In Vivo Swine Model for Developing and Validating Acoustoelectric Brain Imaging of Neuronal Current

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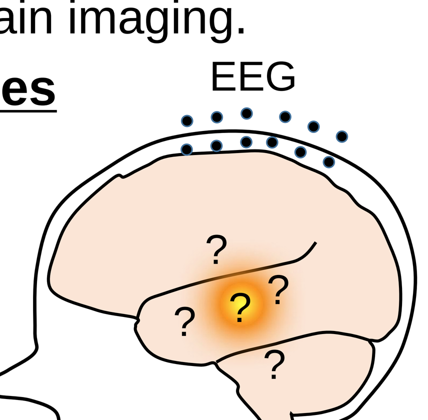
Electrical Brain Imaging

- Abnormal electrical brain activity is linked to a variety of neurological conditions.
- Critical need for a new noninvasive modality capable of 4D high resolution electrical brain imaging.

Limitations of modern techniques



- Tradeoff between invasiveness, resolution, and field-of-view.
- EEG has poor resolution (>1 cm) and is unable to accurately resolve deep dipole sources.

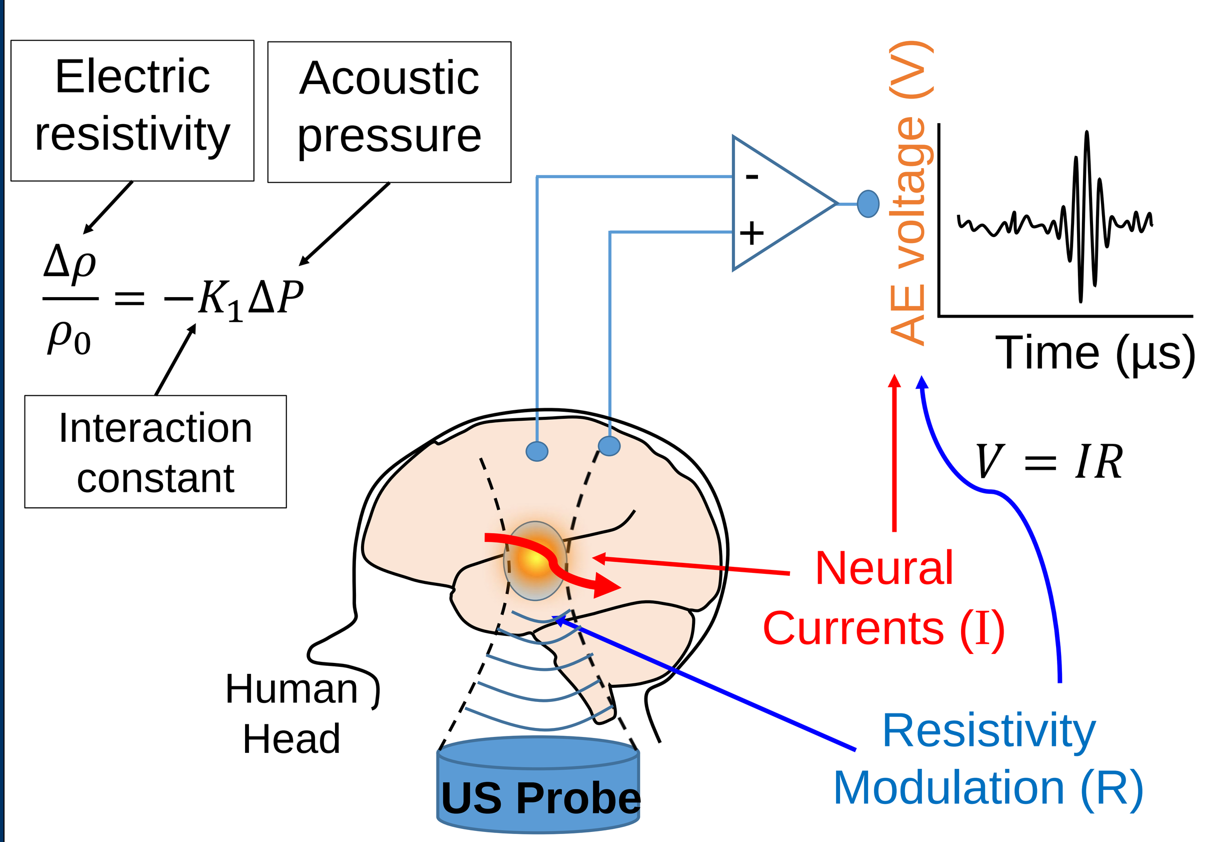
Proposed solution:

