COMSOL CONFERENCE EUROPE 2012

Computational Modeling to Study the Treatment of Cardiac Arrhythmias using Radiofrequency Ablation

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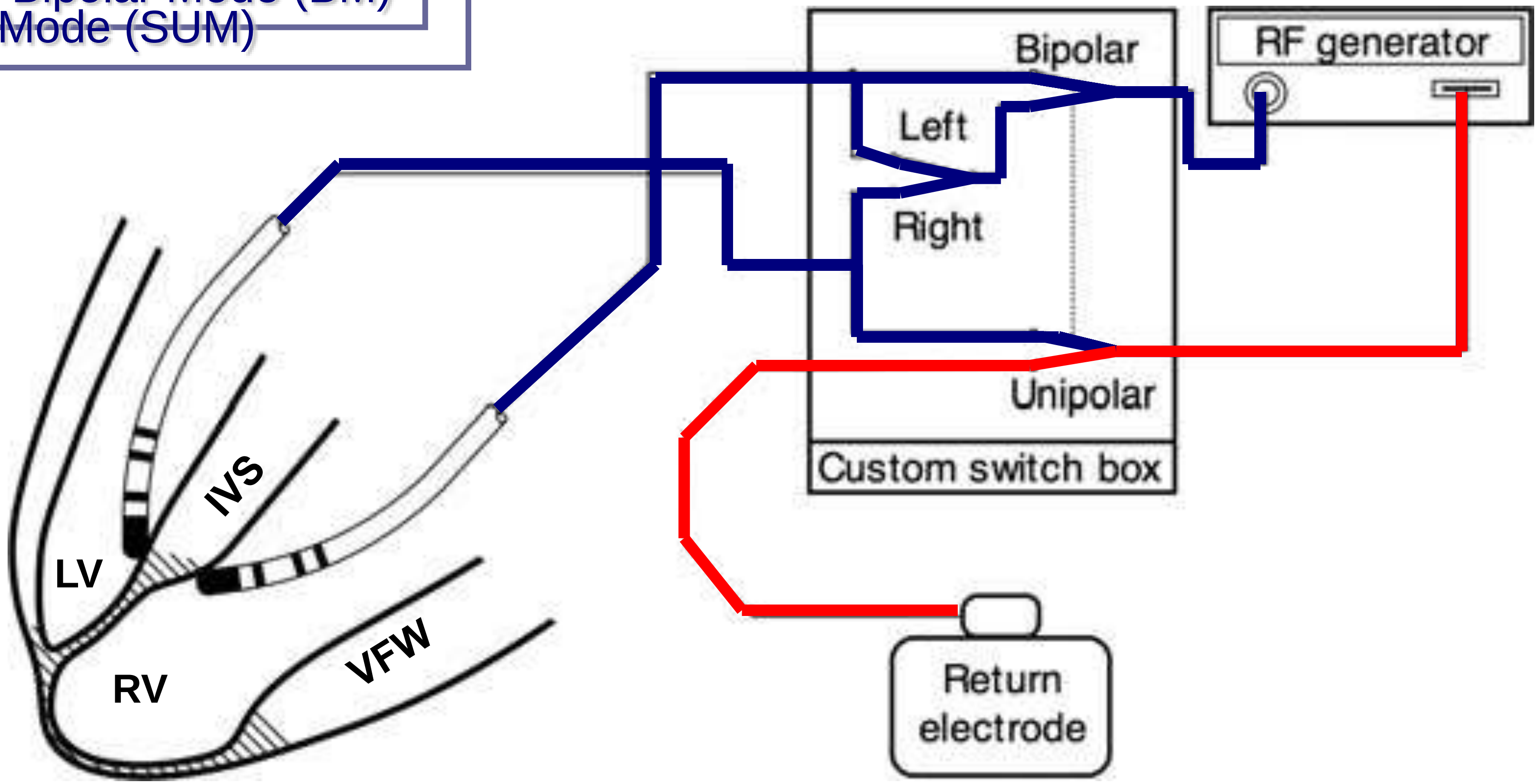
Introduction

- **RF ablation of ventricular wall: previous studies**

Sequential Unipolar Mode (SUM)

Bipolar Mode (BM)



G. Sivagangabalan et. al., PACE, 2010

BM is superior to SUM → IVS ablation

Introduction: Objective

- **RF ablation of ventricular wall:**
  - To assess the thermal lesions created in the ventricular wall during bipolar and sequential unipolar RF ablation
    - Two sites:
      - **Interventricular septum (IVS)**
        - Effect of different septum thicknesses
        - Effect of the misalignment between the catheters
      - **Ventricular free wall (VFW)**
        - Effect of different wall thicknesses
        - Effect of presence of air around epicardial catheter tip
        - Effect of change the orientation of the epicardial catheter tip

