Penetrating Microelectrode Array Inserter Utilizing Ultrasonic Vibration to Reduce Insertion Force and Brain Dimpling

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Neural Implants

- Neural implants have improved our understanding of brain function, and hold great potential to treat many neurological disorders.
- Penetrating electrode arrays provide a direct interface for communication with neural systems including brain, spinal cord, and nerves:
  - Basic science experiments: brain function, neural mechanisms
  - Future clinical applications: brain-machine interfacing, sensory prostheses, restore/modulate organ function

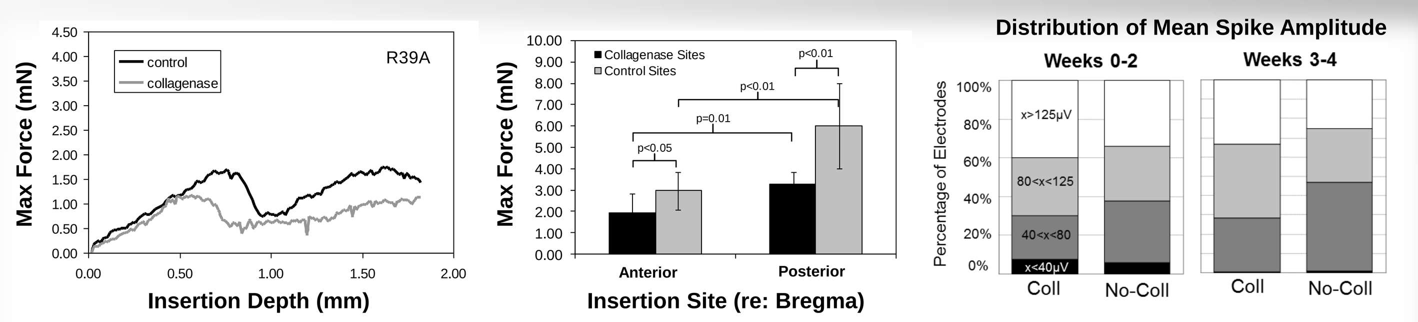
Current Limitations for Penetrating Electrode Arrays

- Establishing stable, chronic multi-channel neural interfaces with penetrating electrode technologies remains a significant challenge limiting clinical translation.
- Densely spaced penetrating electrodes commonly cause significant brain compression (dimpling) in the local region of the implant site.
  - The dimpling of the brain increases risk of implantation trauma and inflammation, and makes it difficult to accurately target specific cortical layers and nerve fibers.

Preliminary Work

Rat *in-vivo* electrode insertion and recording study [1]:

- Thinning out meninges with collagenase enabled less forceful electrode insertion.
  - Reduced force and less tissue dimpling.
- Collagenase-aided implanted electrodes yielded better recording performance (e.g., larger mean spikes).



Left: Insertion profiles for bi-lateral micro-wire electrode array insertions into rat cortex with and without collagenase. *Center:* Means of max insertion force showing effect of insertion site location and collagenase treatment. Error bars represent standard deviation; p-values from Student t-test. *Right:* Mean spike amplitudes trended larger in arrays inserted with collagenase.

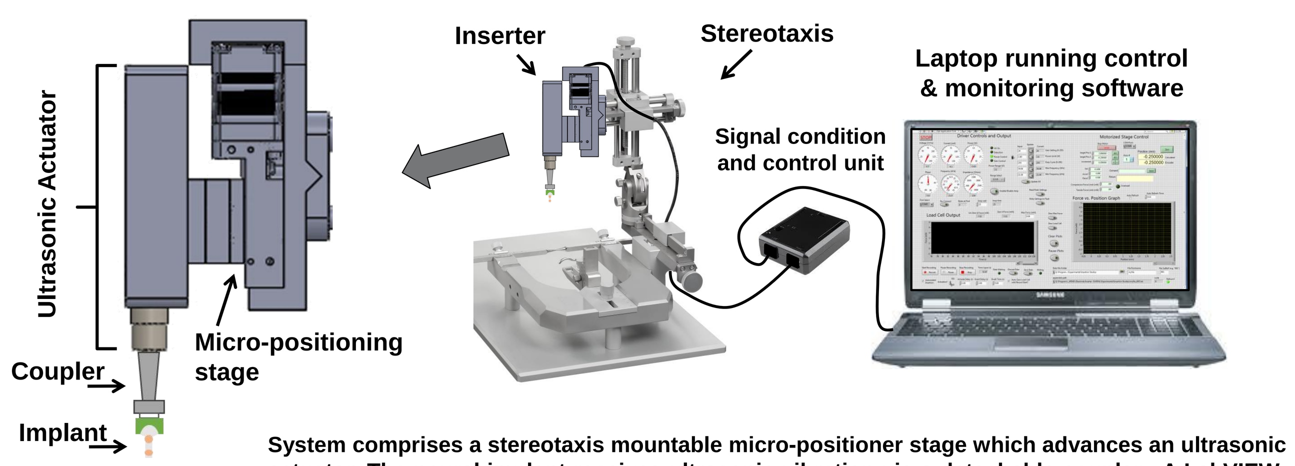
Motivation

To develop an implant insertion system that utilizes ultrasonic vibration to enable smoother insertion of penetrating electrode arrays into neural tissue with significantly less tissue dimpling.

