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Neuroscience NEWS & BUZZ

NeuroWorm: A movable long-term implantable soft fiber electrode for dynamic bioelectronics

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In the field of bioelectronics, achieving long-term, dynamic biological signal monitoring has been a longstanding challenge for researchers. Recently, scientists have introduced a groundbreaking technology—NeuroWorm—by drawing inspiration from nature.[1] This novel soft fiber electrode not only records bioelectrical and biomechanical signals in real time but also has the capability for dynamic positioning, enabling it to move within the body for efficient and precise monitoring. The advent of NeuroWorm marks a significant leap in bioelectronic devices, and its unique mobility and long-term implantability make it an innovative tool poised to disrupt traditional biological monitoring technologies.

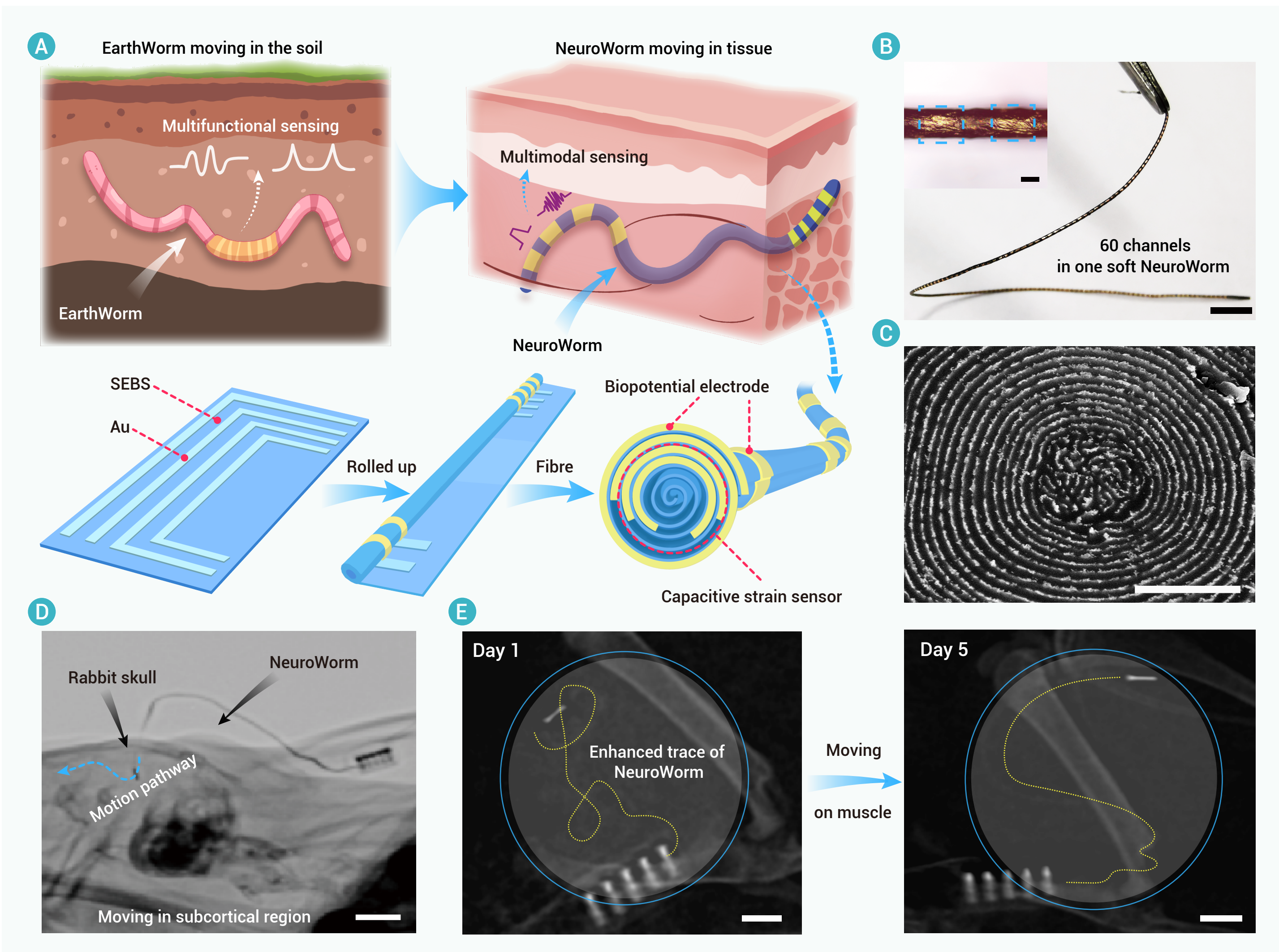

Figure 1. Design, fabrication strategy, and demonstrations of NeuroWorm (A) The concept and fabrication process of NeuroWorm inspired by earthworm. (B) A typical as-prepared microfibre with 60 biopotential electrodes longitudinally distributed along its length. Scale bar: 1 cm (main image) and 100 μm (inset image). (C) SEM image of the cross section of NeuroWorm. The experiment was independently repeated 10 times with similar results. Scale bar: 8 μm. (D) Demonstration of NeuroWorm movement in the subcortical region in a rabbit. Scale bar: 1cm. (E), X-ray images shows the fibre sensor traveling along muscles similar to earthworms. Scale bar: 5 mm. (Source from the *Nature*, 2025, 645(8081): 648-655. Reproduced with permission.[1] Copyright 2025, Springer Nature).