↓

Computational modeling: 2D and 3D → **COMSOL Multiphysics**

Methods: Governing equations

- **Coupled electric-thermal problem**

  - **Thermal problem**: Bioheat Equation is modified by the **Enthalpy Method** → model tissue vaporization

$$\frac{\partial(\rho h)}{\partial t} = \nabla(k\nabla T) + q + Q_m + Q_p$$

$$Q_p = \rho_b \cdot c_b \cdot \omega_b (T - T_b)$$

$$q = \sigma \cdot |E|^2$$

Enthalpy method: phase change of tissue →

$$\rho h = \begin{cases} \rho_l c_l T & 0 < T \leq 99^{o}C \\ \rho h(99) + h_{fg} C \dfrac{(T-99)}{(100-99)} & 99 < T \leq 100^{o}C \\ \rho h(100) + \rho_g c_g (T - 100) & T > 100^{o}C \end{cases}$$

  - **Electrical problem**: Laplace's Equation

$$\nabla \cdot \sigma \nabla \Phi = 0$$

Φ: voltage (V)

$\nabla \Phi \rightarrow |E|$

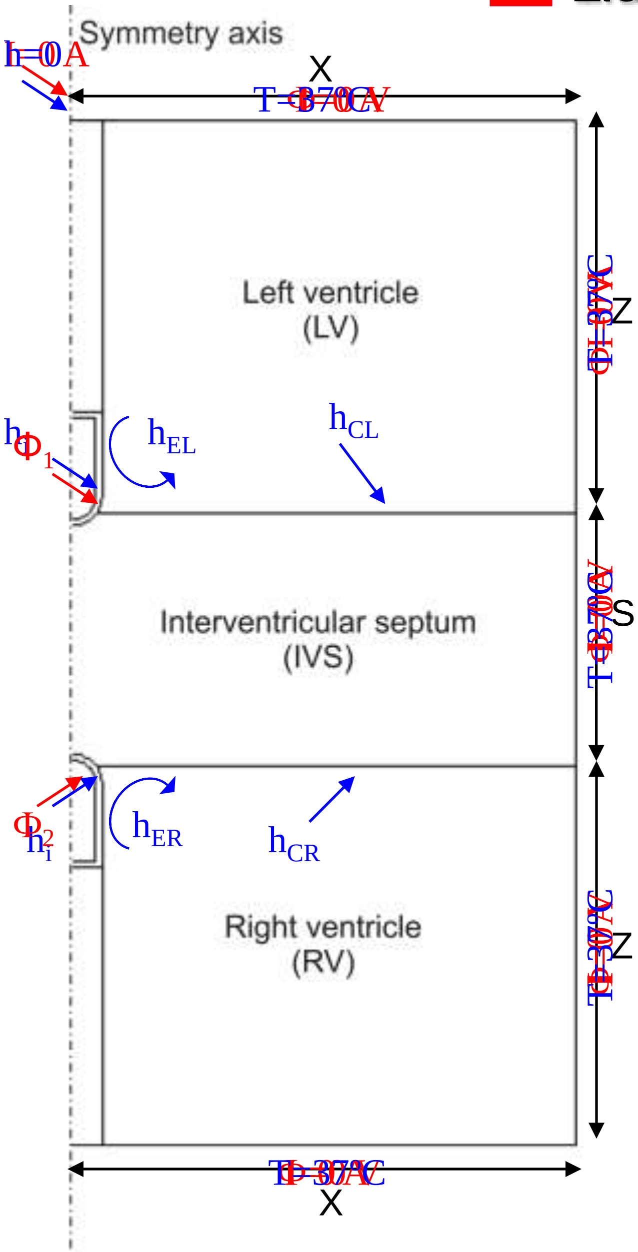
- **Arrhenius Equation:** thermal damage of the tissue

$$\Omega(t) = \int_0^t A \cdot e^{\frac{-\Delta E}{RT}} dt$$

  - A and ΔE for cardiac tissue (Jacques and Gaeeni)
  - **Ω = 1**→ lesion contour

Methods: Numerical models

Electrical boundary conditions

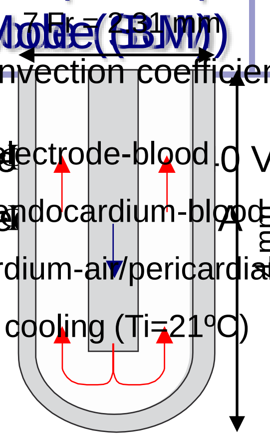


Sequential / Bipolar / Unipolar

Mode (SM) / (BM) / (UM)

- Internally cooled catheters:

7 Fr = 2.31 mm



- Thermal convection coefficients:

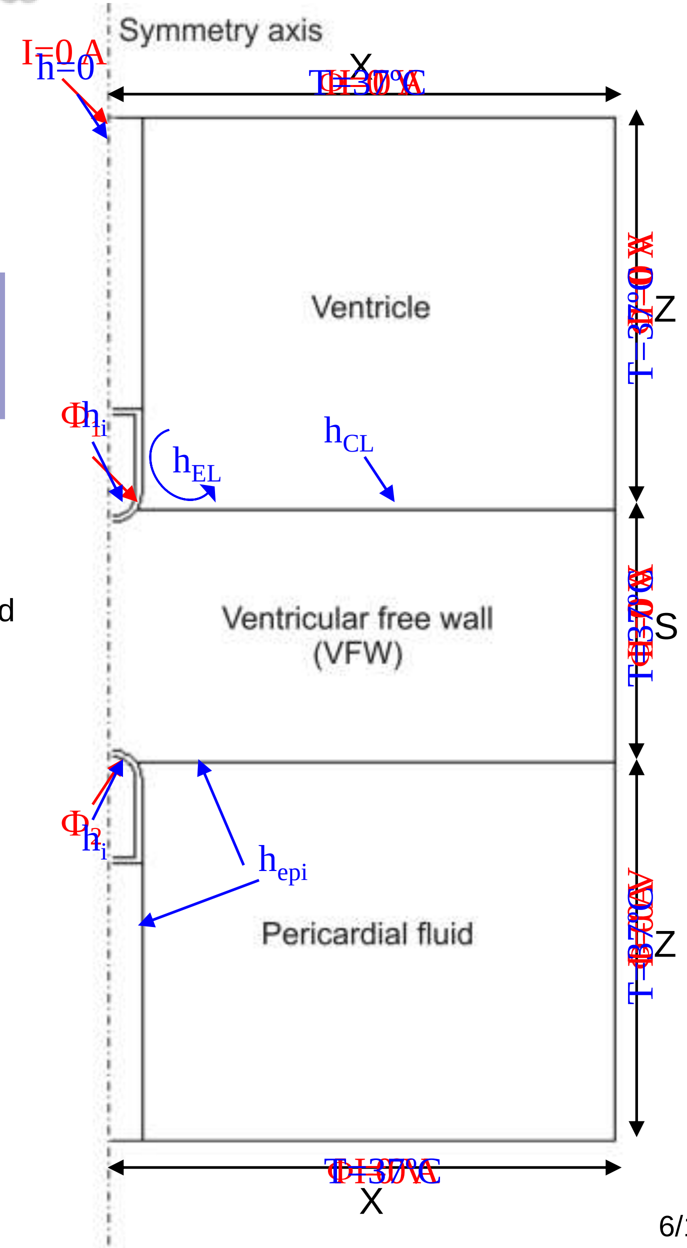
h_{EL} = h_{ER}: electrode-blood

h_{CL} = h_{CR}: endocardium-blood

h_{epi}: epicardium-air/pericardial fluid

h_i: internal cooling (T_i=21ºC)

- Insertion depth: 0.5 mm
- X, Z: Convergence test
- S: ventricular wall thickness

