Exoelectrogens: Recent Advances In Molecular Drivers Involved In Extracellular Electron Transfer And Strategies Used To Improve It For Microbial Fuel Cell Applications

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ABSTRACT
The use of exoelectrogens in microbial fuel cells (MFCs) has given a wide berth to the addition of artificial electron shuttles/conduits as they have the molecular machinery to transfer the electrons exogenously to the electrode surface or to soluble or insoluble electron acceptors. Exoelectrogens transfer the electrons either directly to the electrode surface (via c-Cyts or pili) and/or mediate them by secreting electron shuttles such as, flavins or pyocyanin. Such microorganisms form electroactive biofilms on the electrode surface. They produce cyclopropane fatty acids and exopolysaccahride matrix to modify surface charge, which also provides favorable anchoring points for the retention of c-type cytochromes (c-Cyts). The longer subunit of PilA plays a vital role in cell attachment in the case of a well-known exoelectrogen *Geobacter sulfurreducens* during biofilm formation. *G. sulfurreducens* relies on flavin molecules for mediated electron transfer (MET) during initial biofilm formation and on c-Cyts and pili for the direct electron transfer (DET) during the later phase of biofilm formation. A new protein, *cbcl* inner membrane multiheme c-Cyt has been revealed in *G. sulfurreducens* that participates in the electron transfer when electron acceptor with low reduction potential (below 0.1 V) is used in the MFCs. On the other hand, inner membrane c-type cytochrome ImcH is involved in the reduction of electron acceptors exhibiting the potential above 0.1 V. *Shewanella oneidensis,* another exoelectrogen expresses CheA-3 histidine protein kinase for chemotactic responses to electron acceptors. *S. oneidensis* do not produce pili and utilizes flavin-cytochrome complexes to regulate the electron transfer to the electrode surfaces. The inherent electron transfer rates can be increased in order to improve the MFC performance. Such strategies as the anode surface modification with nanoparticles, expression of the genes for flavin biosynthesis pathway in the exoelectrogens, and chemical treatment of the microbial membrane have shown to increase the current outputs in the MFCs. This article provides the latest information about the exoelectrogens and molecular drivers involved in extracellular electron transfer (EET) mechanisms, and also summarizes the important characteristics of electroactive biofilms. It also highlights the different approaches that have been employed to facilitate the EET mechanisms and some uncommon exoelectrogens used in the MFCs recently.

KEYWORDS: Microbial fuel cell; Exoelectrogen; Extracellular electron transfer; Pili; c-type cytochrome

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