Acoustoelectric Brain Imaging (ABI):

- Novel technique that combines ultrasound with radiofrequency detection to map neuronal currents in real-time with high spatial resolution (1-3 mm^3).

Goal: Develop *in vivo* model to benchmark and validate ABI in large animals.

Acoustoelectric Effect and ABI



- Ultrasound (US) modulates tissue resistivity.
- According to Ohms Law, change in resistivity produces a measurable voltage signal ("AE signal") as the focused pressure wave intersects neural currents [1,2].
- High resolution current density maps (ABI) are generated by rapidly steering the US beam in the brain while detecting the AE signal on one or more electrodes.

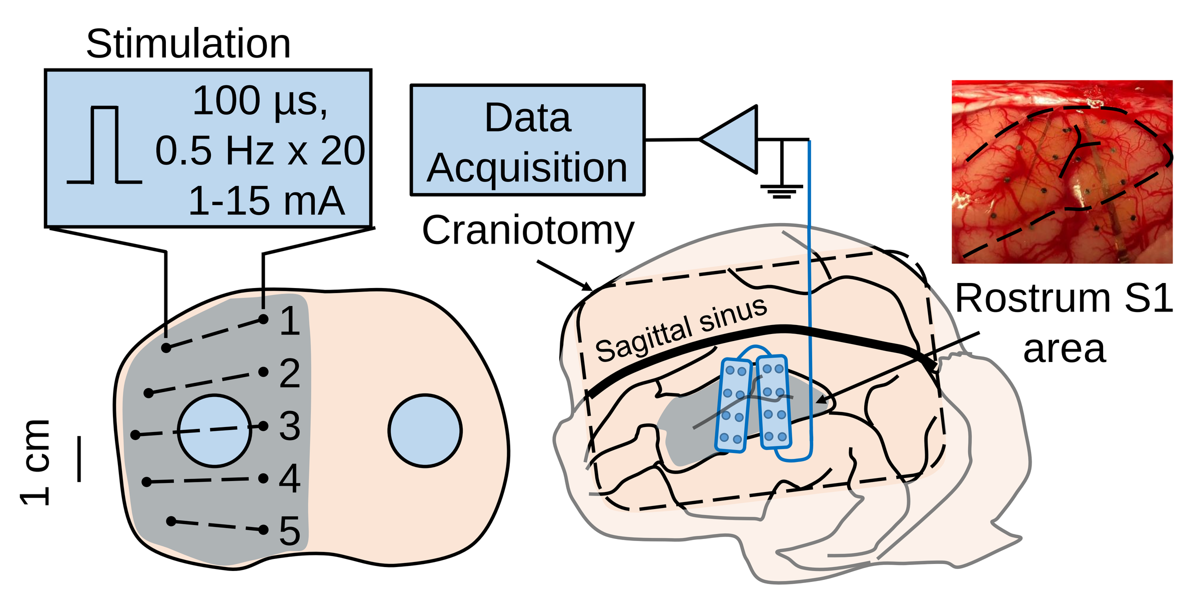
In Vivo Swine Model for Validating ABI: Behavioral Paradigm

- Evoke cortical somatosensory potentials in anesthetized pigs via electrical snout stimulation.
- Create somatotopic maps of rostrum somatosensory area using electrocorticography (ECoG).
- Integrate custom ABI platform for *in vivo* mapping of somatosensory evoked potentials.

