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Design Iterations on Self-Folding Neuroelectrodes

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Background

- **Peripheral nerve interfacing** offers a targeted therapeutic approach for metabolic disorders but requires **mechanically compliant** electrode designs that enable **highly selective** stimulation of relevant nerves.
- Conventional **cuff electrodes** provide stable nerve contact but can be difficult to handle at small scales.
- A prior **self-folding** flexible cuff design improved implantability but were limited to single-site interfacing.
- To support more precise neuromodulation, there is a **clear need for multi-channel interfaces** capable of engaging multiple nerves simultaneously.
- This project builds on the self-folding cuff concept by [1] to create a multi-channel flexible electrode designed for the peripheral nerves innervating brown adipose tissue in mice.

Research Objective: Re-design an existing flexible neuroelectrode to reliably interface multiple nerves in freely moving animals while maintaining relative ease of surgical implantation.

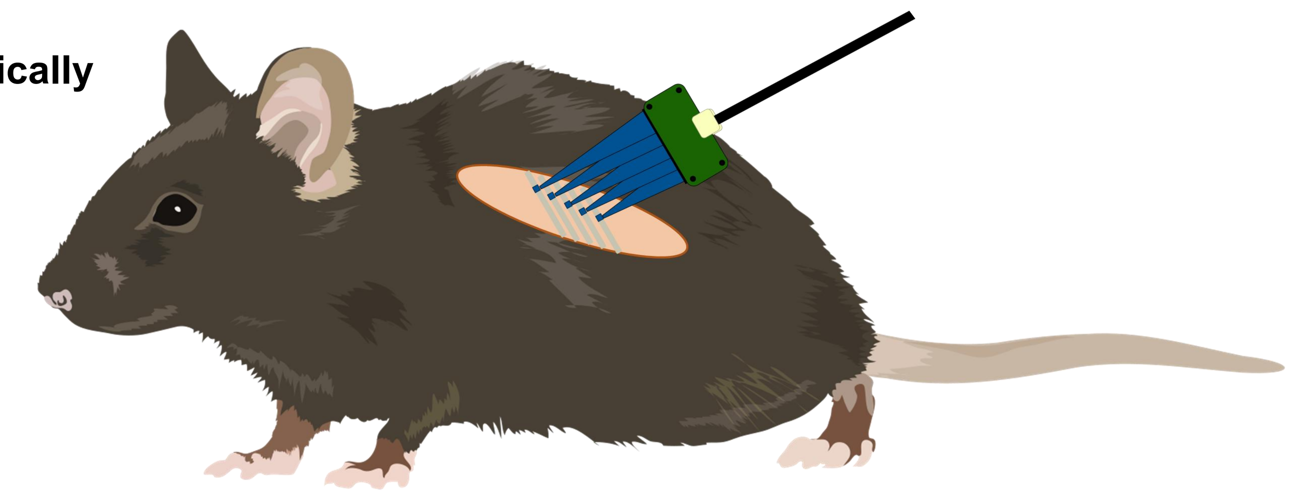
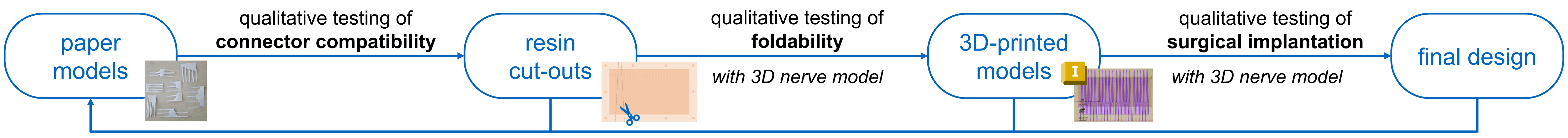


Fig. 1: Conceptual schematic of the multi-cuff electrode system targeting mouse adipose-tissue–associated nerves.