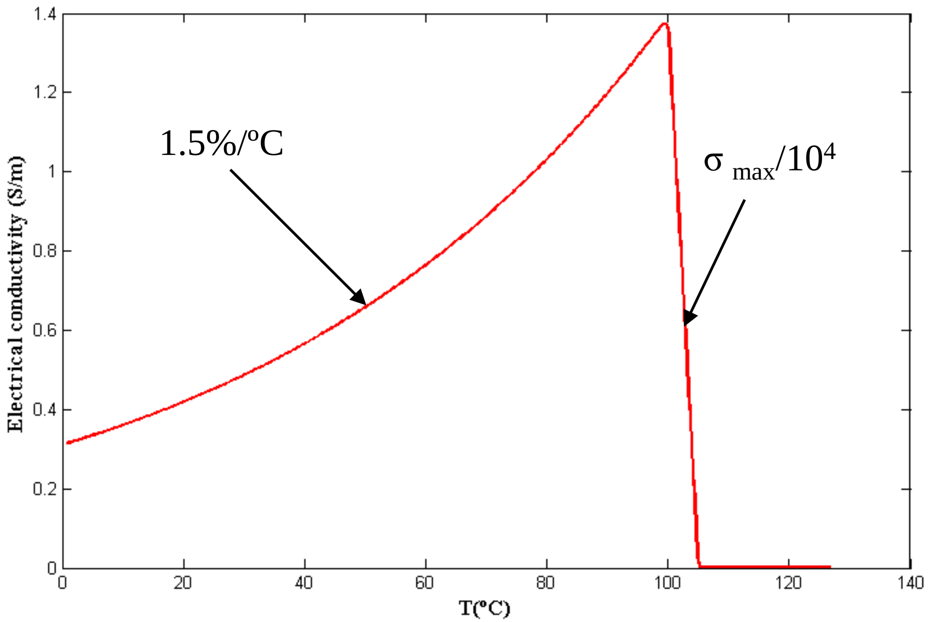


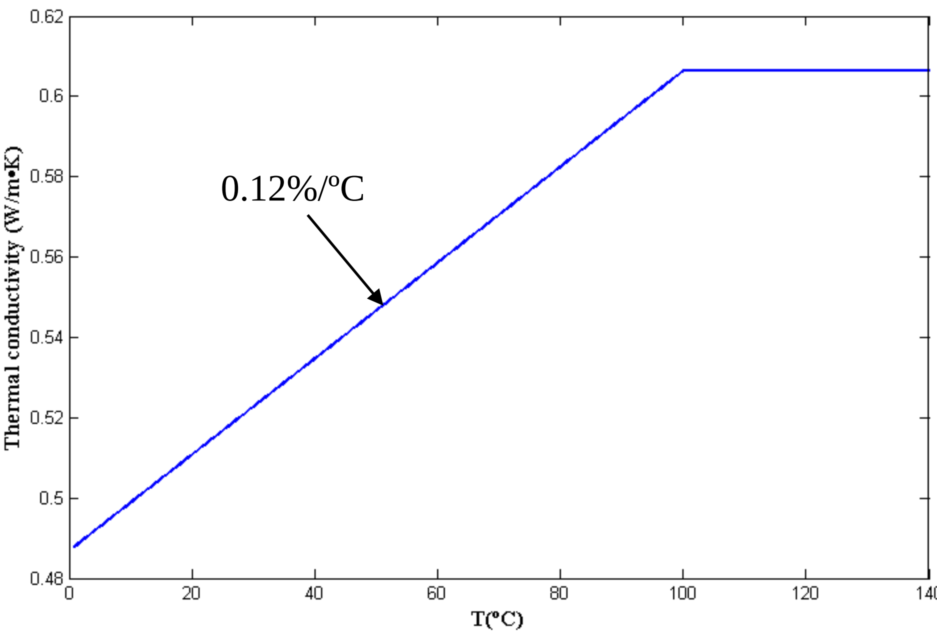
Methods: Model characteristics

- **Thermal and electrical characteristics of the model elements**

Element	σ (S/m)	ρ (kg/m³)	c (J/kg·K)	k (W/m·K)
Tissue	0.541	1060	3111	0.502
Blood	0.99	1000	4180	0.54
Pericardial fluid	1.35	980	4184	0.628
Plastic	10^{-5}	70	1045	0.026
Electrode	$4\cdot10^{6}$	21500	132	71

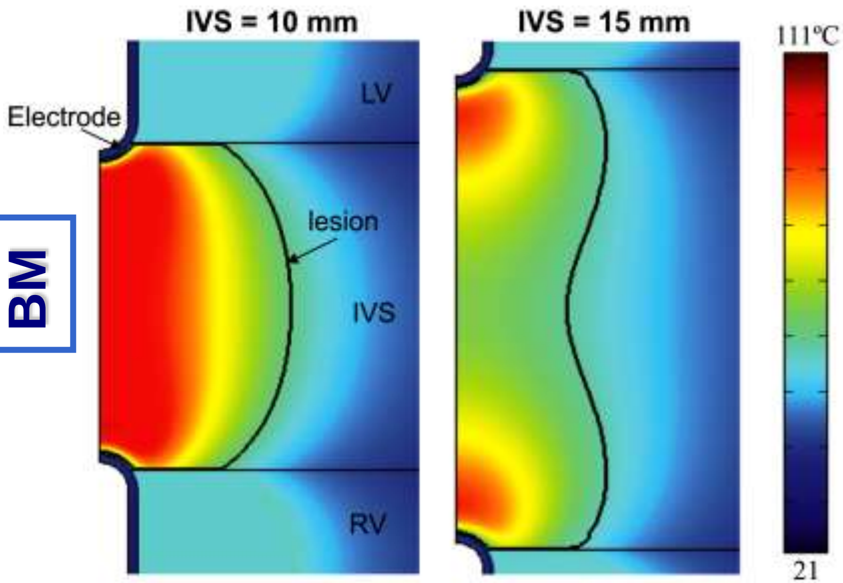
Piecewise functions → Heaviside function: smoothed function **flc2hs** (COMSOL)