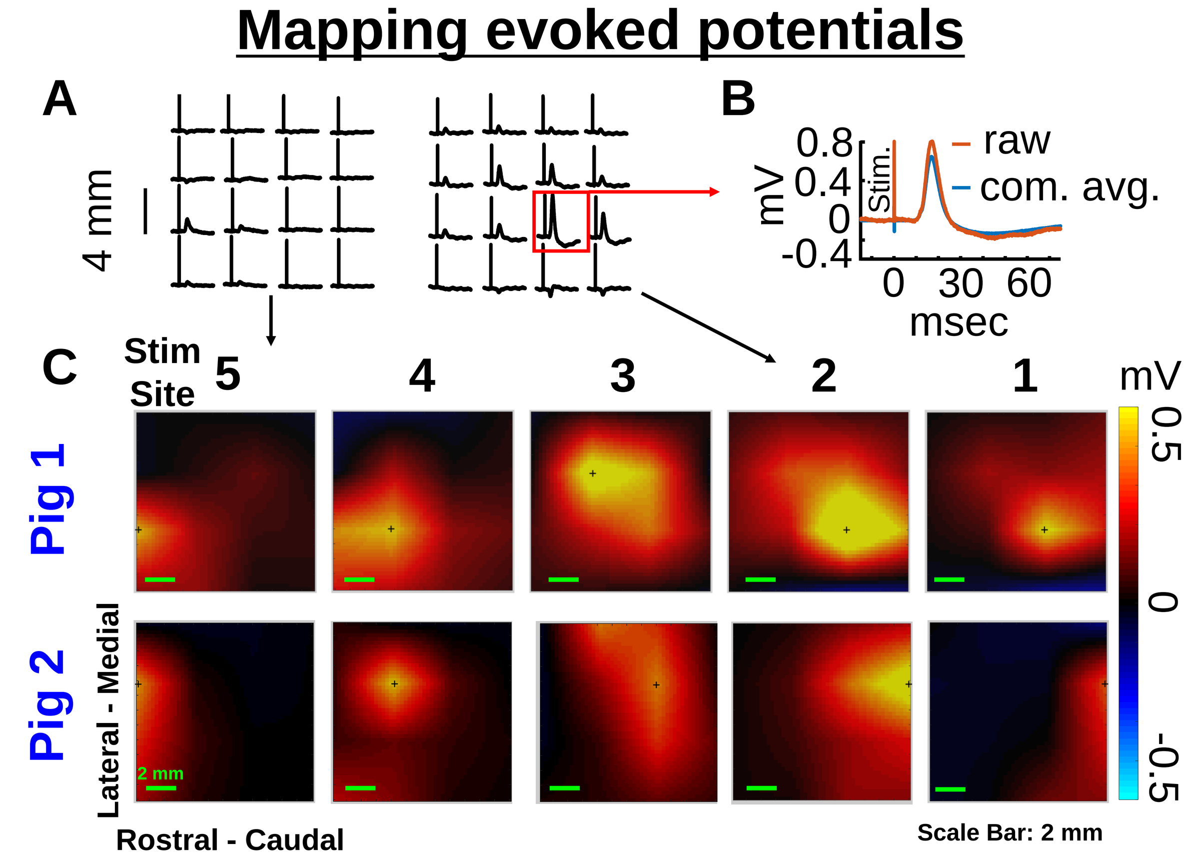
Electrocorticography Mapping

Evoked Potential Mapping Protocol

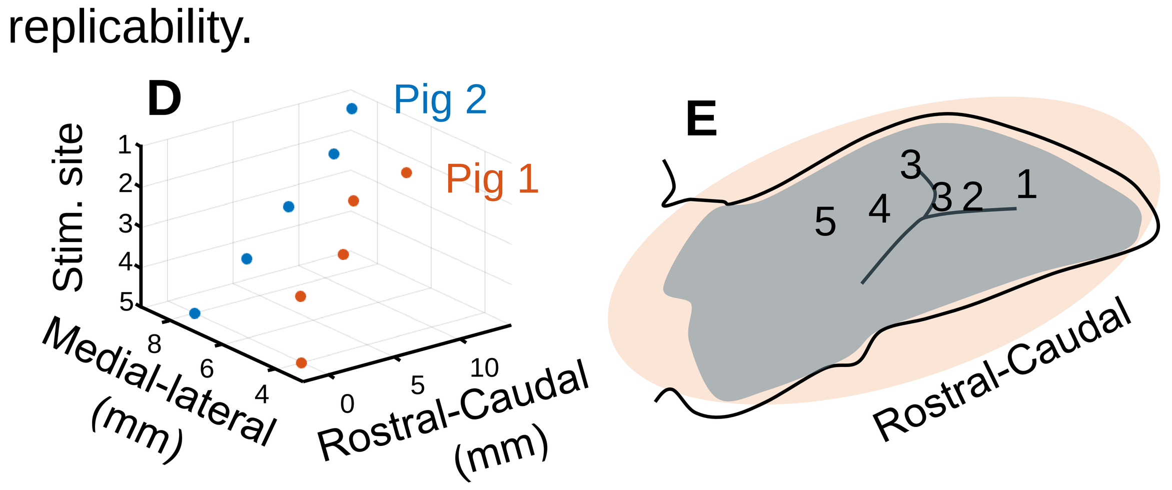
- After craniotomy, right or left snout (rostrum) was electrically stimulated with two needle electrodes.
- Evoked activity across contralateral rostrum somatosensory S1 area mapped with x2,16-channel ECoG electrode array (NeuroNexus).
- Stimulating electrode pair was repeatedly inserted along dorsoventral/vertical axis of snout (5 sites).