Study Hypotheses

1. Use of ultrasonic vibration can reduce insertion force and tissue dimpling during electrode array insertion.
2. Reducing insertion force and dimpling of brain/neural tissue during ultrasonic vibration-aided insertion will lead to improved recording performance and reduced acute inflammatory response.

Ultrasonic Inserter System



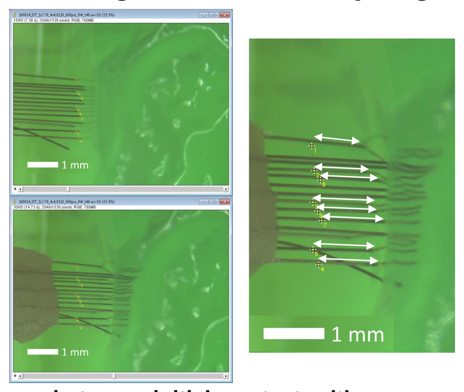
System comprises a stereotaxis mountable micro-positioner stage which advances an ultrasonic actuator. The neural implant receives ultrasonic vibration via a detachable coupler. A LabVIEW-based GUI controls the micro-positioner and actuator, while recording force and position data.

Methods and Measures

Agar Brain Model

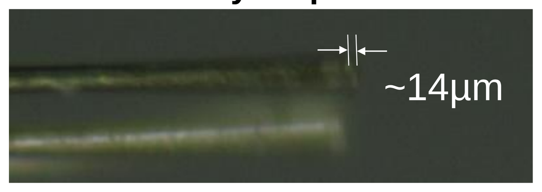
0.85% agarose (pia) on top of 0.5% agarose (brain)

Average Surface Dimpling



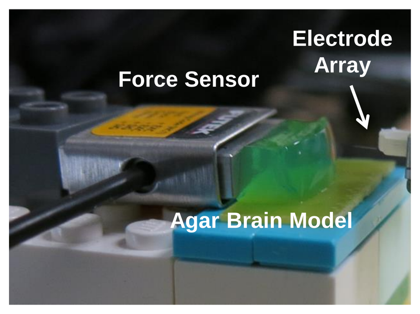
Distances between initial contact with agar surface and the estimated position of the surface at max dimple along a subset of shanks is measured and averaged.

Oscillatory Displacement



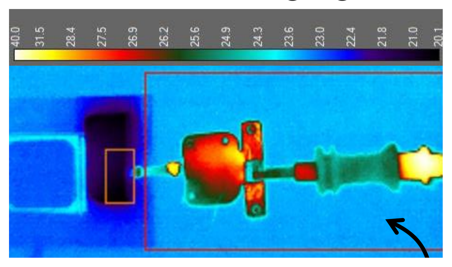
Over-exposed digital microscope images are analyzed using ImageJ to quantify displacement.

Insertion Force



An ultra-low capacity (10g, 2µN resolution) force sensor measures insertion force on the opposite side of agar brain model.