1. Multi-nerve flexible self-cuffing electrode
2. Practical and easy surgical implantation
3. Flexible tethered connection for motion tolerance

1 Designing a flexible self-cuffing electrode for the simultaneous interfacing of multiple nerves



Design Criteria

- Simultaneous interfacing of 5 different nerves on separate channels
- Robust interfacing during surgical procedure
- Compatibility with established fabrication process
- Compatibility with established 16 channel connector

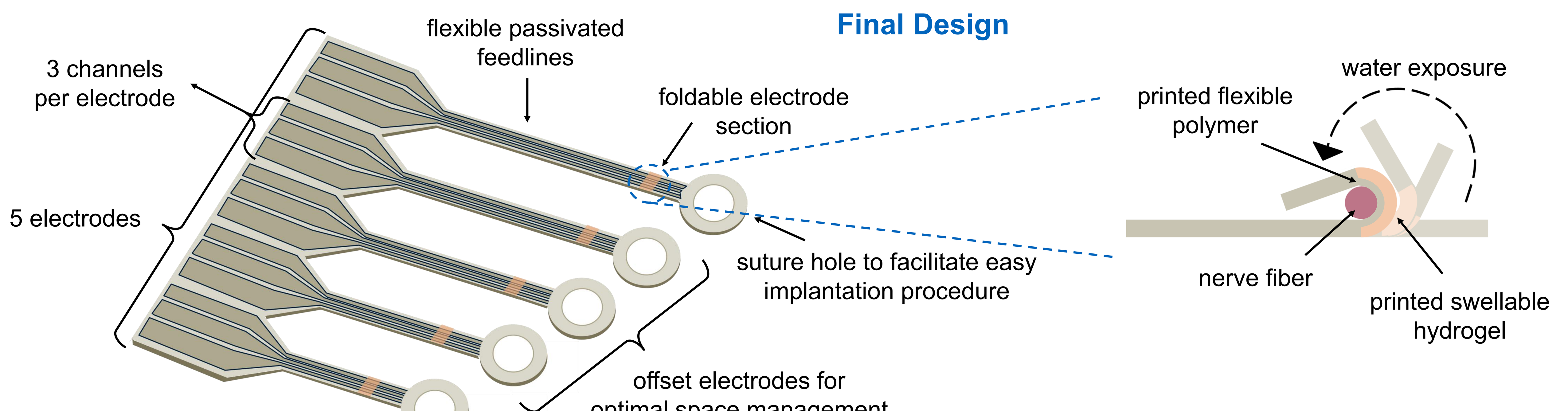


Fig. 2: Illustration of the 5-cuff flexible self-folding electrode system.

2 Designing easy surgical implantation

- Individual electrode placement is challenging; **self-folding alone** proved **unreliable** during multi-electrode implantation.
- A **scaled 3D-printed nerve model** with wire "nerves" was used to refine the procedure.
- A custom applicator was designed to **hold electrodes under the nerves** and **enable sutured cuffing** before self-folding and removal.

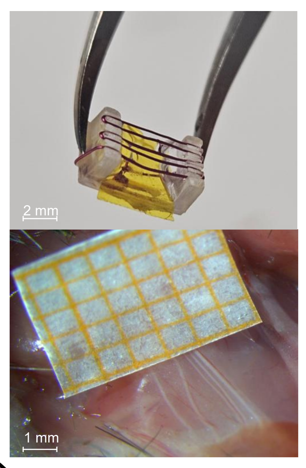


Fig. 3: Scaled 3D-printed nerve model (top) based on mouse adipose-tissue anatomy (bottom).