Mapping evoked potentials

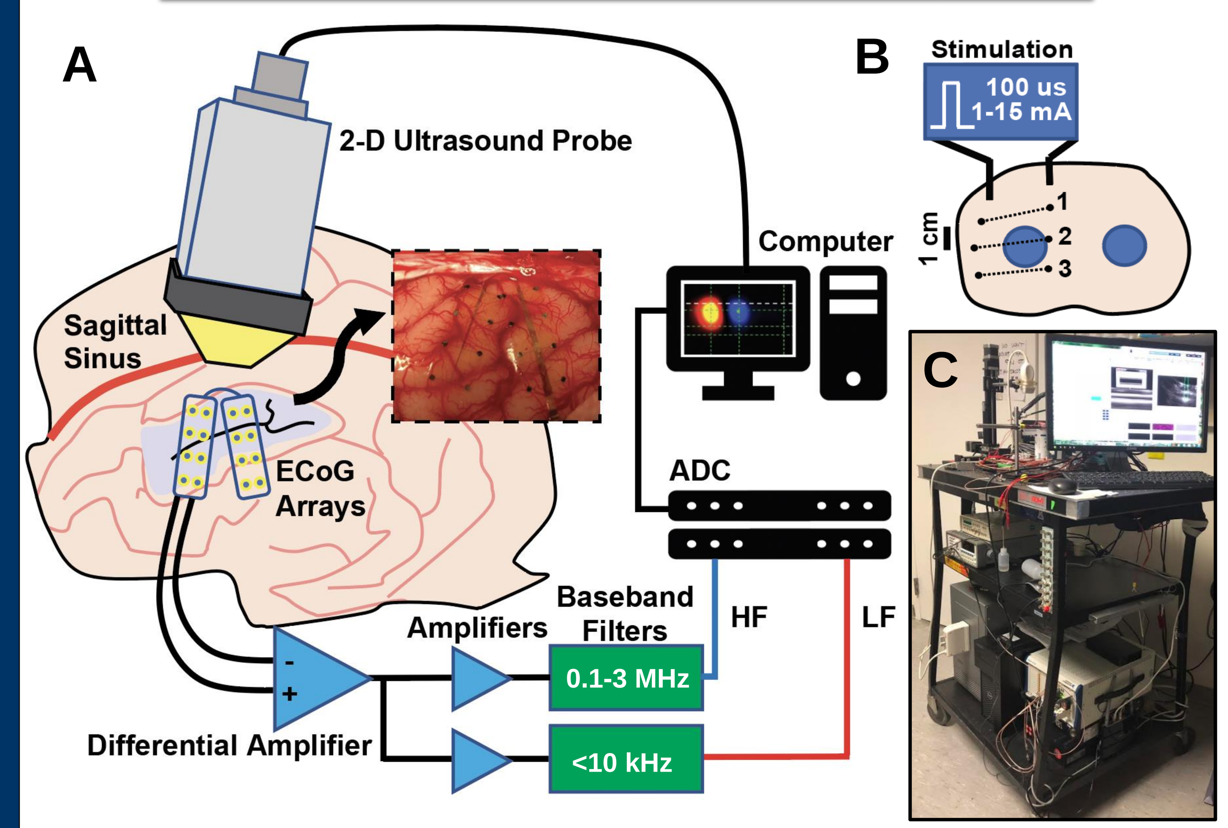


A) Evoked potentials over rostrum somatosensory area during snout stimulation Site 2 and Site 5.
B) Zoomed in evoked signal from indicated channel
C) Somatotopic maps of peak cortical activation for each stimulation site. Maps for two pigs demonstrate replicability.



D) Recording locations of peak activation relative to stimulation site. E) Approximate area of rostrum S1 represented by receptive field of stimulation site.

