species was the discovery, that they do not produce any electron shuttles, but directly transfer electrons extra cellularly to iron oxide [3]. Subsequent studies have demonstrated electrically conductive pili and the outer membrane c-type cytochrome OmcS, as the route of extracellular electron flow between the microbes and the iron oxides [4,5]. Iron oxide particles are normally much smaller than the bacterial cells, leading to the microbes being planktonic in the environment, expressing flagella too in the search for oxidised electron acceptor [6]. During this time, Geobacter species are capable of utilising the extensive heme containing c-type cytochromes as capacitors to hold excess electrons, until a suitable electron acceptor can be found to allow the cytochromes to be discharged [7].

The electricity breathing ability of these microbes can be collected from the environment as an electrical current, using a device called a Microbial Fuel Cell (MFC) [8-10]. Microbes utilise an electrode as an electron acceptor for anaerobic respiration. Initially designed for the harvesting of electrical current from organic compounds, difficulties in scalability above pilot scale has seen their application in power production, focused towards the powering of low power devices in aquatic environments [11-13]. Some of the more interesting current applications of MFC include applications where the harvesting of electrical current is not the primary focus, these include: acting as sensors for microbial metabolism in subsurface environments [14]; stimulating bioremediation of organic environments by providing an electrode as an electron acceptor [15]; and providing a means for balancing electron flow during the production of the microbial production of commodity chemicals [16].

Compared to metal reduction in the environment, an electrode can act as an infinite electron sink. This leads to both similarities and differences in the microbial behaviours utilising these insoluble electron acceptors. Geobacter species are extensively enriched within the electrode-associated communities of MFC, when a diverse range of environmental inoculum and organic carbon source are used [11]. Geobacter species seem to be the most adapted in utilising an electrode as an electron acceptor. They produce the highest current density of both pure and mixed cultures in a MFC; are able to directly interact with an electrode without the use of an electron shuttle, and produce relatively thick biofilms (>60 µm) [17]. This biofilm has the unusual property of being electrically conductive, allowing all cells within the biofilm to be metabolically active and capable of transferring electrons to the electrode, across distances greater than 50 cell lengths [18,19]. Geobacter species on the electrode surface utilise a network of pilin and the outer membrane cytochromes, more specifically OmcZ, to electrically connect to the electrode [20-22]. The ability to produce a conductive biofilm and act as a capacitor has seen an interest in utilizing these microbes in bioelectronics applications [23].

The range of applications has been further broadened with the discovery that microbes can also utilize an electrode as an electron donor. The molecular method for electron transfer from an electrode does not appear to share any molecular similarities with the electron transfer to an electrode or iron oxide. The electrically conductive pilin, the outer membrane cytochromes, OmcS and OmcZ, are not essential for the microbes to accept electrons from the electrode. The only protein current found to be essential is a separate outer membrane c-type cytochrome, whose current roll is unknown [24]. Being able to provide energy to microbes, directly utilizing an electrode, has significant potential in the bioremediation of a number of recalcitrant contaminates, such as chlorinated compounds [15,25], toxic and radioactive metals [26], and nitrate [27,28]. Microbes may also act as catalysts on an electrode, for the conversion of an electrical current to hydrogen and methane [29-31]. Electrons may also be utilised as a reductant for the reduction of organic compounds to commodity chemicals [32,33].

Some microbes can even utilise the reducing power of an electrode to fix carbon dioxide for the production of organic chemicals. Due to the similarities to photosynthesis, the microbial fixation of carbon dioxide utilising an electrode as a reduction process has been termed electrosynthesis [32]. Electrosynthesis has the potential to produce liquid transportation fuels and other useful organic commodities in

***Corresponding author:** Ashley Franks, Department of Microbiology, La Trobe University, Melbourne, Victoria, 3086, Australia, Tel: +61 3 9479 2206; Fax: +61 3 9479 1222; E-mail: A.franks@latrobe.edu.au

Received November 19, 2012; **Accepted** November 21, 2012; **Published** November 26, 2012

Citation: Franks A (2012) What's Current with Electric Microbes? J Bacteriol Parasitol 3:e116. doi:10.4172/2155-9597.1000e116

a more efficient and environmentally sustainable manner, than other biomass based biofuel production strategies.

