Cell Bioelectrochemistry: Past, Present, and Future

Bioelectrochemistry is an important field in biology and bioengineering because it involves the study of fundamental biological activities such as signal transduction and energy production. In the late 18th century, several giants in electrochemistry made historical progress in bioelectrochemistry. In this period, two of these giants, Luigi Galvani and Alessandro Volta, disputed over the so-called frog experiments, where frog legs were found to twitch if in contact with an iron fence. After a long debate, the muscle twitches were recognized to be induced by the current flowing between two dissimilar metals. Johann Wilhelm Ritter was inspired by this debate and performed experiments on his own body by using high voltage. This debate and related experiments called a great deal of attention from various fields, and the importance of electrochemical processes in living beings was realized. The series of outstanding scientific activities brought about opening the new era of bioelectrochemistry.

During the last 200 years, bioelectrochemistry has widened its territory by incorporating various research fields in both fundamental and applied cell biology and bioengineering. In fundamental research, bioelectrochemistry has made important contributions in understanding cell bioenergetics: the key process in energy production by respiration and photosynthesis is biological electron transport. Many membrane phenomena are electrochemical processes; membrane potential is the driving force of signal transduction in the nervous system and of membrane transport. Electrochemical measurements have been extensively employed to characterize basic functions of proteins and biomolecules that are closely related with cell activities. Because of the fundamental importance of cell bioelectrochemistry, many researchers involved in this field have been awarded Nobel Prize, including Alan Lloyd Hodgkin, Andrew Fielding Huxley, and Sir John Carew Eccles in 1963 for elucidating the ionic mechanism of the cell membrane and Erwin Neher and Bert Sakmann in 1991 for discovering the function of single ion channels in cells.

In applied research, bioelectrochemistry has made significant contributions to modern biotechnology. The electrochemical biosensor is the most successful application of bioelectrochemistry. Nowadays, an amperometric glucose-monitoring sensor is essential for patients with diabetes to ensure a healthy daily life. As next-generation biosensors, many researchers have developed various cell-based biosensors by using bacteria, plant, and mammalian cells, some of which have been used in medical, health, environmental, and food-safety fields. Currently, the fields of cell engineering and bioenergy are being extensively investigated. Furthermore, micro-/nano-electrochemical devices and systems have been developed and applied to characterization of live cells

It is difficult to predict the future direction of cell bioelectrochemistry research. However, the progression of research from simple to complex and from isolated to aggregated system (three- and four-dimensional) should be continued to further strengthen bioelectrochemistry. We must take into account long-term and bird's-eye perspectives, conduct interdisciplinary collaboration, and incorporate advanced and sophisticated technologies and tools from other areas. I am convinced that the future of cell bioelectrochemistry is bright. Cell bioelectrochemistry will remain an indispensable area in fundamental biology and will continue to play a major role in the future development of advanced biosensors, artificial biosystems, and bioelectronics and production of fine biochemicals and biomaterials.