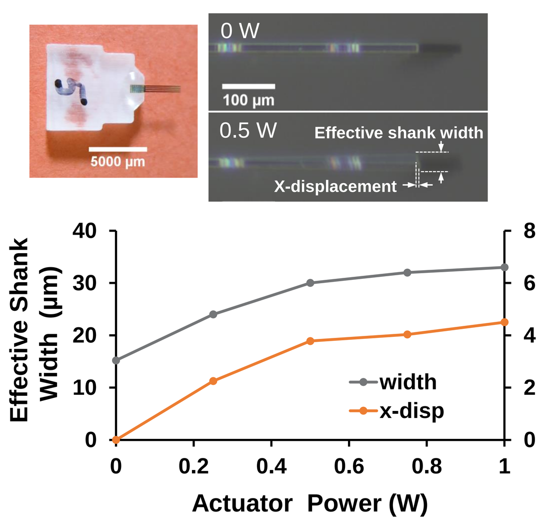
Thermal Imaging

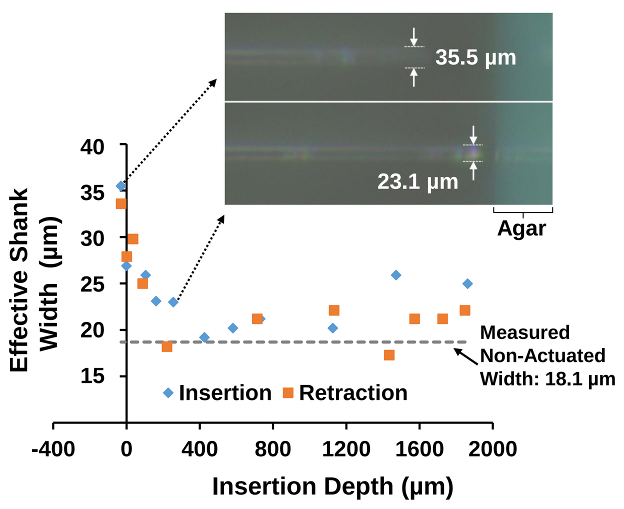


A FLIR 450sc infrared thermal camera is used to measure potential heat generation at the agar surface and to identify coupling inefficiencies.

Oscillatory Displacement vs. Power

- Vibration amplitude controlled by input power
- Out-of-plane vibration diminishes upon contact





Demonstration of digital optical microscopy method for measuring oscillatory displacement of an actuated NeuroNexus probe. *Left:* Displacement vs. actuator power for probe in air, measured from still image series using ImageJ. *Right:* Analysis of out-of-plane vibration of shanks near agar surface: out-of-plane motion diminishes quickly after initial contact.

Acknowledgments

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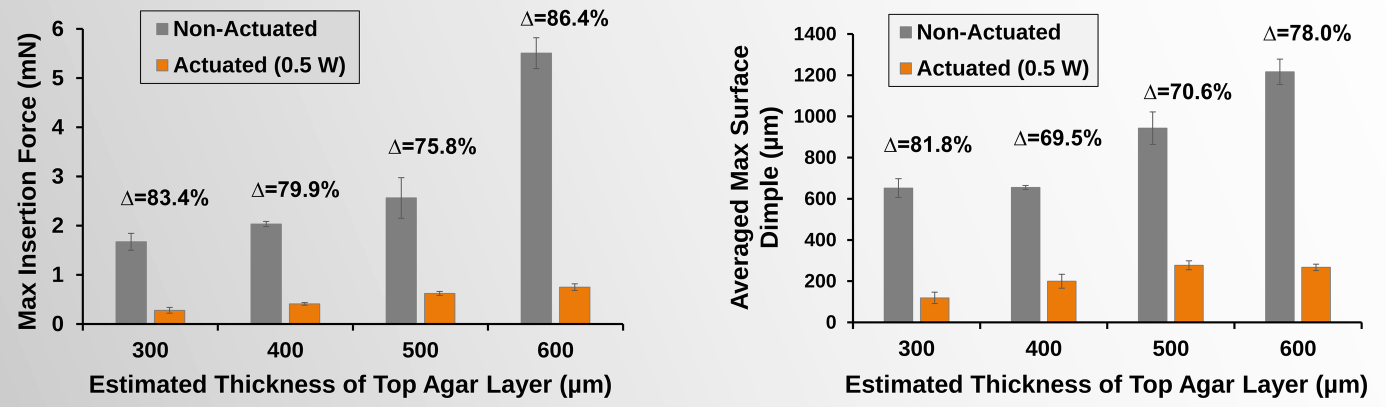
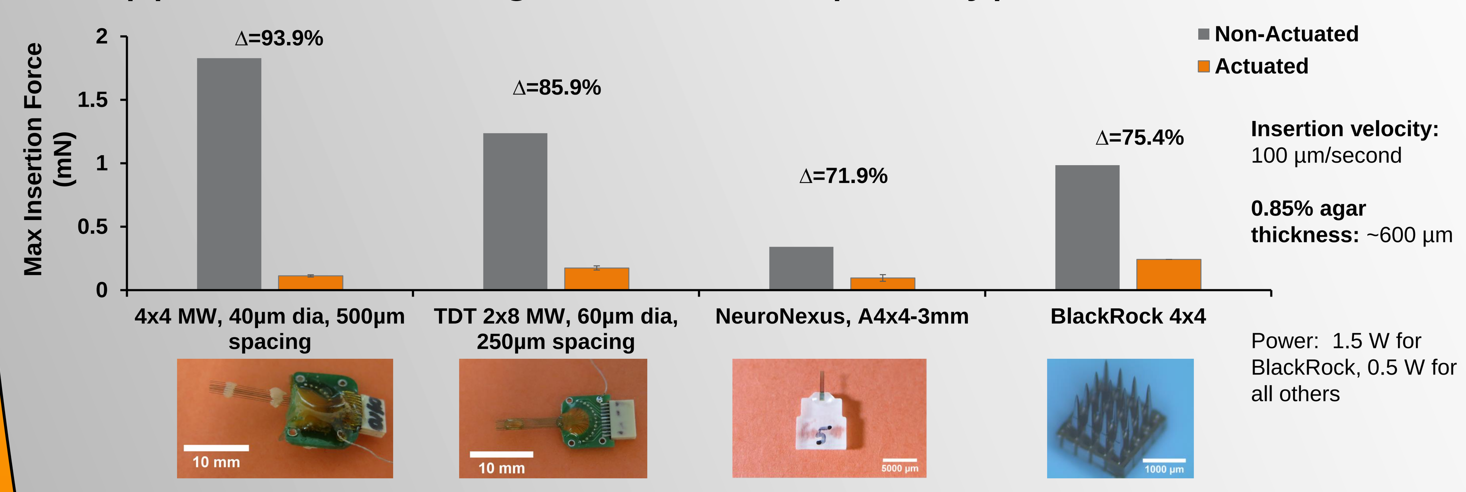
Reduction in Implant Insertion Force and Surface Dimpling