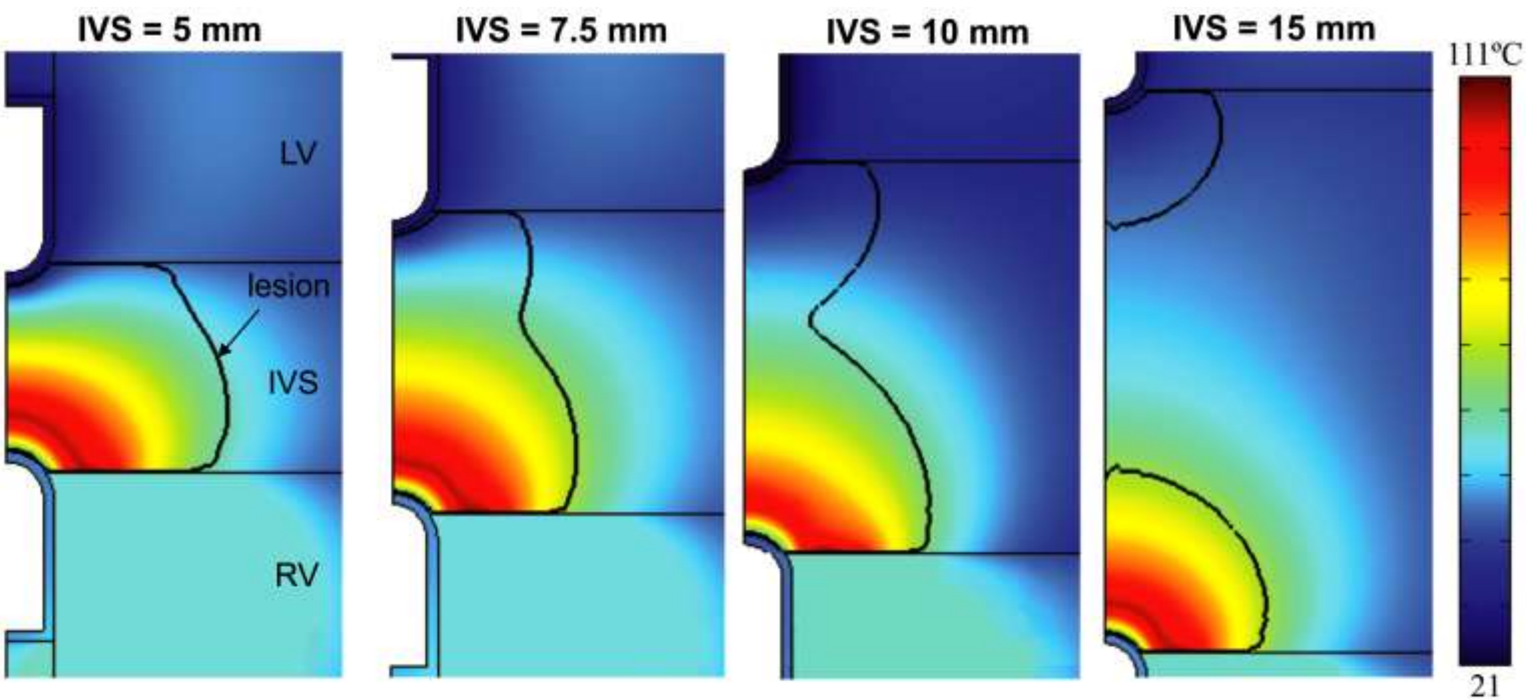
Results: Interventricular septum (IVS) ablation