While it may be thought that the ability to interact with insoluble minerals, metals and metalloids in the environment gives the Geobacter species an advantage on an electrode, recent findings suggest the evolution of conductive biofilms may have evolved from syntrophic interactions with methanogenic microbes. Previously, it has been considered that syntrophic interactions in methane producing communities occurred mainly through hydrogen transfer between the partners, where by the electron-donating partner would produce hydrogen and the electron-accepting methanogen would utilise hydrogen as an electron source. Studies of electric bacteria have demonstrated that microbes in methanogenic communities are capable of directly transferring electrons through large aggregates to each other. Direct interspecies electron transfer can be the primary mechanism for electron transfer in methanogenic aggregates [34,35], although this is not always the case [36].

During direct interspecies electron transfer, Geobacter species produce an electrically conductive network capable of long-range transfer, more resembling the biofilm produced on an electrode, rather than when grown on iron oxides. These microbes within conductive anaerobic syntrophic networks are a new potential source of electric bacteria with beneficial characteristics.While great inroads have been made, our understanding of electric bacteria is still limited. Evaluation of the full potential of electric microbes in industrial, biomaterial and environmental applications is reliant on the growing field of electro microbiology.

References

1. Lovley DR, Phillips EJP (1988) Novel mode of microbial energy metabolism: organic carbon oxidation coupled to dissimilatory reduction of iron or manganese. Appl Environ Microbiol 54: 1472-1480.
2. Lovley DR, Ueki T, Zhang T, Malvankar NS, Shrestha PM, et al. (2011) Geobacter: the microbe electric's physiology, ecology, and practical applications. Adv Microb Physiol 59: 1-100.
3. Nevin KP, Lovley DR (2000) Lack of production of electron-shuttling compounds or solubilization of Fe(III) during reduction of insoluble Fe(III) oxide by Geobacter metallireducens. Appl Environ Microbiol 66: 2248-2251.
4. Mehta T, Coppi MV, Childers SE, Lovley DR (2005) Outer Membrane c-Type Cytochromes Required for Fe(III) and Mn(IV) Oxide Reduction in *Geobacter sulfurreducens*. Appl Environ Microbiol 71: 8634-8641.
5. Reguera G, McCarthy KD, Mehta T, Nicoll JS, Tuominen MT, et al. (2005) Extracellular electron transfer via microbial nanowires. Nature 435: 1098-1101.
6. Childers SE, Ciufo S, Lovley DR (2002) Geobacter metallireducens accesses insoluble Fe(III) oxide by chemotaxis. Nature 416: 767-769.
7. Esteve-Nunez A, Sosnik J, Visconti P, Lovley DR (2008) Fluorescent properties of c-type cytochromes reveal their potential role as an extracytoplasmic electron sink in *Geobacter sulfurreducens*. Environ Microbiol 10: 497-505.
8. Bond DR, Holmes DE, Tender LM, Lovley DR (2002) Electrode-Reducing Microorganisms That Harvest Energy from Marine Sediments. Science 295: 483-485.
9. Franks AE, Malvankar N, Nevin KP (2010) Bacterial biofilms: the powerhouse of a microbial fuel cell. Biofuels 1: 589-604.
10. Tender LM, Reimers CE, Stecher HA 3rd, Holmes DE, Bond DR, et al. (2002) Harnessing microbially generated power on the seafloor. Nat Biotechnol 20: 821-825.
11. Franks AE, Nevin KP (2010) Microbial Fuel Cells, A Current Review. Energies 3: 899-919.
12. Logan BE, Rabaey K (2012) Conversion of Wastes into Bioelectricity and Chemicals by Using Microbial Electrochemical Technologies. Science 337: 686-690.
13. Lovley DR, Nevin KP (2011) A shift in the current: new applications and concepts for microbe-electrode electron exchange. Curr Opin Biotechnol 22: 441-448
14. Williams KH, Nevin KP, Franks A, Englert A, Long PE, et al. (2010) Electrode-based approach for monitoring in situ microbial activity during subsurface bioremediation. Environ Sci Technol 44: 47-54.
15. Zhang T, Gannon SM, Nevin KP, Franks AE, Lovley DR (2010) Stimulating the anaerobic degradation of aromatic hydrocarbons in contaminated sediments by providing an electrode as the electron acceptor. Environ Microbiol 12: 1011-1020.