- 70-90% reduction of max insertion force and surface dimple with ultrasonic vibration

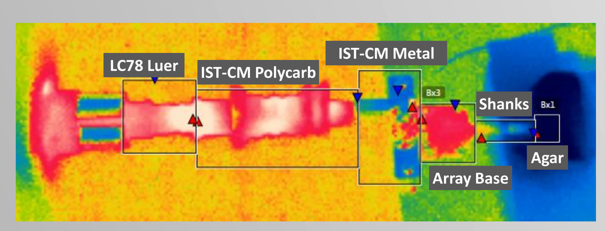


Comparison of actuated and non-actuated insertion force (Left) and surface dimpling (Right) of a 4x4 micro-wire array (40 µm, 500 µm spacing) inserted into 0.5% agar model with varying thicknesses of top 0.85% agar layer (to simulate pia). Insertion velocity: 200 µm/sec. Actuation significantly reduces insertion force/dimpling below non-actuated force/dimpling for all 0.85% agar layer thicknesses studied. Δ indicates percentage reduction. Error bars indicate standard error.

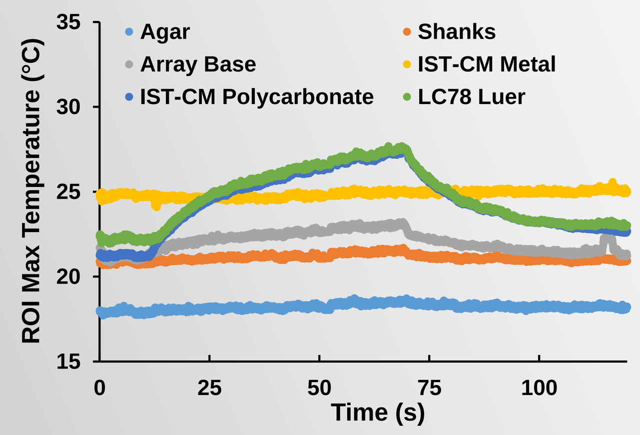
- Actuated vs. non-actuated insertion comparison video:
- Applicable to a range of neural implant types



- Thermal imaging data suggests enhanced insertion can be achieved with no risk of tissue over-heating

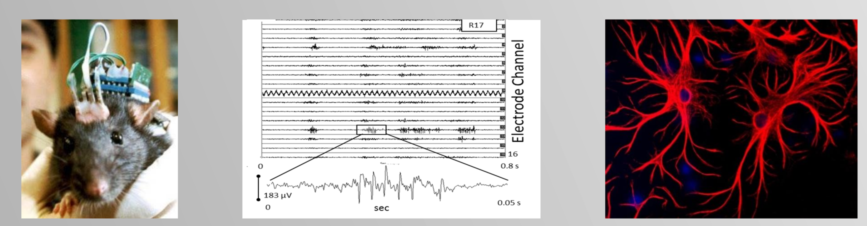


Example of thermal data obtained from 60 seconds of 0.5 W actuation in an agar model. Custom micro-wire, Tucker-Davis, and NeuroNexus arrays were tested and all resulted in a less than 0.9°C temperature increase at agar surface after 60 seconds of continuous actuation.



Current/Future Work

- *In-vivo* animal testing to evaluate whether ultrasonic vibration-aided insertion of electrodes into brain tissue may reduce the inflammatory response and improve neural interface performance:
  - Electrode impedance
  - Neural recording quality over time
  - Immunohistochemistry



- In addition to the brain, future applications of the technology yet to be explored include both spinal cord and peripheral nerve targets.

References

1. Paralikar K, Clement R. Collagenase-aided intracortical microelectrode array insertion: effects on insertion force and recording performance. *IEEE Trans Biomed Eng.* 2008;55(9):2258-2267.

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