BM



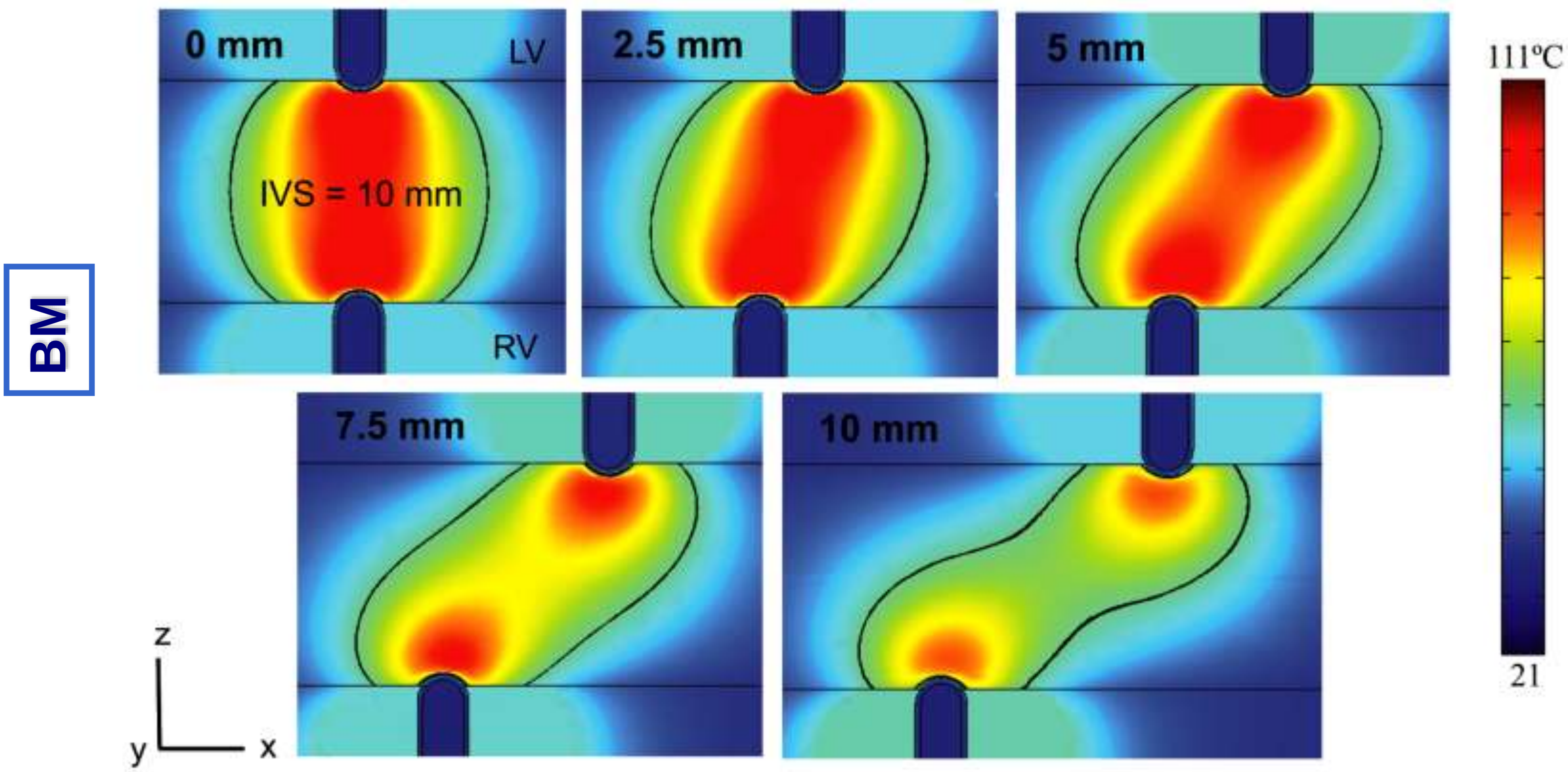
- **Different IVS thicknesses (5-15 mm)**
  - **BM:**
    - Always transmural and symmetrical lesions
  - **SUM:**
    - IVS ≥ 12.5 mm → not transmural lesions
    - Always asymmetrical lesions

SUM



Results: Interventricular septum (IVS) ablation

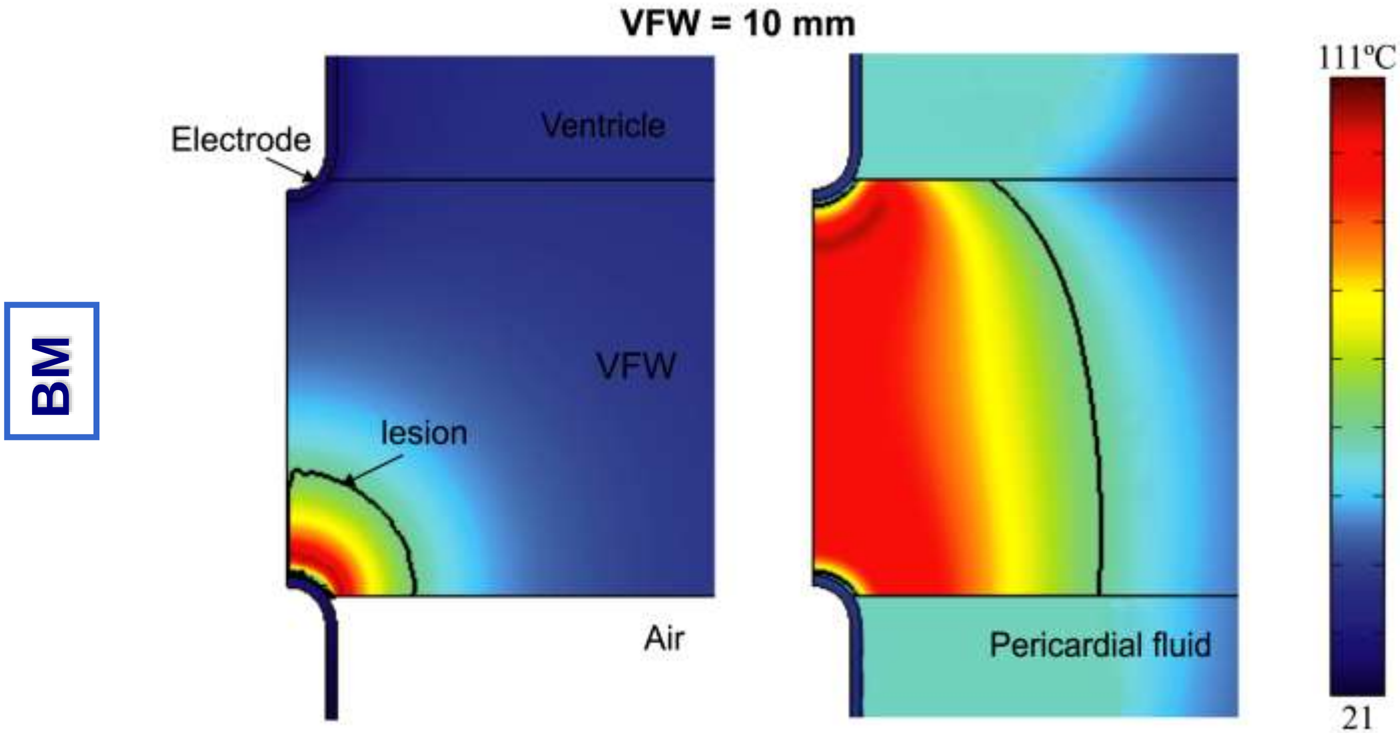
- Effect of the progressive misalignment between the catheters