Setup for *In Vivo* ABI in Swine

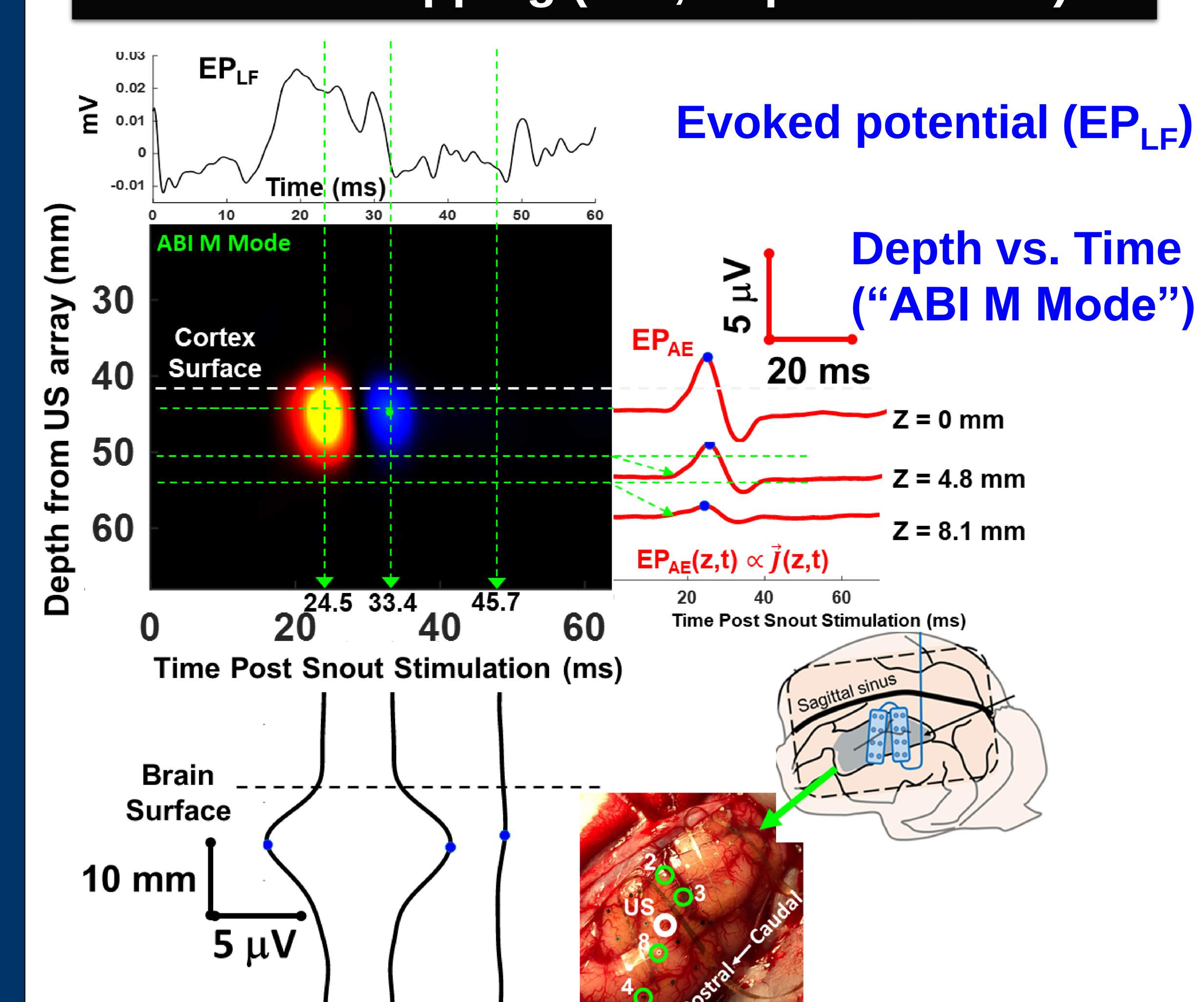


A) Custom 0.6 MHz 2D US array with 3D printed adapter positioned above pig brain [3]; US pulses focused and steered near somatosensory cortex.

B) Needle electrodes fixed in snout for stimulation; ECoG