16. Flynn JM, Ross DE, Hunt KA, Bond DR, Gralnick JA (2010) Enabling unbalanced fermentations by using engineered electrode-interfaced bacteria. MBio 1: e00190-e00110.
17. Nevin KP, Richter H, Covalla SF, Johnson JP, Woodard TL, et al. (2008) Power output and columbic efficiencies from biofilms of *Geobacter sulfurreducens* comparable to mixed community microbial fuel cells. Environ Microbiol 10: 2505-2514.
18. Franks AE, Nevin KP, Glaven RH, Lovley DR (2010) Microtoming coupled to microarray analysis to evaluate the spatial metabolic status of *Geobacter sulfurreducens* biofilms. ISME J 4: 509-519.
19. Franks AE, Nevin KP, Jia H, Izallalen M, Woodard TL, et al. (2009) Novel strategy for three-dimensional real-time imaging of microbial fuel cell communities: monitoring the inhibitory effects of proton accumulation within the anode biofilm. Energ Environ Sci 2: 113-119.
20. Nevin KP, Kim BC, Glaven RH, Johnson JP, Woodard TL, et al. (2009) Anode biofilm transcriptomics reveals outer surface components essential for high density current production in *Geobacter sulfurreducens* fuel cells. PLoS One 4: e5628.
21. Reguera G, Nevin KP, Nicoll JS, Covalla SF, Woodard TL, et al. (2006) Biofilm and Nanowire Production Leads to Increased Current in *Geobacter sulfurreducens* Fuel Cells. Appl Environ Microbiol 72: 7345-7348.
22. Malvankar NS, Vargas M, Nevin KP, Franks AE, Leang C, et al. (2011) Tunable metallic-like conductivity in microbial nanowire networks. Nat Nanotechnol 6: 573-579.
23. Lovley DR (2012) Electromicrobiology. Annu Rev Microbiol 66: 391-409.
24. Strycharz SM, Glaven RH, Coppi MV, Gannon SM, Perpetua LA, et al. (2011) Gene expression and deletion analysis of mechanisms for electron transfer from electrodes to *Geobacter sulfurreducens*. Bioelectrochemistry 80: 142-150.
25. Strycharz SM, Gannon SM, Boles AR, Franks AE, Nevin KP, et al. (2010) Reductive dechlorination of 2-chlorophenol by Anaeromyxobacter dehalogenans with an electrode serving as the electron donor. Environ Microbiol Rep 2: 289-294.
26. Gregory KB, Lovley DR (2005) Remediation and recovery of uranium from contaminated subsurface environments with electrodes. Environ Sci Technol 39: 8943-8947.
27. Park HI, Kim Dk, Choi YJ, Pak D (2005) Nitrate reduction using an electrode as direct electron donor in a biofilm-electrode reactor. Process Biochem 40: 3383-3388.
28. Gregory KB, Bond DR, Lovley DR (2004) Graphite electrodes as electron donors for anaerobic respiration. Environ Microbiol 6: 596-604.
29. Cheng S, Xing D, Call DF, Logan BE (2009) Direct Biological Conversion of Electrical Current into Methane by Electromethanogenesis. Environ Sci Technol 43: 3953-3958.
30. Geelhoed JS, Hamelers HV, Stams AJ (2010) Electricity-mediated biological hydrogen production. Curr Opin Microbiol 13: 307-315.
31. Van Eerten-Jansen MCAA, Heijne AT, Buisman CJN, Hamelers HVM (2012) Microbial electrolysis cells for production of methane from CO2: long-term performance and perspectives. International Journal of Energy Research 36: 809-819.
32. Nevin KP, Hensley SA, Franks AE, Summers ZM, Ou J, et al. (2011) Electrosynthesis of organic compounds from carbon dioxide is catalyzed by a diversity of acetogenic microorganisms. Appl Environ Microbiol 77: 2882-2886.
33. Nevin KP, Woodard TL, Franks AE, Summers ZM, Lovley DR (2010) Microbial

electrosynthesis: feeding microbes electricity to convert carbon dioxide and water to multicarbon extracellular organic compounds. mBio 1: e00103-e00110.

34. Morita M, Malvankar NS, Franks AE, Summers ZM, Giloteaux L, et al. (2011) Potential for direct interspecies electron transfer in methanogenic wastewater digester aggregates. MBio 2: e00159-11.

35. Summers ZM, Fogarty HE, Leang C, Franks AE, Malvankar NS, et al. (2010) Direct exchange of electrons within aggregates of an evolved syntrophic coculture of anaerobic bacteria. Science 330: 1413-1415.

36. Rotaru AE, Shrestha PM, Liu F, Ueki T, Nevin K, et al. (2012) Interspecies electron transfer via Hydrogen and formate rather than direct electrical connections in cocultures of *Pelobacter carbinolicus* and *Geobacter sulfurreducens*. Appl Environ Microbiol 78: 7645-7651.