- **As the misalignment is increased:**
  - Longer lesions (hourglass shape)
  - Lesions remain transmural and symmetrical

Results: Ventricular free wall (VFW) ablation

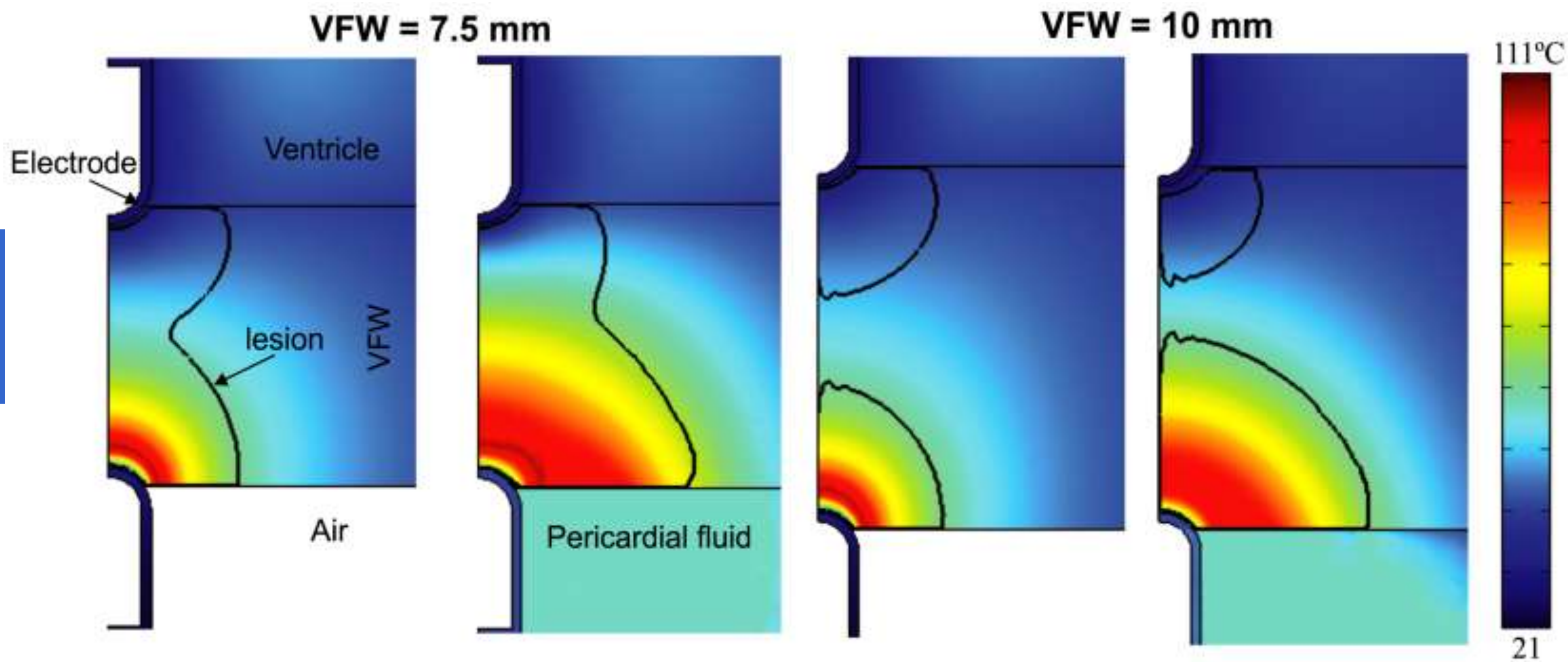
- Effect of presence of air around the epicardial catheter tip



