History of Bioelectronics: A review based on groundbreaking discoveries to explore future directions

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Abstract. Bioelectronics is an emerging interdisciplinary field that integrates biology and electronics to create new technologies for interacting with biological systems. Its history can be traced back to the 1950s. Since then, significant progress has been made in bioelectronics, with the development of biosensors, wearable devices, and implantable medical devices for treating various diseases. Recent advances in nanotechnology and materials science have further propelled the field of bioelectronics, enabling the development of more sophisticated devices for detecting and manipulating biological signals and molecules. As the field continues to evolve, new innovations and applications are likely to emerge, further expanding the impact of bioelectronics on biomedicine and healthcare.

Keywords: Bioelectronics, Wirelessly Powered Implantable, implantable medical devices, biosensors.

1. Introduction

Bioelectronics is a fast expanding multidisciplinary topic that blends biological and electrical concepts. It involves the creation of devices and technologies that interact with biological systems, such as cells and tissues. Healthcare, biotechnology, and biomedicine are only a few of the many fields in which this discipline is applicable. Bioelectronics devices can be used to diagnose, treat, and monitor numerous biological processes, such as biological signals, biological molecules, and biological systems. Implantable medical devices, biosensors, and wearable devices for monitoring vital signs are examples of bioelectronic devices.

Bioelectronics can be traced back to the introduction of integrated circuits in the middle of the twentieth century. As integrated circuit technology has progressed and the size of electronic components has shrunk to the nanometer scale, it has become possible to include molecules as the tiniest units on a chip, signifying the beginning of molecular electronics. The elements of recognition, protection, memory, amplification, switching, and conduction, among others, in organic compounds, polymers, and biomolecules make them more suitable for electronic devices, thereby contributing to the development of bioelectronics.

In recent decades, the discipline of bioelectronics has expanded, indicating a wide range of potential applications. As a young field of study, its concept, research substance, and even its appellation are not as well-established as those of more established fields. As such, it should be investigated, developed, and improved. This paper will provide a brief history of bioelectronics, investigating the field's advancements as well as its current and prospective future applications.

2. History Review

At present, bioelectronics has been developing very rapidly. Since the concept came into being in the 1950s, human beings have made breakthroughs in this field almost every year, especially in the last 25 years, the development is very rapid. Reviewing the development of these decades, this paper finds a few representative events in the development of bioelectronics for analysis. Through such analysis a general description of bioelectronics can be obtained.

(Alwarappan et. al., 2010)4 give a short prologue to bioelectronics followed by insights concerning biosensors and their order in view of the sub-atomic acknowledgment part, techniques for transduction, and materials utilized. (Strakosas et. al., 2016)5 sum up the techniques that have been utilized up to this point to biofunctionalize polydioxythiophenes with an end goal to work on the biotic/abiotic interface. (Xu et. al., 2020)8 portray the plan, combination, and assessment of two sorts of multifunctional zwitterionic direct poly(carboxybetaine thiophene) (PCBTh) and permeable poly(carboxybetaine thiophene- - 9,9'- bifluoreneylidene) (PCBTh-BF) polymers, which can be easily orchestrated utilizing Yamamoto and Suzuki polycondensation, individually. (Wang et. al., 2021)9 center around the new advances in biocompatible guides in view of normal biopolymers for stretchable bioelectronics. Other persuasive work incorporates (Göpel et. al., 1994)1, (Willner et. al., 2005)2, (Dorf, 2006)3, (Knopf et. al., 2018)6, (Lee et. al., 2018)7, (Malliaras et. al., 2022)10.

(Göpel et al., 1994)1 provide an introductory overview of the field of bioelectronics, which involves the interface of biological systems with electronic devices. They discuss the significance of biosensors, which enable the detection and quantification of various biological substances, in this field.

(Willner et. al., 2005)2 delve deeper into the theoretical foundations and applications of bioelectronics. They also discuss the use of bioelectronic devices for drug delivery and tissue engineering.

(Dorf, 2006)3 provides a comprehensive overview of sensors, including those used in biomedical applications. The book discusses a variety of sensor categories, such as optical, chemical, and biosensors, as well as their associated transduction techniques and materials.

(Alwarappan et. al., 2010)4 examine the application of nanomaterials in bioelectronics, emphasising their potential to enhance the performance of biosensors and other bioelectronic devices.

(Strakosas et al., 2016)5 provides a summary of the techniques used to biofunctionalize polydioxythiophenes, which are extensively employed in biosensor applications. They discuss how altering the surface of a material can increase its biocompatibility and sensitivity to biological analytes.

(Knopf et. al., 2018)6 provide an introductory text on biosensors and bioelectronics, covering topics such as sensor design, fabrication, and testing. In addition, the book discusses emerging trends in the field, such as the use of flexible and wearable sensors.

(Lee et. al., 2018)7 discuss the use of chemical sensors based on organic transistors in ubiquitous bioelectronics. The article emphasises the potential of such sensors for monitoring biomarkers and other physiological parameters in real time.

Design, synthesis, and evaluation of two varieties of multifunctional zwitterionic polymers for use in implantable bioelectronics are described (Xu et. al., 2020)8. The authors discuss the unique properties of the materials, which include high biocompatibility and biofouling resistance.