DISCOVERY AND INNOVATION

NeuroWorm introduces a completely new design concept inspired by the adaptability and dynamic movement of earthworms in nature. By mimicking their segmented structure, NeuroWorm features designed with highly soft, stretchable, and controllable electrodes (Figure 1). These electrodes integrate multi-channel arrays capable of recording both electrophysiological and mechanical signals simultaneously. More importantly, this fiber electrode can actively move within the body, guided by an external magnetic field to precisely reach target areas, enabling dynamic and real-time monitoring.

The key innovation of NeuroWorm lies in its ability to move freely within tissues, unlike traditional static electrodes.[2-4] This mobility allows researchers to adjust the electrode's position and configuration in real time, ensuring accurate signal acquisition and long-term stability. Its unique combination of structure and functionality not only broadens the application scope of bioelectronic devices but also provide new perspectives for personalized long-term health monitoring.

Key advantages and applications

NeuroWorm has wide-ranging potential across multiple disciplines. In neuroscience, it can dynamically navigate to specific regions of the brain or nervous system without requiring reimplantation, enabling real-time recording of neural activity. Traditional brain-machine interfaces (BMIs) typically require electrodes to be fixed in place, and if misaligned or drifted, reimplantation is necessary. NeuroWorm's active mobility overcomes this limitation, greatly reducing the need for secondary surgeries and lowering patient risk.

Additionally, NeuroWorm shows great potential in muscle monitoring. By implanting it into muscle tissue, researchers can obtain real-time electromyography (EMG) signals, providing more accurate bioelectrical data for studying motor neuron diseases, muscle atrophy, and other conditions. NeuroWorm's stretchability allows it to adapt to muscle movement, avoiding the mechanical mismatch associated with traditional rigid electrodes, thereby reducing immune responses and inflammation in tissues. More importantly, NeuroWorm can be implanted into muscle via a small incision, and it has demonstrated stable biological signal collection in rats for over 43 weeks. Even after 54 weeks of implantation, the fibroblast encapsulation around the fiber remained minimal, indicating its excellent biocompatibility.

Impact and inspiration

The introduction of NeuroWorm not only advances the frontiers of bioelectronic technology but also opens new possibilities for personalized medicine. NeuroWorm has vast application potential in long-term disease monitoring, neurorehabilitation therapy, and prosthesis control. For example, in muscle exoskeleton systems, NeuroWorm can serve as a tool for collecting electrophysiological signals, real-time muscle status monitoring, and movement adjustment. For patients with neurodegenerative diseases, NeuroWorm offers long-term, minimally invasive monitoring, allowing them to track their health status from home and avoid frequent hospital visits.

Furthermore, the innovative design of NeuroWorm also inspires new thinking in the field of bioelectronics. It breaks the limitations of traditional fixed electrodes and proposes a new device model capable of dynamically interacting with biological tissues (Figure 1). This device not only provides real-time data but also allows for adjustments based on the biological body's needs, opening up greater possibilities for future smart therapies.

Challenges and considerations

Despite its tremendous potential, NeuroWorm still faces several challenges before it can reach widespread application. First, ensuring its long-term biocompatibility and stability after implantation remains a key issue that requires further investigation. Although initial animal studies have shown promising biocompatibility in mice and rabbits, more comprehensive clinical data will be needed to confirm its safety in humans.

In addition, the current magnetic field control mechanism of NeuroWorm has certain limitations. At present, the precision and responsiveness of magnetic guidance are insufficient to fully adapt to the complex in vivo environment.[5] Therefore, enhancing magnetic control accuracy or developing alternative actuation strategies will be crucial directions for future research and practical deployment.

CONCLUSION

Overall, NeuroWorm represents a significant breakthrough in the field of bioelectronics, combining dynamic monitoring capability with long-term implantability to open new horizons for applications in neuroscience, muscle research, and personalized medicine. As the technology continues to evolve, NeuroWorm holds great promise for providing patients with more precise and adaptable bioelectrical monitoring solutions, thereby driving the medical field toward greater intelligence and individualization. Nevertheless, as this innovative technology progresses toward clinical and practical implementation, addressing key challenges such as long-term stability, biocompatibility, and the optimization of control methods remains essential for its future development. In summary, the emergence of NeuroWorm not only pushes the boundaries of modern bioelectronics but also injects new momentum into the development of health monitoring, disease treatment, and intelligent rehabilitation technologies.

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AUTHOR CONTRIBUTIONS

F. Han and Z.Y. Liu conceived the topic and drafted the manuscript. Q.H.Y. Yu, Q.S. Li and Y. Zhang contributed to figure design and manuscript revision. Q. Tian and provided critical discussion and guidance on content structure. H.R. Zheng, G.L. Li and Z.Y. Liu supervised the work, revised the manuscript, and approved the final version. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

Hairong Zheng is the Editor-in-Chief of The Innovation Informatics, and Zhiyuan Liu is an Academic Editor of The Innovation Informatics. Both were blinded from reviewing or making final decisions on this manuscript. Peer review was handled independently of them and their research groups. The other authors declare no conflicts of interest.