- **Different VFW thicknesses (5-15 mm)**
  - **With air:**
    - Never transmural lesions: lack of thermal lesion on the endocardial side
  - **With pericardial fluid:**
    - Transmural and symmetrical lesions, for VFW ≤ 15 mm

Results: Ventricular free wall (VFW) ablation

- Effect of presence of air around the epicardial catheter tip

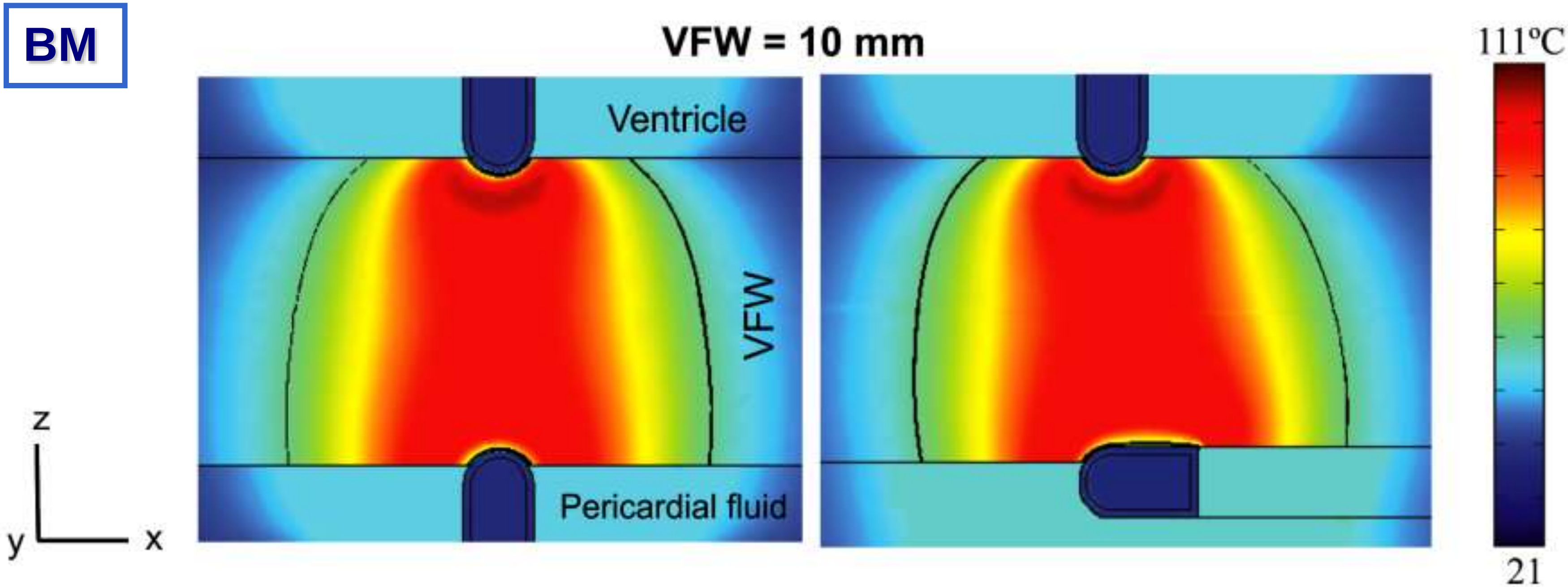


SUM

- **Different VFW thicknesses (5-15 mm)**
  - **Similar results (with air or pericardial fluid):**
    - VFW ≤ 7.5 mm→ transmural lesions
    - VFW ≥ 10 mm → not transmural lesions
  - **Difference:**
    - With pericardial fluid: larger lesions on the epicardial side

Results: Ventricular free wall (VFW) ablation

- **Effect of the orientation of the epicardial catheter tip**



- **The orientation of the catheter (perpendicular or parallel):**
  - Not have a significant effect on lesion geometry
  - Lesions remain transmural and symmetrical

Conclusions

- The results suggest that **BM** is in general more effective than **SUM** in achieving transmurality through the ventricular wall:
  - **IVS ablation**
    - BM is always superior to SUM → transmural and symmetrical lesions, even if misalignment between catheters occurs during ablation
  - **VFW ablation**
    - BM is superior to SUM, except when the epicardial catheter tip operates in air
    - The orientation of the epicardial catheter tip is irrelevant in terms of lesion shape and depth

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