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DOI
10.1186/s42234-025-00185-6

Publication date
2025

Document Version
Final published version

Published in
Bioelectronic Medicine

Song and Serdijn *Bioelectronic Medicine* (2025) 11:22
https://doi.org/10.1186/s42234-025-00185-6

Bioelectronic Medicine

EDITORIAL

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Bioelectronic medicine: wearable and implantable electronics

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This special collection explores the rapidly evolving field of wearable and implantable electronic devices. These integrated microsystems leverage state-of-the-art technologies in electrical, magnetic, optical, and ultrasound neuromodulation and recording to interact with biological tissues (Hu et al. 2024). Designed to be soft, flexible, stretchable, biocompatible, and minimally invasive, these devices enable long-term implantation (Yifei et al. 2024). They are engineered for adaptability, featuring self-learning capabilities and the ability to adjust and upgrade themselves to meet changing therapeutic needs, ultimately improving patient outcomes. Furthermore, continuous operation of these devices is enabled through the integration of wireless power transfer, physiological energy harvesting, multiplexed signal acquisition, local signal processing, and wireless data transmission, facilitating the development of soft, multimodal, and scalable flexible electronic systems for reliable long-term biointerfacing (Won et al. 2018, De Ridder et al. 2024). Recent breakthroughs in materials science and microfabrication have facilitated the seamless integration of bioelectronic devices with the human body. Emerging technologies such as electronic skin, neural stimulation electrodes, and optogenetics have demonstrated significant potential in the diagnosis and treatment of neurological diseases, inflammatory conditions, and other complex disorders, improving treatment precision and effectiveness (Wu et al. 2023, Liu et al. 2024a). These innovations not only advance the development of wearable and implantable devices but also provide solid technical support for smart healthcare and precision medicine. They are expected to have a profound and lasting impact on the future of medical care.

The collection presents two pioneering research papers and three high-quality review articles that address a wide array of topics, ranging from material design and energy transfer optimization to advanced neural signal processing, neural modulation technologies, and smart medical devices. Mahmud and his team (Mahmud et al. 2024) discuss recent progress in optimizing wireless power transfer (WPT) systems within the human body using metamaterials to improve the efficiency of implantable medical devices, analyzing the current challenges and potential future developments. Within the realm of device innovation Liu et al. (2024b), have developed a miniaturized, multi-channel vagus nerve stimulation system, integrating a 16-channel ASIC chip for precise current regulation and supporting Bluetooth-based remote control. Both in vitro and in vivo experiments demonstrate the system's potential in restoring autonomic nerve function following heart transplantation, offering a novel solution for the precise regulation of cardiovascular autonomic recovery. Paggi and colleagues (Paggi et al. 2024) designed a microfabricated, multi-channel silicon-based soft cuff electrode with adjustable size and facilitating simple implantation, overcoming the limitations of traditional electrodes in neural adaptability. Six-week implantation studies showed the electrode's outstanding biocompatibility and long-term stability, providing a viable and long-lasting solution for clinical neural modulation and repair therapies. In neural signal processing for

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high-density brain implants (Sodagar et al. 2025), systematically reviewed key on-implant digital signal processing methods for data compression and classification, highlighting the critical role of hardware efficiency in designing scalable, multi-channel wireless brain-implantable systems, and providing valuable insights for advancing high-throughput brain–computer interface technologies. Sugden et al. (2023) comprehensively discuss the applications of wearable electroencephalography (EEG) devices for remote brainwave data collection, emphasizing their potential in non-invasive monitoring brain plasticity, learning mechanisms, and neuropsychiatric disorders. They also discuss the technological challenges and future development directions for enabling widespread clinical adoption.

In conclusion, this special collection underscores the transformative potential of wearable and implantable electronic devices in advancing healthcare, encompassing improvements in treatment precision, as well as facilitating long-term monitoring and adaptive therapeutic strategies. We anticipate that these studies will inspire further exploration of key technologies, including efficient signal acquisition, non-invasive monitoring, flexible devices, precision neurotherapy and intelligent treatment systems, thereby driving the evolution of healthcare systems towards greater intelligence, personalization, and remote capabilities. Finally, we extend our sincere gratitude to all the authors and reviewers for their invaluable contributions to this special issue.

Abbreviations

WPT	Wireless power transfer
ASIC	Application-specific integrated circuit
EEG	Electroencephalography

Acknowledgements
The authors would like to thank their colleagues for constructive discussions and the editorial team for their valuable support during the preparation of this article.

Author contributions
Enming Song and Wouter A. Serdijn conceived the study, supervised the work, and wrote the manuscript. All authors read and approved the manuscript.

Funding
Not applicable.

Data availability
Not applicable.

Declarations

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 1 August 2025 / Accepted: 21 August 2025
Published online: 19 September 2025

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