High Speed Ultrasound Imaging for Targeting and Monitoring Trans Esophageal HIFU During Cardiac Procedures

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Ventricular arrhythmias
- Electrical dysfunction → Abnormal heart rhythm
- May be lethal
- Healthy or pathologic hearts
- Focal activation or re-entry circuits

Origin #1 of ventricular arrhythmias
- Re-entry circuits
- Scars in the myocardium
1. Normal conduction
2. Slowed down conduction
3. No conduction

- Focal activation by hyper automatism

- Re-entry
- Hyper automatism
Clinical case #1

65 yo Man, infarct, electrical storms on tachycardia, multiple shocks with internal defibrillator

Endo cavitary mapping of the cardiac activity

Early activation

Late activation

RF ablation ➔ Arrhythmia under control

Clinical case #2

47 yo Woman, dilated cardiopathy, no coronary disease, electrical storm

Endocardial mapping of cardiac activity

Epicardial mapping of cardiac activity

Different sites of activation – What happens in the cardiac wall?
Clinical case #2

Heterogeneous scar evidenced by contrast-enhanced T1 weighted MRI

Current mapping solutions are invasive and not always reliable
RF works for 50% of ventricular arrhythmias

Goal and description of work

Need for an efficient method to localize and treat the arrhythmic focus
• Electromechanical wave imaging for assessing cardiac activity
• Trans esophageal HIFU probe for non invasive and sharp treatment
• Passive elastography for evaluating the quality of the ablation

Trans esophageal probe

Therapy transducer
- f = 3MHz - Focal 40 mm
- 8 rings truncated at 14 mm
- Dynamic focusing = 17-55mm

Imaging transducer
- Clinical transducer
- 5 MHz - 64 elements

Bessière et al. UMB 2016
Trans esophageal probe

Feasible, safe, but not good animal model

Proof of concept in non human

Good acoustic window, but poor efficacy due to motion
**Ex vivo tests with gating**

Experiments on ex vivo beating hearts

![Graph showing gated sonications for achieving transfixing thermal lesions](Image)

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**Cardiac activity mapping**

Electromechanical Wave Imaging: Mechanical mapping

- High frame rate ultrasound
- Non- or mini-invasive
- Cardiac activity in muscles thickness

![Diagram showing cardiac activity mapping](Image)

*Source: Provost et al. PNAS 2011: 108:8565-8570*
**EWI on ex-vivo working heart**

- 2 swine hearts
- Electrophysiological behavior

**Blind study**: Retrieve pacing protocol from EWI propagation pattern without prior knowledge

- 15 MHz, 4000 fps
- Epicardial, endocardial pacing and sinus rhythm
- 97 acquisitions

- Phase-shift estimation
- Displacement maps
- Electromechanical wave propagation visualization

**Blind study results**

- Endocardial pacing
- Epicardial pacing
- Sinus rhythm (no pacing)

89% of pacing protocols accurately retrieved

→ Need for standardized interpretation

→ EWI's potential for in-depth tissue activity characterization

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Monitoring by elastography

Mapping of tissue elasticity by analyzing shear wave propagation.

\[ E = 3 \rho C_s^2 \]

Shear-wave elastography
External ultrasonic push (radiation force).

Passive elastography
Natural physiologic noise (heart-beats, valve opening/closing,...)

High contrast between normal and ablated tissues on strain elastography. Kwiecinski et al. PMB 2015

Passive elastography

"Seismology of the biological tissues" (noise correlation)

Passive elastography – Ex vivo

Stiffness increase due to HIFU can be measured with passive elastography ex vivo
Passive elastography on beating hearts

Stiffness increase due to HIFU can be measured with passive elastography ex vivo in moving organs.

Take home message

- HIFU can be delivered through the esophagus in order to ablate cardiac tissues.
- Electromechanical wave imaging can be used for detecting arrhythmic foci in the myocardium.
- Passive elastography can be used for evaluating the quality of the ablation in beating hearts.

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