Where Sound Meets Electricity: The Acoustoelectric Effect in Biomedicine

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The Acoustoelectric Effect

\[ \frac{\Delta \rho}{\rho} = -K_i \Delta P \]

Local Modulation

Exploiting the AE Effect Depends on Ohm's Law

\[ dV = K'iP_\rho dP \]

A Setup for Detecting the AE Signal

The Acoustoelectric Effect in Biomedicine

1. Ultrasound Current Source Density Imaging
2. Novel Devices to Monitor Acoustic Exposure

Novel Ultrasound-Enhanced Electrophysiology

Mapping an US Beam During Therapy

Electrical Mapping of Biopotentials: Clinical Relevance

Neurosurgery
(Epilepsy, Parkinsons)

Cardiac Surgery
(Arrhythmia)

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Can Ultrasound Enhance Traditional Electrophysiology and Mapping of Biopotentials?

**Proof of Concept Experiments**

- Passive current in neural tissue
- Dipole in saline
- Physiologic current in live heart prep

**Conventional Electrophysiology**

**Spatial and Temporal Resolution**

- EEG
- Local Field Potential
- Action Potential

**Dipole in saline**

**Olafsson, Witte et al. (2008)**

**Conventional Electrophysiology**

**Tradeoff: Resolution for Invasiveness**

- Many Cells -> Spatial Resolution
- Single Cell
- Surface -> Invasiveness
- Penetrating

**Ultrasound Current Source Density Imaging of a Nerve**

**UCSDI Proportional to Pressure and Current Density**

AE signal detection possible at pressure within range of medical imaging (<2 MPa) and at physiologically relevant current density (<10 mA/cm²)

**3-D Ultrasound Current Source Density Imaging of a Nerve**

- UCSDI automatically co-registered with pulse echo US
- Resolution of UCSDI determined by ultrasound focus
Unpublished Work Image Removed

Ultrasound Current Source Density Imaging
Top View (photograph)
Structure (Pulse echo)
Current Density (UCSDI)

Coming soon: IEEE UFFC Symposium, 2009

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Ultrasound Current Source Density Imaging
Dipole In Saline

→ Scan ultrasound beam in NaCl bath
→ At each beam location, for each electrode pair, detect AE signal and solve a mini-inverse problem

Ultrasound Current Source Density Image
From a Single Electrode Pair

Comparison with Conventional Reconstruction of Current Source

UCSDI Simulation  
UCSDI Measured  
Conventional Reconstruction (No Ultrasound)

Ultrasound Current Source Density Imaging
Cardiac Activation Wave in Live Heart Prep
Experimental Timing

- Heart Pacing Rate (PRF) = 3 Hz
- BDM used to limit cardiac motion

Orientation

B Mode Movie 1: Atrial Stimulation

B Mode Movie 2: Apical Stimulation

M-mode Imaging

AE is spatially separable

AE is temporally separable

Correlation: UCSDI vs. Conventional ECG

UCSDI compared with conventional electrophysiology (no ultrasound)

Potential advantages of UCSDI
- Direct imaging of biopotentials and current flow in 4D
- Spatial resolution determined by US focus (<1 mm³)
- Fewer assumptions (e.g., conductivity, sources, etc.)
- Less invasive with possibly fewer electrodes
- Automatic co-registration with pulse echo ultrasound

Major Challenges:
- Sensitivity
- Instrumentation

What if the ultrasound beam pattern \( P(x,y,z,t) \) was the unknown, but you had control of the current density \( J(x,y,z,t) \)?

The Acoustoelectric Hydrophone:

Why Monitor Medical Ultrasound Exposure?

1) Ensure Safety
2) Guide Treatment

Focused Ultrasound Surgery

- Lithotripsy
- Uterine Fibroids
- Tumor Therapy
- Thrombolysis
- Drug/Gene Delivery

Novel Devices to Monitor Acoustic Exposure
- Diagnostic Imaging: 0.1 W/cm²
- Sonolysis: 0.5 W/cm²
- Hyperthermia: 3 W/cm²
- Coagulation: 5 W/cm²
- Necrosis (HIFU): >1000 W/cm²

Acoustic Power
An ideal hydrophone should have these qualities:

- High sensitivity (<50 kPa)
- Inexpensive/Disposable
- High bandwidth (>20 MHz)
- Resilient to high intensities

The Acoustoelectric Hydrophone:

Early Prototypes

The Acoustoelectric Hydrophone:

Early Prototypes

Apparatus for Testing Hydrophones

Effects of Current and Pressure on the Acoustoelectric Signal

Comparing Hydrophones: Axial/Lateral Beam Slices

Copper Tape, Thick Film Resistor

Low Power AE Hydrophone:

↑ Resistance  ↓ Current:
(no net signal loss)
Next Generation:
MEMS-based AE Hydrophones

Key advantages of AE Hydrophone
• Disposable hydrophone based on conduction
• Sensitivity (<20 kPa) proportional to bias current
• Faithful reproduction of US beam pattern

Focus of ongoing work
• Optimize material composition and design
• Test high bandwidth devices (10+ MHz)
• Evaluate damage threshold at high intensities

Acknowledgements