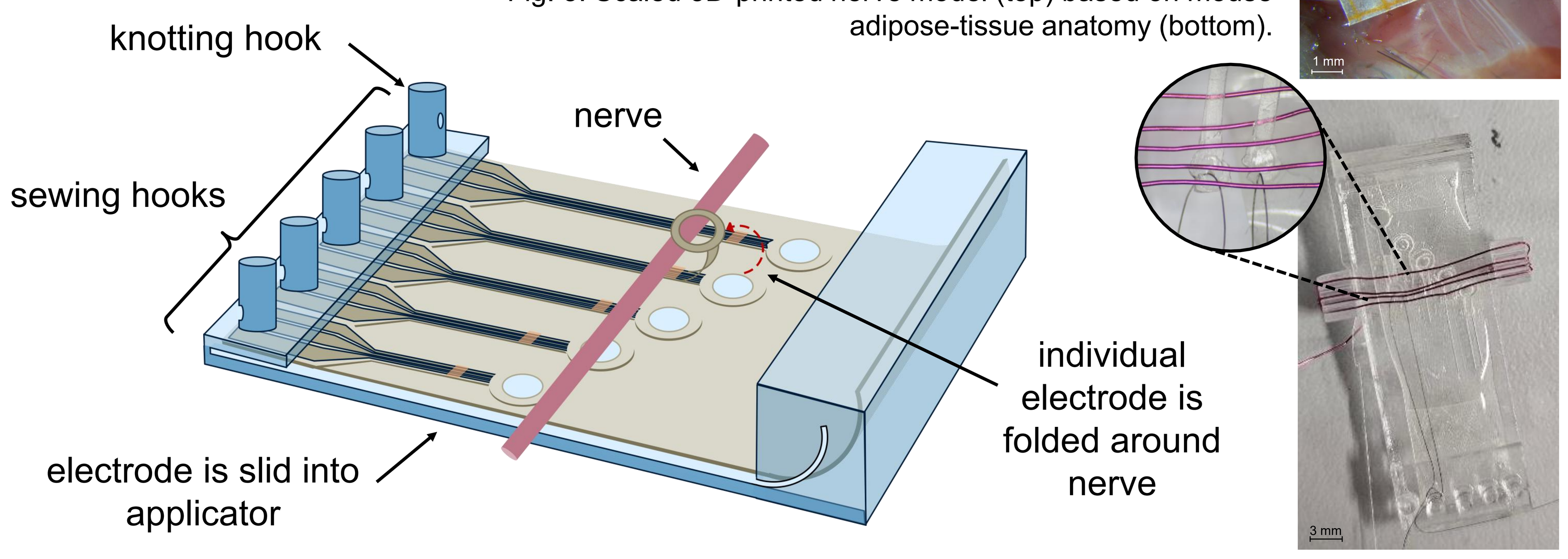
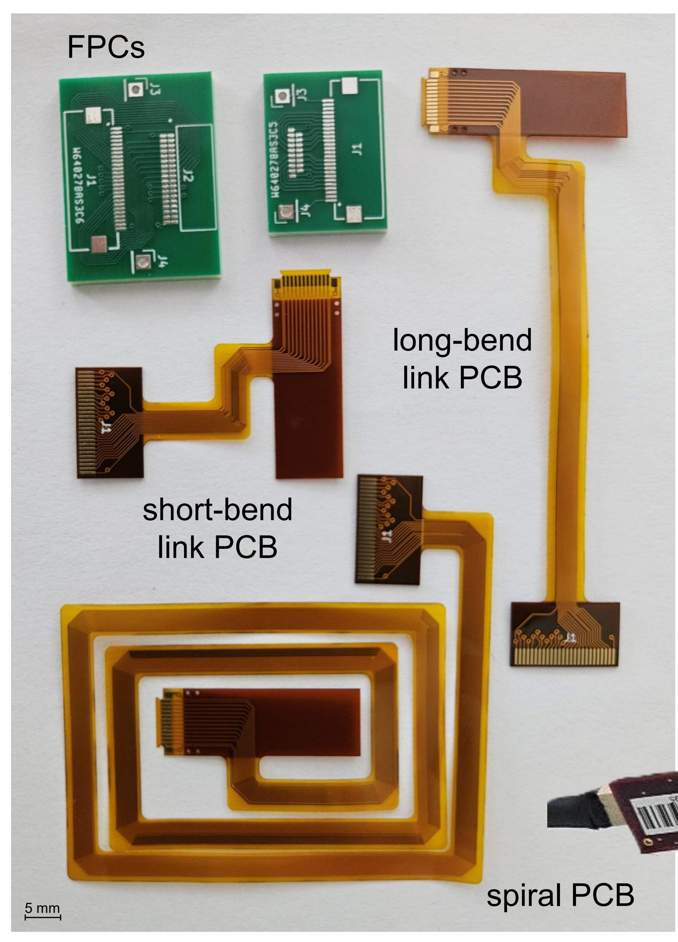