The focus of (Wang et al., 2021)9 is the development of biocompatible conductors based on natural biopolymers for use in stretchable bioelectronics. The article discusses recent advancements in this field and emphasises the potential of these materials for use in implantable and wearable devices.

The authors (Malliaras et. al., 2022)10 introduce organic bioelectronics by discussing the fundamentals of electronic materials and devices, as well as their application to biological systems. The authors discuss the use of organic electronic materials in bioelectronic applications such as biosensors, neural interfaces, and artificial organs.

(Das et al., 2020)12 examine the evolution of implantable brain devices that are biointegrated and wirelessly powered. The article discusses various aspects of these devices, such as their design, materials, and wireless charging techniques.

(Wu et al., 2021)13 provide a comprehensive review of biomedical applications of electrical impedance tomography (EIT). The authors discuss EIT's numerous circuits and systems, as well as its applications in disciplines such as lung imaging and neural recording.

3. Discussion

After gaining insights from the aforementioned literature, my attention was drawn towards two particular technologies, namely, wirelessly powered implantable technology and brain computer interface (BCI) technology. It's important to note the close ties between these two technologies and the commonalities they share. The goal of wirelessly powered implantable technology is to create implantable devices that are powered wirelessly, doing away with the need for regular battery changes. In contrast, BCI technology is geared towards connecting the human brain with an external piece of equipment in order to facilitate thought-based control of said instrument. There is a great deal of interest in studying both of these technologies because of their potential applications in biomedical engineering. It is clear that the combination of these two technologies can pave the way for the creation of implanted devices with new capabilities and greater precision.

Propels in brain designing and related exploratory strategies worked on how we might interpret the cerebrum. With respect to a model, progress in fMRI (utilitarian attractive reverberation imaging) advancements extended our knowledge of neuronal circuits and assist us with understanding how explicit cerebrum action connected to various brain circuits. Notwithstanding, size and compactness limit the utilization of such neuroimaging apparatuses to investigate cerebrum action during everyday living. Moreover, one more urgent imperative of fMRI in cerebrum research is the low spatiotemporal goal. In opposite, convenient surface electroencephalography (EEG) allows the continuous checking and assessment of cerebrum movement perceptibly for an extensive stretch of time. Nonetheless, same similarly as with fMRI, the low spatiotemporal goal of EEG attacks the exactness of estimation and is inconsistent with neuroscience concentrates on situations like single-neuron goal. Individual neurons comprise the morphological as well as functional units of the mind and their spatiotemporal accounts are vital to appropriately comprehend the cerebrum capability. These days, to record extracellular exercises, including activity possibilities and nearby field possibilities (LFPs), implantable brain gadgets are generally usually utilized.

4. Conclusion

Bioelectronics is a swiftly expanding discipline with the potential to revolutionise healthcare and biomedicine. The potential applications of bioelectronics are vast and range from disease diagnosis and treatment to the development of novel drugs and therapies.

It is anticipated that bioelectronics will have a significant impact on the diagnosis and treatment of diseases. Bioelectronics has the potential to enhance patient outcomes and reduce healthcare costs by providing new tools and technologies for disease detection at an earlier stage. Biosensors that detect biomarkers in blood or other physiological fluids, for instance, could be used to detect cancer or other diseases prior to the onset of symptoms, allowing for earlier intervention and treatment. In addition, bioelectronics could be used to develop novel therapies that are more effective and less invasive than existing treatments.

It is anticipated that bioelectronics will have a significant impact on the creation of ubiquitous devices. Widespread use of wearable bioelectronics devices, such as fitness monitors and smartwatches, to monitor physical activity and pulse rate is already the case. However, it is anticipated that these devices will become increasingly sophisticated, monitoring vital signs and other health metrics in real time. This could enable remote patient surveillance, enabling healthcare providers to monitor patients' health status remotely and intervene as needed.

Bioelectronics is also anticipated to have a significant impact on implantable bioelectronics devices, such as pacemakers and cochlear implants. These devices have already improved the lives of millions of people around the globe, and their sophistication is anticipated to increase in the future. For instance, implantable devices with a broader spectrum of capabilities, such as drug delivery or real-time monitoring of physiological parameters, could be created.

It is anticipated that bioelectronics will play an important role in the advancement of biotechnology and biomedicine. By providing new instruments for the study of biological systems, bioelectronics could contribute to the acceleration of discovery in these fields. Biosensors that can detect the presence of specific molecules, for instance, could be used to study cellular signalling pathways, whereas implantable devices could be used to monitor the activity of neurons in the brain.

Ultimately, it is anticipated that bioelectronics will play a crucial role in the development of precision medicine. Bioelectronics could improve patient outcomes and decrease healthcare costs by providing new tools for tailoring treatments to individual patients based on their unique genetic composition and medical history. Biosensors that can detect genetic mutations, for instance, could be used to identify patients who are likely to respond to a particular therapy, while implantable devices could be used to administer personalised doses of medications and other therapies.

Consequently, the potential applications of bioelectronics are vast and hold great promise for the advancement of healthcare and biomedicine. As this field continues to develop, it is probable that new innovations and applications will emerge, expanding the influence of bioelectronics in these crucial areas.

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