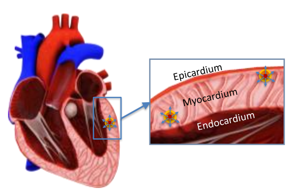
High Speed Ultrasound Imaging for Targeting and Monitoring Trans Esophageal HIFU During Cardiac Procedures

Cyril Lafon
LabTAU, INSERM, University of Lyon, France

AAPM 2019, July 16, San Antonio, TX

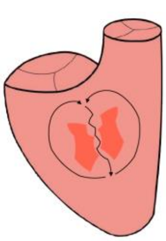
Ventricular arrhythmias

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

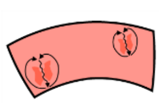


2

Origin #1 of ventricular



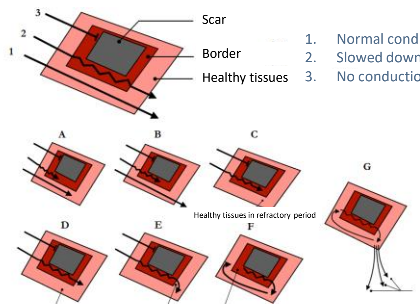
- Re-entry circuits
- Scars in the myocardium



3

Origin #1 of ventricular

LAB TAU

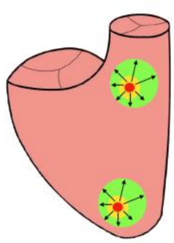


1. Normal conduction
2. Slowed down conduction
3. No conduction

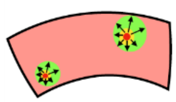
4

Origin #2 of ventricular

LAB TAU



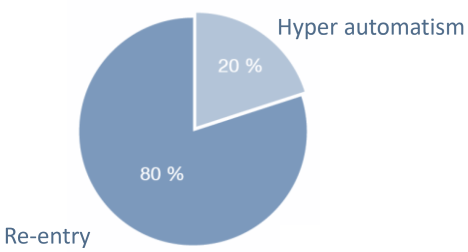
- Focal activation by hyper automatism



5

Origins of ventricular

LAB TAU

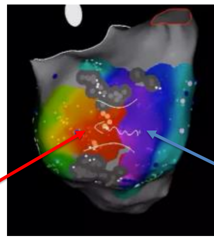


6

Clinical case #1

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

Endo cavitary mapping of the cardiac activity

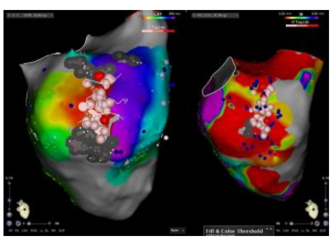


Early activation

Late activation

7

Clinical case #1



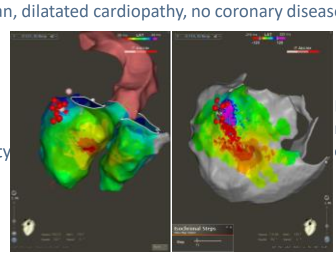
RF ablation ☞ Arrhythmia under control

8

Clinical case #2

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

Endocardial mapping of cardiac activity



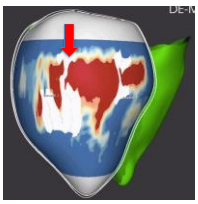
Epicardial mapping of cardiac activity

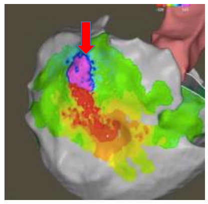
Different sites of activation – What happens in the cardiac wall?

9

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

10

Goal and description of work

Need for an efficient method to localize and treat the arrhythmic focus

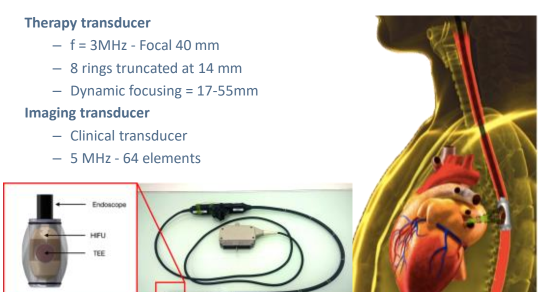
- Electromechanical wave imaging for assessing cardiac activity
- Trans esophageal HIFU probe for non invasive and sharp treatment
- Passive elastography for evaluating the quality of the ablation

11

Trans esophageal probe

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

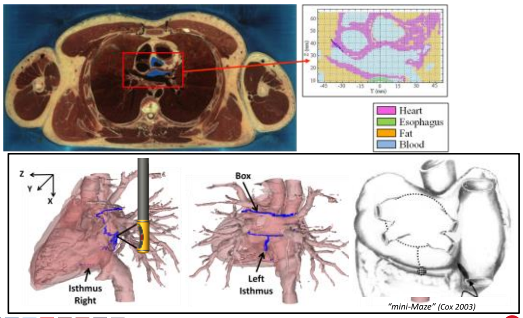
Imaging transducer
- Clinical transducer
- 5 MHz - 64 elements