Fig. 4: Illustration of the applicator used for guiding and securing individual cuff electrodes during the implantation procedure (left). Fixation of individual electrodes via sutures (right).

3 Designing a motion-tolerant tether



- Rigid FPC connectors routed signals to external wiring for real-time recording.
- **Flexible PCBs** designed in KiCad provided **strain relief** between the electrode and external connector.
- **Three geometries** were qualitatively evaluated for maximizing the animal's range of motion.
- In vivo testing in locusts indicated that the **spiral design** provided the **greatest flexibility** with minimal stress on the electrode system.

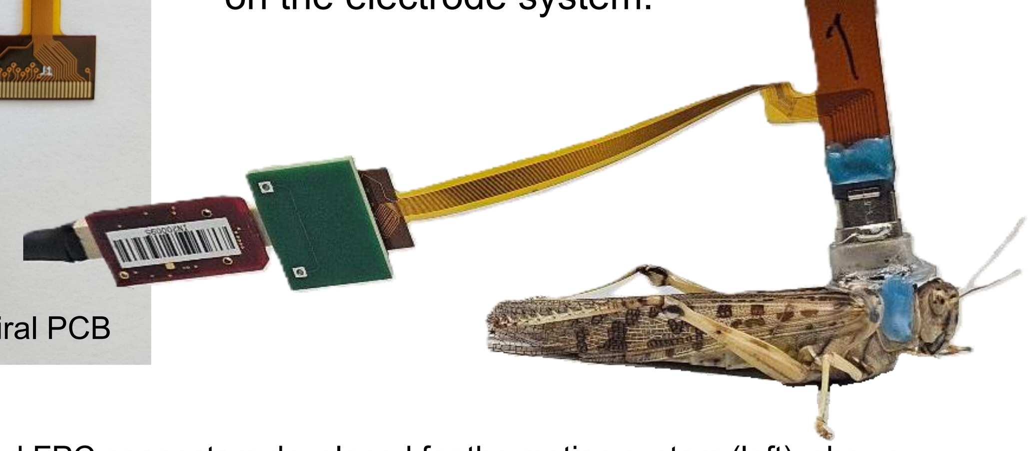


Fig. 5: Printed flexible PCBs and FPC connectors developed for the motion system (left), shown alongside the long bent flexible PCB implemented in a live locust for qualitative in vivo evaluation (right).

Limitations and Outlook

The current evaluation of the redesigned electrode system was **primarily qualitative**, and quantitative metrics – such as stimulation thresholds, impedance spectra, and signal-to-noise ratios – have not yet been obtained. **Comprehensive electrochemical characterization** and **in vivo testing** will be essential to assess long-term stability, selectivity, and functional performance. Additionally, the **mechanical behavior** of the multi-channel design **under chronic motion** and its **reliability** during repeated implantation procedures remain to be validated. Future work should focus on these assessments and on refining the geometry and connector system to further enhance usability and multi-site interfacing capability.

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References:
[1] L. Hiendlmeier, F. Zurita, J. Vogel, F. Del Duca, G. Al Boustani, H. Peng, I. Kopic, M. Nikić, T. F. Teshima, B. Wolfrum, 4D-Printed Soft and Stretchable Self-Folding Cuff Electrodes for Small-Nerve Interfacing. Adv. Mater. 2023, 35, 2210206. https://doi.org/10.1002/adma.202210206