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Research Highlight

ElHyX enables multimodal implantable bioelectronics for autonomous disease management

Lei Zhang [a], Cui Ye [b], You Yu [c], Yu Song [d], Yadong Xu [e], Wenzheng Heng [f], Songsong Tang [g], Minqiang Wang [a,*]

[a] Global Institute of Future Technology, Centre for Future Health and Intelligent Exercise, Shanghai Jiao Tong University, Shanghai 200240, China
[b] School of Public Health, Shanghai Jiao Tong University School of Medicine, Shanghai 200240, China
[c] School of Biomedical Engineering, Shanghaitech University, Shanghai 201210, China
[d] Department of Biomedical Engineering, College of Biomedicine, City University of Hong Kong, Hong Kong 999077, China
[e] School of Advanced Materials, Peking University Shenzhen Graduate School, Shenzhen 518055, China
[f] School of Integrated Circuits, Peking University, Beijing 100871, China
[g] School of Biomedical Engineering, Division of Life Sciences and Medicine, University of Science and Technology of China, Hefei 230026, China

Implantable bioelectronics are transforming modern medicine by enabling a shift from passive disease diagnosis toward active therapeutic intervention [1]. Through intimate communication with biological systems, these devices can continuously monitor physiological signals, assess organ function, and modulate neural activity, creating new opportunities for precision medicine, chronic disease management, and closed-loop therapy [2,3]. However, their widespread application remains limited by the difficulty of maintaining stable interfaces with soft and dynamically moving tissues [4]. Mechanical mismatch, inadequate tissue adhesion, and deformation-induced signal instability continue to compromise long-term performance [5,6]. Developing implantable platforms that simultaneously achieve robust biointegration, stable electrical functionality, and multifunctional operation therefore remains a critical challenge for next-generation bioelectronic medicine.

Writing in *Nature Materials*, Li et al. [7] reported an elastomer–hydrogel cross-functional (ElHyX) platform that integrates stretchable, strain-insensitive conductivity with wet-tissue adhesion for multimodal physiological sensing and closed-loop therapy. By integrating strain-insensitive conductivity, robust wet-tissue adhesion, multimodal sensing, and neuromodulation into a single platform, ElHyX establishes stable bioelectronic interfaces under dynamic physiological conditions. More importantly, the authors demonstrated a closed-loop disease management system that couples physiological monitoring with therapeutic neuromodulation, highlighting a significant step toward autonomous bioelectronic medicine. As illustrated in Fig. 1, the ElHyX platform features a biphasic architecture with molecular integration of an elastomer phase and a bioadhesive hydrogel phase (Fig. 1a). This design enables biochemical sensing (Fig. 1b and c) and maintains high stretchability under mechanical deformation (Fig. 1d). The resulting devices are further capable of neuromodulation (Fig. 1e) and electrophysiological recording (Fig. 1f). The feasibility of such an integrated system is ultimately demonstrated in a diabetic rat model for closed-loop blood glucose management (Fig. 1g).

At the heart of ElHyX is a biphasic architecture that integrates elastomers and hydrogels into a single bioelectronic platform. Although both materials have been extensively explored for bioelectronic applications [8], combining their respective advantages remains challenging because of weak interfacial interactions. To overcome this limitation, Li et al. [7] established a molecularly integrated interface by polymerizing the bioadhesive hydrogel network *in situ* from the chemically modified elastomeric matrix. Rather than simply covalently coupling two preformed materials, this approach generates a molecularly integrated biphasic material in which the hydrogel phase is directly grown from the elastomer, ensuring seamless interfacial bonding and robust mechanical integrity. Notably, the hydrogel layer rapidly absorbs interfacial water and forms strong adhesion to wet tissues, eliminating the need for conventional fixation strategies during implantation. Furthermore, the ElHyX platform enables on-demand detachment upon application of a high-concentration urea solution, which weakens the hydrogen bonds between the hydrogel and tissue. This reversible adhesion mechanism provides a safe and clinically valuable pathway for device retrieval after the completion of therapy.