Bessière et al. UMB 2016

12

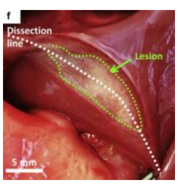
Trans esophageal probe

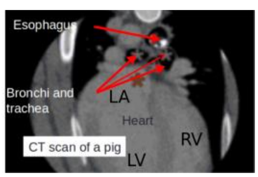


Constanciel et al. IEEE UFFC 2013

13

Proof of concept in pigs in vivo



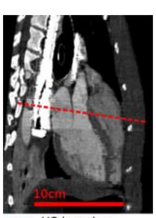


Feasible, safe, but not good animal model

Bessière et al. UMB 2016

14

Proof of concept in non human



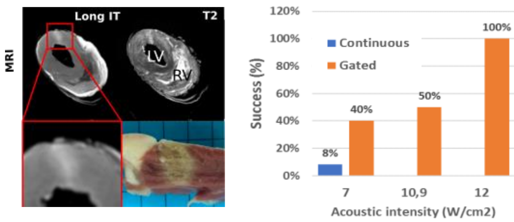
---- US imaging

Good acoustic window, but poor efficacy due to motion

15

Ex vivo tests with gating

Experiments on ex vivo beating hearts



Gated sonications for achieving transfixing thermal lesions

Greillier et al. UMB 2018

16

Goal and description of work

Need for an efficient method to localize and treat the arrhythmic focus

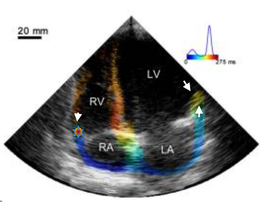
- Electromechanical wave imaging for assessing cardiac activity
- Trans esophageal HIFU probe for non invasive and sharp treatment
- Passive elastography for evaluating the quality of the ablation

17

Cardiac activity mapping

Electromechanical Wave Imaging: Mechanical mapping

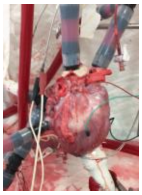
- High frame rate ultrasound
- Non- or mini-invasive
- **Cardiac activity in muscles thickness**

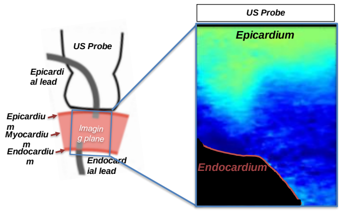


Source: Provost et al. PNAS 2011; 108:8565-8570

1

EWI on ex-vivo working heart





- 2 swine hearts
- Electrophysiological behavior

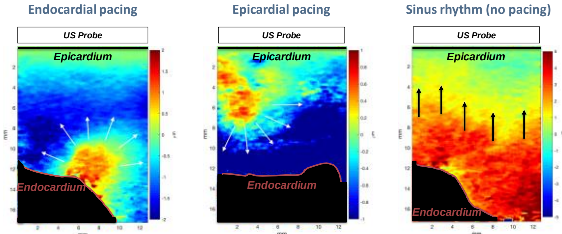
- 15 MHz, 4000 fps
- Epicardial, endocardial pacing and sinus rhythm
- 57 acquisitions

- Phase-shift estimation → displacement maps
- Electromechanical wave propagation visualization

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

19

Blind study results



89% of pacing protocols accurately retrieved
→ Need for standardized interpretation
→ EWI's potential for in-depth tissue activity characterization

20

Goal and description of work

Need for an efficient method to localize and treat the arrhythmic focus

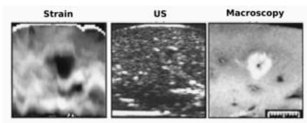
- Electromechanical wave imaging for assessing cardiac activity
- Trans esophageal HIFU probe for non invasive and sharp treatment
- Passive elastography for evaluating the quality of the ablation

21

Monitoring by elastography

Mapping of tissue elasticity by analyzing shear wave propagation.

$$E \sim 3\rho C_s^{\,2}$$



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

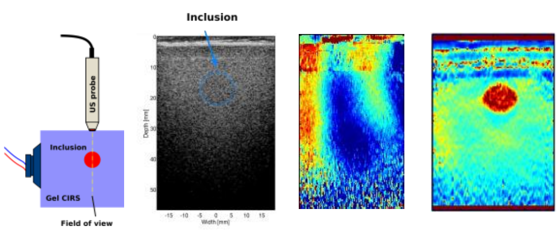
Shear-wave elastography
External ultrasonic push (radiation force).

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

22

Passive elastography

“Seismology of the biological tissues” (noise correlation)



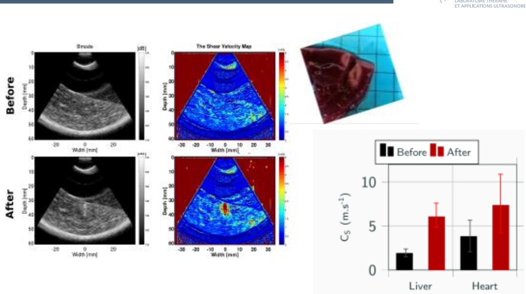
Bmode

Shear wave displacement

Passive elastography

23

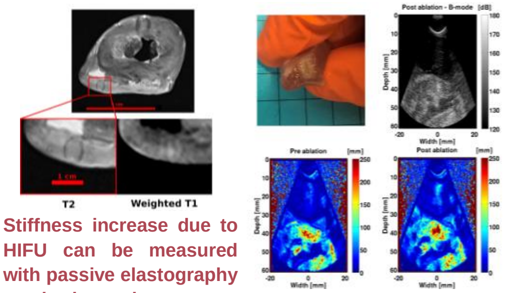
Passive elastography – *Ex vivo*



Stiffness increase due to HIFU can be measured with passive elastography *ex vivo*

24

Passive elastography on beating



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

25

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.

26

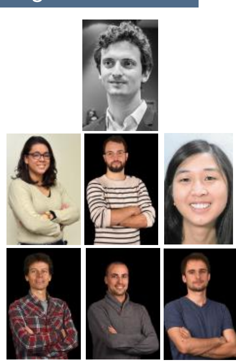
Acknowledgments

LabTAU
Francis Bessière
Jade Robert
Paul Greillier
Elodie Cao
Stefan Catheline
Ali Zorgani
Loic Daunizeau

IHU Lyric (Bordeaux)
Fanny Vaillant
Bruno Quesson

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

France Life Imaging



27