Bioelectrics

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Springer

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ISBN 978-4-431-56093-7 ISBN 978-4-431-56095-1 (eBook)
DOI 10.1007/978-4-431-56095-1

Library of Congress Control Number: 2016950238

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Japan KK

Preface

Bioelectrics is a new field encompassing both the science and technology of applying electrical stimuli to biological systems. Typical stimuli utilize what is called pulsed power, a pulse with high voltage and/or current with a pulse width from subnanoseconds to milliseconds. Pulsed power may be altered to such forms as pulsed electric fields, plasmas, shock waves, pulsed electromagnetic waves, and pulse light. Application targets include specific cells such as cancer cells and bacteria, more complex arrangements such as tissues and organs, and complex environments and ecosystems including plant and animal species. Elucidation of effects of pulsed power on biology has led to numerous applications in such fields as medical treatment and welfare, environment, food, agriculture and fisheries, and biotechnology.

Research integrating pulsed power science and technology with the biological and medical fields began in 2000. The Research Center for Bioelectrics, Old Dominion University, was established in 2002 by Dr. Karl Schoenbach; the Bioelectrics Research Center, Kumamoto University, was established in 2007 by Dr. Hidenori Akiyama. The International Bioelectrics Consortium was established in 2005 by three institutions, Old Dominion University (USA), Kumamoto University (Japan), and Karlsruhe Institute of Technology (Germany). By 2016, the consortium had grown to encompass participation by15 universities and institutions.

Military research has driven an increase in the size of pulsed power generators. Sandia National Laboratories' Z Machine, the largest pulsed power generator in the world, has stored energy capabilities of 20 MJ, output current of 26 MA, X-ray peak power of 350 TW, and diameter of about 33 m. Concurrent development of low- to no-maintenance pulsed power supply systems continue to expand industrial applications. Such systems require only moderate output power and a small footprint but do require high repetition rate and high-functioning pulsed power.

The rapid development of bioelectric science and technology leads to hope that, in the near future, bioelectrics will substantially contribute to such global concerns as cancer treatment, environmental maintenance, and food and energy supplies.

Chapter 1 contains an introduction to the application of bioelectrics. Electroporation, the electropermeabilization of cell membranes, is a fundamental and the most thoroughly studied bioelectric effect due to pulsed electric fields. This chapter provides background into the research history of this effect and introduces medical and biotechnological applications based on both reversible and irreversible electropermeabilization with millisecond to microsecond pulses. The Chap. 1 also demonstrates application of nanosecond- to picosecond-range pulses with pulsed electric fields ranging from a kV/cm to more than 100 kV/cm; these affect not only the cell plasma membrane but also subcellular structures.

Chapter 2 includes an introduction into pulsed power technology. Pulsed power is produced by transferring energy generally stored in capacitors and inductors to a load very quickly through switching devices. The chapter focuses on the basics of two key technologies, electric circuits and switches, tools used for pulsed power measurement, and delivery of electric pulses to biological tissues using antennas.

Chapter 3 includes discussions about unique electromagnetic agents ranging from cold plasma to electromagnetic radiation. Nonequilibrium plasmas in gases and liquids are known to produce reactive agents that contribute to biological effects including membrane disruption and apoptosis. These reactive agents include ultraviolet radiation, heat, reactive oxygen-based and nitrogen-based species, charged particles, and electric fields. The interactions between pulsed electromagnetic fields and biological systems are included.

Chapter 4 outlines biological responses to pulsed electric fields (PEFs), which exert profound effects on cells by interacting with the cell membrane and other cellular components. The initial discussion within this chapter is a description from multifaceted standpoints of interactions of PEFs with biological membranes, membrane pore formation, and their physiological significance; this is followed by a description of subcellular events induced by PEFs including their effects on the cytoskeleton and signal transduction. The chapter also provides a detailed description on irreversible electroporation and cell death by PEFs.

Chapter 5 covers the use in medical applications. Therapeutic applications of bioelectrics have been developed for a large number of medical conditions including cancer, wound healing, ischemia, cardiovascular disease, and diabetes. Utilization of bioelectrics-based medical techniques has recently surged as the potential of such techniques lies in a more holistic approach to fundamental biophysical mechanisms driving underlying success.

Chapter 6 includes a discussion of environmental applications such as food and biomass processing. PEF-based techniques have been demonstrated to be energy saving and persistent in efficacy for bacterial inactivation in wastewater and liquid food and for the eradication of cyanobacteria in surface waters, obviating harmful chemical usage. PEF treatment offers specific advantages for component extraction—low heat influx, low energy demand, and selectivity of compound release—which make PEF processing suitable for winemaking, for extraction of sugar from sugar beets and valuable components from fruits and vegetables, and in PEF downstream processing of microalgae.

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