Beyond its unique biphasic structure, ElHyX exhibits exceptional electromechanical stability. Maintaining reliable electrical performance under large deformation remains a persistent challenge for stretchable bioelectronics because conventional conductive composites often experience network disruption and conductivity loss during stretching [9]. By incorporating eutectic gallium-indium (EGaIn) liquid metal into the elastomer matrix, the authors created dynamically reconfigurable conductive pathways that adapt to mechanical deformation [10]. As a result, ElHyX maintains stable electrical performance even under strains approaching 900%. Such strain-insensitive conductivity is particularly advantageous for implantable bioelectronic interfaces subjected to continuous mechanical deformation.

* Corresponding author.
E-mail address: minqiangwang@sjtu.edu.cn (M. Wang).

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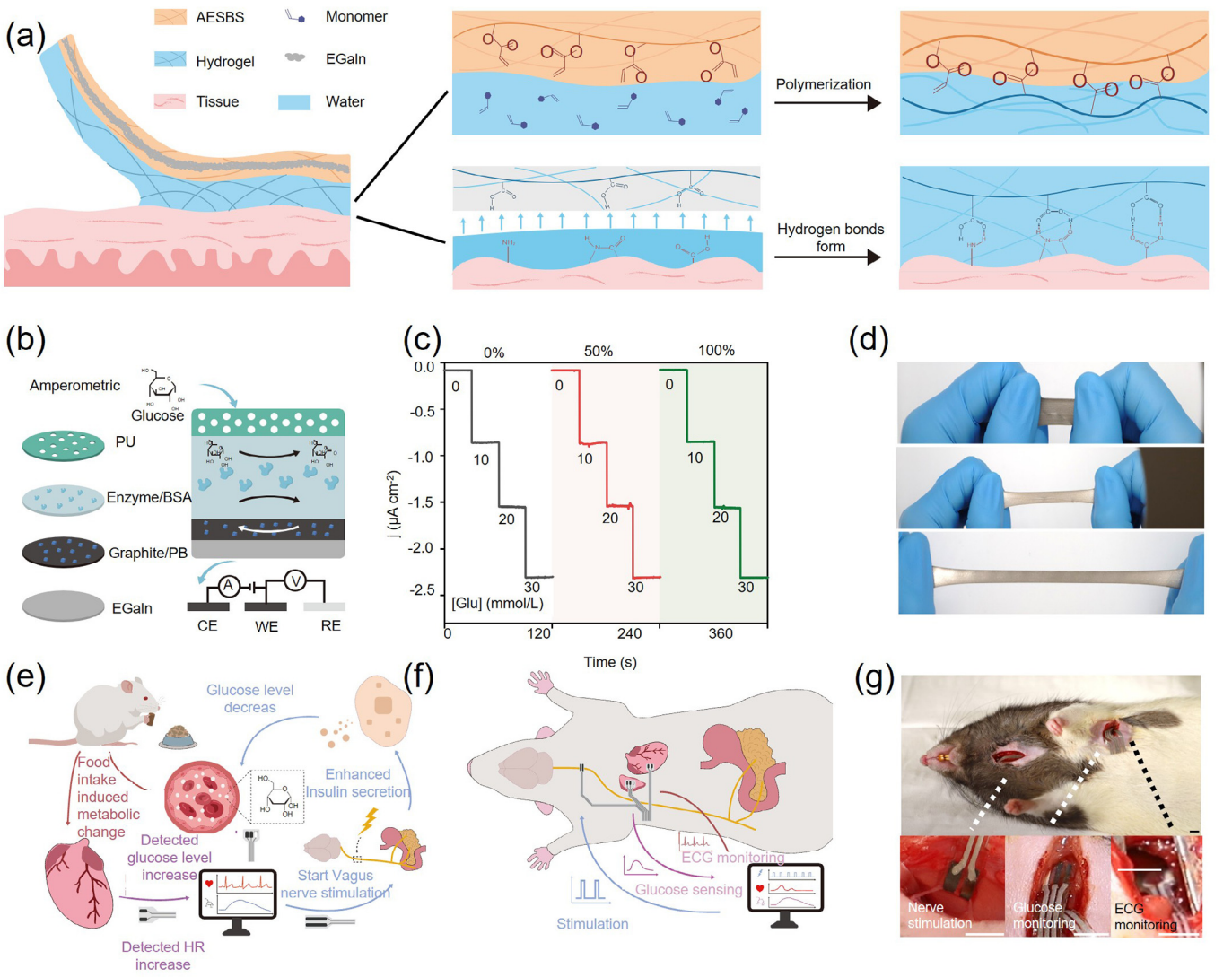