electrodes were used to record evoked potentials (<10 kHz) and AE signals (>0.1 MHz).

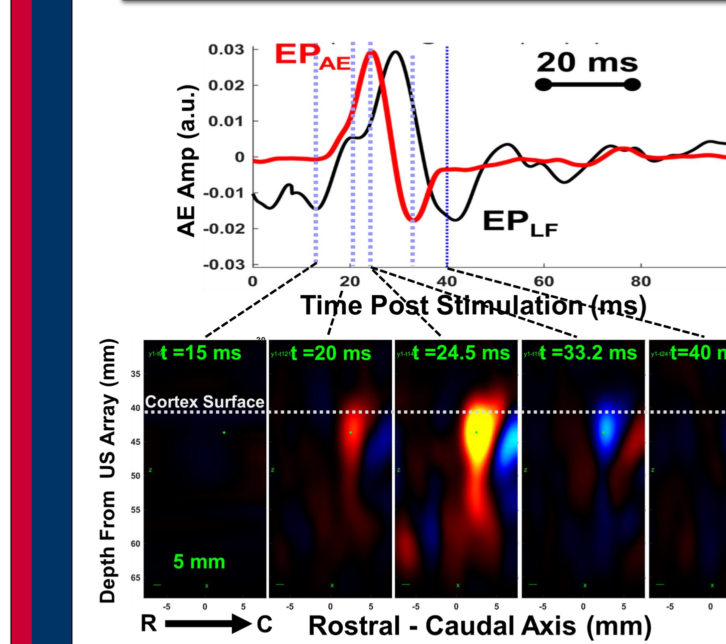
C) Mobile system for real-time stimulation, electrophysiology, and imaging (ABI and pulse echo).

Current Mapping (ABI, Depth vs. Time)



