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4D Transcranial Acoustoelectric Imaging of Current Densities in Human Head Phantom

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Background, Motivation and Objective:
As the gold standard for noninvasive electrical mapping of the human brain, electroencephalography (EEG) depends on detection of bioelectric fields, which are blurred as they pass through the brain and skull leading to poor resolution (>10 mm) and inaccuracies, especially for mapping deep structures. To overcome this limitation, we propose 4D (space + time) transcranial acoustoelectric brain imaging (tABI) for noninvasive, high-resolution mapping of neuronal currents at a resolution determined by the US focus. tABI employs focused ultrasound (US) to locally modulate tissue resistivity according to the acoustoelectric (AE) effect. The goal of this study is to demonstrate noninvasive tABI by delivering US through skull to generate time-varying maps of the embedded current sources.

Statement of Contribution/Methods:
A gel phantom mimicking the electrical and mechanical properties of the human brain was prepared inside an adult human skull. EEG-like current sources were created by injecting time-varying current through platinum needle electrodes or contacts on a clinical depth array embedded below the brain surface. An ultrasound beam from a custom 0.6 MHz 2D array or 2.5 MHz linear array was electronically steered at 4 kHz into the brain phantom to generate AE interaction signals detected by EEG electrodes placed on or under the skull cap for comparison (Fig 1A, 1B). AE signals were further amplified, filtered, and demodulated prior to display.

Results/Discussion:
4D tABI maps depict the magnitude and direction of a current sources 20 – 80 mm below the surface. Despite a loss of 71% at 0.6 MHz through thick skull, the peak AE signal, sensitivity and SNR recorded from skull electrodes were 3.77±0.78 μV, 0.36 μV/mA, and 14.3±1.24 dB, compared to 5.73 μV, 0.63 μV/mA, and 14.5 dB recorded from electrodes directly on the gel phantom (Fig 1C-1F). Despite the modest reduction in sensitivity and SNR with noninvasive electrodes, tABI is still within range of detecting the strongest neural currents in the human brain (~1 mA/cm^2) with safe US pulses (MI<1.9). Ongoing refinements to the imaging system could push detection limits to weaker neural currents (<0.1 mA/cm^2), opening the possibility of 4D tABI as a revolutionary modality for accurate, high resolution mapping of evoked potentials in the human brain.

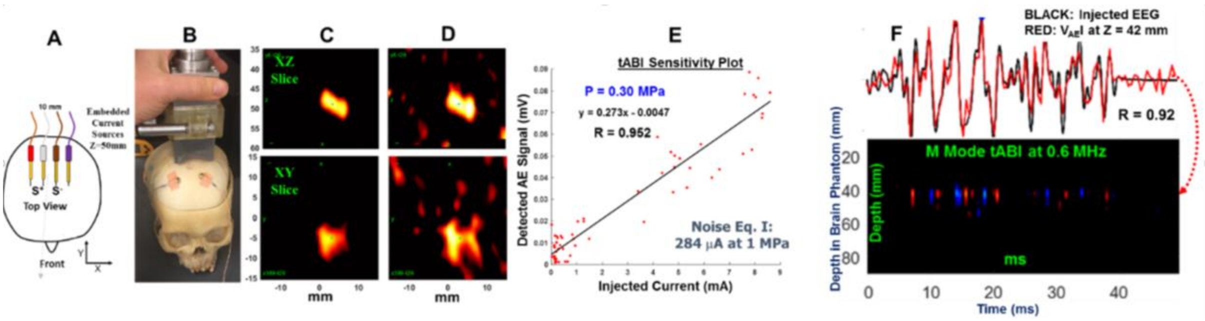

Fig. 1. A) Top view profile of needle electrodes embedded in brain phantom; B) Photo of human skull with gold EEG electrodes and custom 0.6 MHz 2D matrix US array; Cross sectional images through embedded monopole detected from brain (C) and skull surface (D); E) Sensitivity plot of injected current vs. AE signal amplitude; F) AE Color M Mode depicting depth vs. time of EEG-like current injection 40 mm below skull top.