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Emerging Frontiers in Soft and Stretchable Bioelectronics for Neurological and Cardiac Therapies

Chiang Wei-Ming*

Department of Biomedical Engineering, National Yang Ming Chiao Tung University, Taipei, Taiwan

Introduction

Soft and stretchable bioelectronics are at the forefront of a transformative shift in biomedical engineering, particularly in applications related to neurological and cardiac therapies. Traditional implantable devices, while effective, are often limited by their rigidity, bulkiness and incompatibility with the dynamic, soft nature of biological tissues. These mismatches can lead to inflammation, mechanical failure and reduced therapeutic performance. In contrast, soft bioelectronic systems, composed of flexible substrates, stretchable conductors and biocompatible interfaces, offer improved mechanical conformity, long-term stability and seamless integration with tissues such as the brain and heart. Recent research has focused on leveraging these properties for applications like epilepsy treatment, brain tumor management and cardiac pacing. These next-generation systems enable precise monitoring and intervention while minimizing physiological disruption. As the need for chronic, minimally invasive therapies increases, soft and stretchable bioelectronics are becoming essential tools for enhancing clinical outcomes in both neurological and cardiovascular fields [1].

Description

In the domain of neuroengineering, soft bioelectronics have opened new possibilities for diagnosing and treating complex brain disorders such as epilepsy and glioblastoma. These devices can be implanted directly onto the brain's surface or integrated into neural tissue to monitor electrophysiological activity and deliver targeted electrical stimulation. Unlike rigid neural probes, soft interfaces reduce tissue damage and allow for long-term implantation without significant immune response. Notable advances include multifunctional brain interfaces capable of simultaneous recording, stimulation and localized drug delivery. For instance, materials such as stretchable polymers and bioresorbable substrates are being used to fabricate devices that adapt to brain micromotions, enhancing comfort and precision. These soft platforms are particularly valuable in epilepsy, where continuous, high-resolution data collection is vital for seizure prediction and prevention. Furthermore, in brain tumor therapy, bioelectronic systems that conform to the brain's curved architecture enable localized, controlled treatment delivery while monitoring tissue response an approach that significantly reduces systemic side effects compared to traditional methods.

Equally promising are stretchable bioelectronic systems tailored for cardiac applications, particularly in rhythm regulation and post-surgical cardiac care. A critical development in this area is the use of laser-induced graphene embedded in water-responsive, nonswellable PVA gels, creating robust, stretchable interfaces for cardiac pacing. These materials maintain electrical performance even under repetitive mechanical stress, making them ideal for interfacing with the constantly contracting heart. By conforming to the myocardial surface, stretchable bioelectronics offer superior contact and signal fidelity, improving pacing accuracy and reducing the risk of arrhythmias. Additionally, soft cardiac patches have been engineered to provide not only electrical stimulation but also mechanical support and drug delivery following myocardial infarction. Such multifunctional devices are crucial in regenerative medicine, where synchronized mechanical and bioelectrical healing is essential. With their capacity for high flexibility, durability and biocompatibility, these systems are reshaping how clinicians approach chronic heart disease, enabling therapies that were previously impractical with rigid devices [2].

Conclusion

The integration of soft and stretchable bioelectronics into neurological and cardiac therapies represents a significant step forward in personalized and precision medicine. By overcoming the mechanical and biological limitations of traditional implants, these advanced systems offer improved functionality, reduced invasiveness and enhanced biocompatibility. Whether enabling seizure monitoring and localized brain tumor treatment or supporting cardiac pacing with high fidelity and resilience, these technologies reflect the convergence of material science, electronics and medicine. As research continues to refine these platforms, their clinical translation will expand, offering patients safer, more effective treatment options for some of the most challenging health conditions.

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Conflict of Interest

None

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***Address for Correspondence:** Chiang Wei-Ming, Department of Biomedical Engineering, National Yang Ming Chiao Tung University, Taipei, Taiwan; E-mail: chiangweiming@nycu.edu.tw*

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