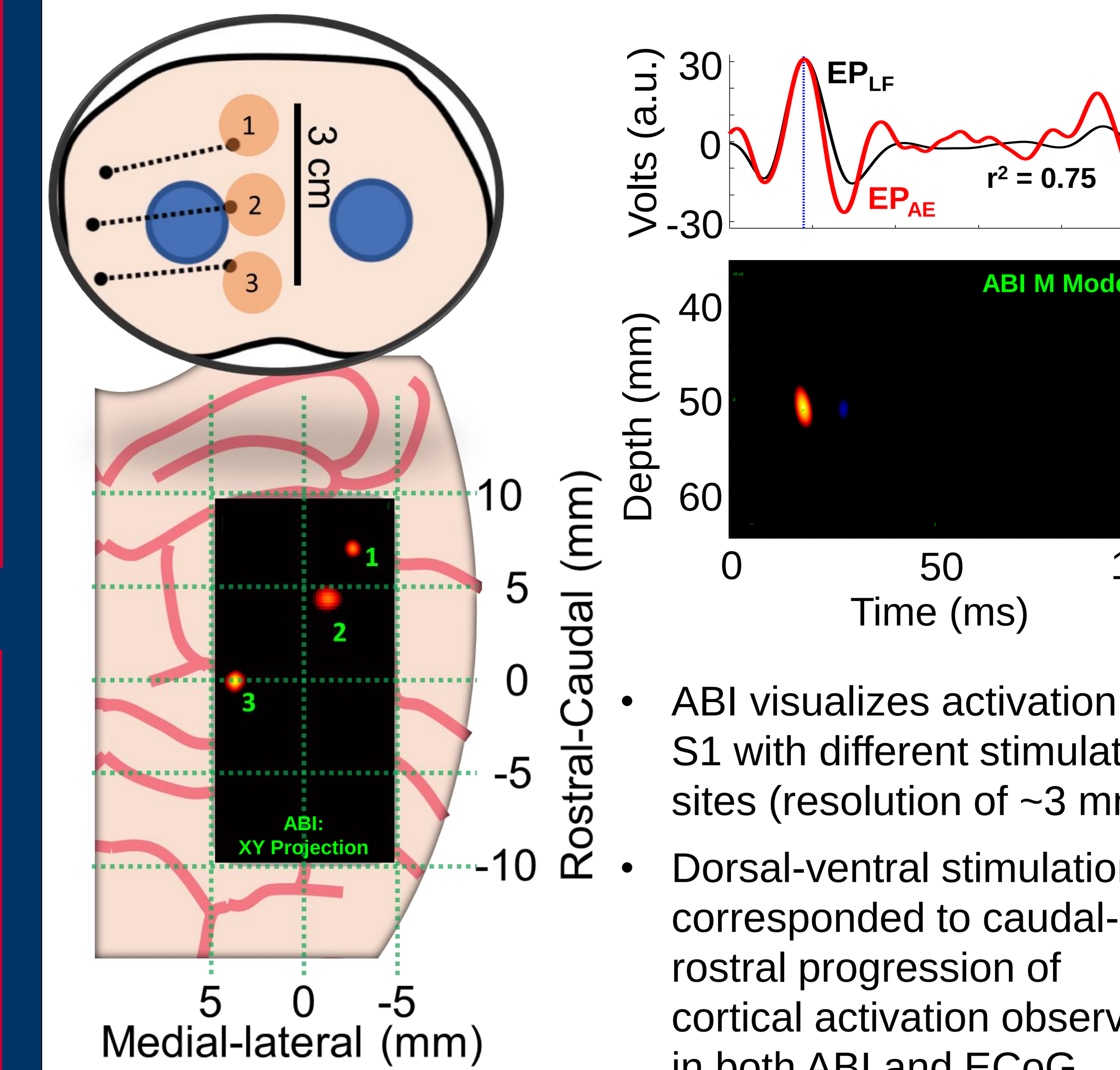
- ABI M Mode: Each row denotes time profile of local currents at a single depth; each column denotes local currents along depth at a single time point during EP.

Current Mapping (ABI, Cross-Sections)



- US beam steered across S1, producing cross-sectional ABI maps during snout stimulation.
- High correlation with a delay between EP_{AE} and EP_{LF}.

Somatotopic Mapping: ABI vs. ECoG



- ABI visualizes activation of S1 with different stimulation sites (resolution of ~3 mm)
- Dorsal-ventral stimulation corresponded to caudal-rostral progression of cortical activation observed in both ABI and ECoG voltage maps [4]

Summary and Future Work

- **First validation of *in vivo* ABI**; swine model allows for spatiotemporal control of neural currents for validating ABI.
- ABI able to accurately map evoked currents in the swine brain at a resolution of 3 mm and <1 msec.
- Cortical activation, detected by both ECoG and ABI, dependent on site of snout stimulation and consistent with organization of S1 in swine [4].
- Key steppingstone towards a new modality for human brain imaging (e.g., electrical mapping during neurosurgery).
- Noninvasive ABI possible with transcranial US [5].

References and Grant Support

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