Fig. 1. Construction principle, sensing characteristics, and *in vivo* validation of the ElHyX platform for closed-loop blood glucose management. (a) ElHyX formation and adhesion mechanism; (b) glucose sensor structure; (c) strain insensitive detection; (d) high stretchability of EGaIn SBS; (e) closed loop blood glucose management concept; (f) schematic of *in vivo* implantation in a rat; (g) photograph of the implanted device. Reprinted with permission from Ref. [7], Copyright 2026, Springer Nature.

Leveraging these material advantages, the authors developed a versatile platform for multimodal sensing. Through direct ink writing and a library of printable functional inks, ElHyX can be readily configured for both electrophysiological recording and biochemical sensing. ElHyX-based electrodes enabled stable acquisition of electrocardiogram (ECG) and electromyogram (EMG) signals under substantial deformation. Beyond bioelectrical monitoring, the platform also supports electrochemical sensing through the incorporation of functional materials. By integrating Prussian blue-modified graphite electrodes with enzymatic recognition elements, the authors established sensitive glucose sensors capable of real-time monitoring *in vivo*. The modular design further enables sensing of additional biomarkers. Polyaniline (PANI) is incorporated for pH sensing due to its high sensitivity and reversible electrochemical behavior, while carbon nanotubes (CNTs) provide superior electrocatalytic activity toward uric acid detection. This material versatility underscores the potential of ElHyX as a multifunctional sensing platform.

Importantly, the capabilities of ElHyX were validated in physiologically relevant *in vivo* settings. When implanted onto the surface of a beating rat heart, the device maintained intimate contact with the tissue and continuously recorded high-fidelity ECG signals. Similarly, implanted glucose sensors successfully tracked dynamic changes in interstitial glucose concentrations. The authors further demonstrated the adaptability of the platform by constructing a flexible neural cuff for peripheral nerve interfacing. Benefiting from its conformal adhesion and mechanical compliance, the device established stable contact with neural tissues and enabled reliable electrical stimulation, eliciting controllable motor responses. These results demonstrate the capability of ElHyX to operate reliably in complex biological environments. Notably, the original study further validated the long-term stability of ElHyX through extended *in vivo* evaluations over 14 to 28 d. Encapsulated devices maintained robust ECG signal acquisition, glucose sensing capability, and effective neural stimulation throughout this period, with histological analysis confirming minimal inflammatory responses and excellent tissue compatibility. These long-term data underscore the clinical translational potential of the ElHyX platform.

Perhaps the most compelling aspect of this work is the integration of physiological sensing and therapeutic intervention within a single implantable platform. While most existing bioelectronic sys-

tems primarily perform either monitoring or stimulation [11,12], ElHyX combines ECG recording, glucose sensing, and vagus nerve stimulation within a unified device architecture. Leveraging continuous physiological feedback, the system automatically initiates selective efferent vagus nerve stimulation (eVNS) in response to elevated glucose levels and heart rate. Unlike bilateral vagus nerve stimulation, which activates both afferent and efferent fibers and may inadvertently trigger hepatic glucose release, eVNS selectively targets efferent pathways to promote insulin secretion and glucose clearance, thereby achieving more effective glycemic regulation. In diabetic rat models, this closed-loop strategy effectively attenuated postprandial glucose excursions and accelerated glucose recovery. More importantly, this work moves implantable bioelectronics beyond passive sensing toward adaptive therapeutic intervention, highlighting the growing potential of intelligent bioelectronic medicine.

Despite these advances, several challenges remain for clinical translation. The long-term *in vivo* stability of the hydrogel phase, particularly its potential dehydration and mechanical degradation in dynamic physiological environments, requires systematic investigation. The chronic biocompatibility of EGaIn liquid metal, including its long-term tissue interactions and potential leakage, must be thoroughly evaluated. Additionally, the integration of multiple sensing and stimulation modalities within a single platform without compromising overall device reliability poses significant engineering challenges. Future systems should also incorporate a broader range of biomarkers, wireless power delivery, and AI assisted decision making to enhance autonomy.

Conflict of interest

The authors declare that they have no conflict of interest.

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