Meshless Modelling for Heat-based Robotic Navigation of Radio Frequency Catheter Ablation


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1. Statement of clinical need

Atrial Fibrillation (AF) is the most common cardiac arrhythmia and a major risk factor for ischemic stroke.

- **Radio Frequency Catheter Ablation** (RFCA) is a minimally invasive technique utilised to treat AF where a catheter is navigated to the heart through the femoral vein [1] (Fig. 1).

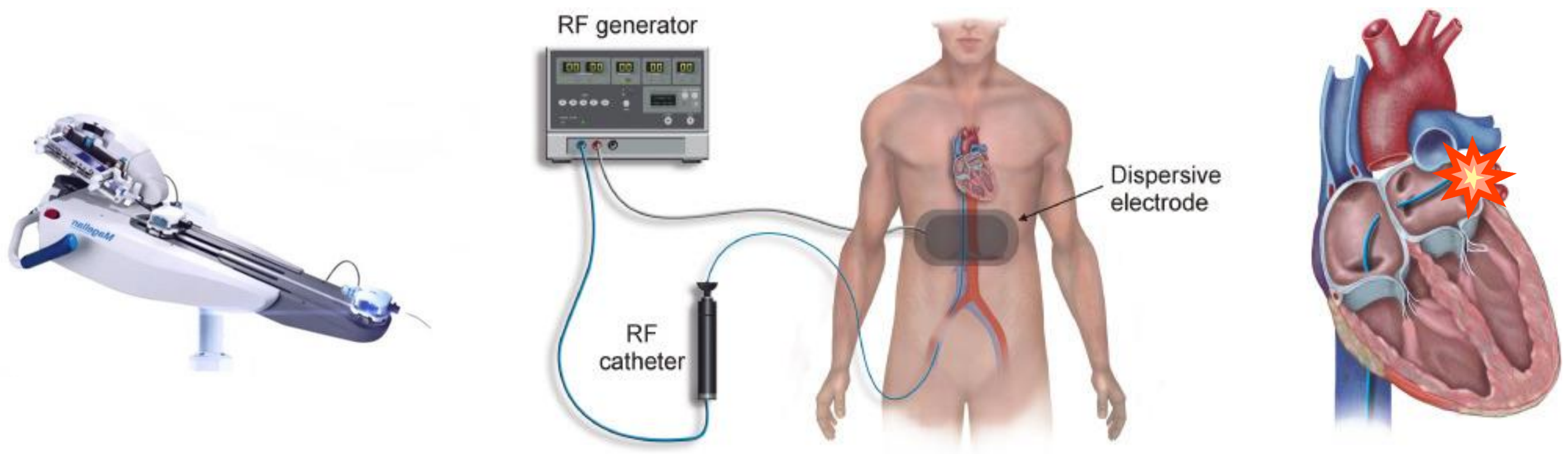

Figure 1: *Main procedural steps of Radio Frequency Catheter Ablation.*

- Catheter navigation is performed either manually or by using robotic navigation systems. Robotic navigation allows for more effective ablation lesions, but may lead to higher risk of cardiac perforation [2]
- Computational models may predict lesion formation effectively. However, their clinical application is limited since they have been developed for single-site ablation and numerical accuracy depends on the quality of mesh discretization [3].

Aim of this work

We propose a new **meshless model** to simulate tissue heat distribution during robotic-navigation-assisted ablation while considering conditions of **multi-site ablation**.

2. Methods

- The meshless **Fragile Points Method** (FPM) is used to solve the bioheat and electrical equations that describe the thermoelectrical phenomenon of RFCA.
- The domain of interest is discretized by a set of randomly distributed points which are enclosed in non-overlapping subdomains (Fig. 2).
- Local discontinuous polynomials are employed as trial functions.
- Time-dependent Dirichlet conditions are employed to account for the time interval between the start and end of each ablation (**multi-site**)

Multi-site ablation mathematical model

$$\rho c(T)\frac{\partial T}{\partial t} - \nabla\cdot(k(T)\nabla T) = q$$

$$\nabla\cdot(\sigma(T)\nabla\Phi) = 0$$

$$\Phi = \Phi u(t - t_s)$$

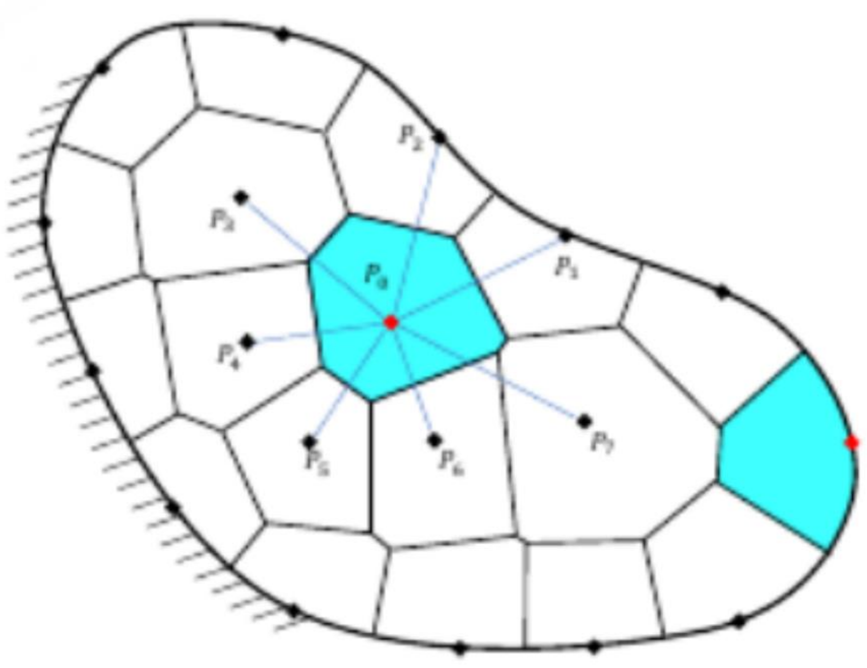

Figure 2: *Domain of interest discretization using the Fragile Points Method.*

Ablation protocol

- 3D porcine ventricular tissue block (40×40×20 mm)
- Density ρ = 1076 kgm−3; specific heat c_0 = 3017 Jkg−1K; thermal conductivity k_0 = 0.518 Wm−1K; electrical conductivity σ_0 = 0.54 Sm−1.
- Two ablation sites s_1 = (0, −1, 20) mm and s_2 = (0, 1, 20) mm. Ablation time t_a = 30 s. Simulations with catheter indentation at perpendicular position and rotated around the x-axis by 30°.

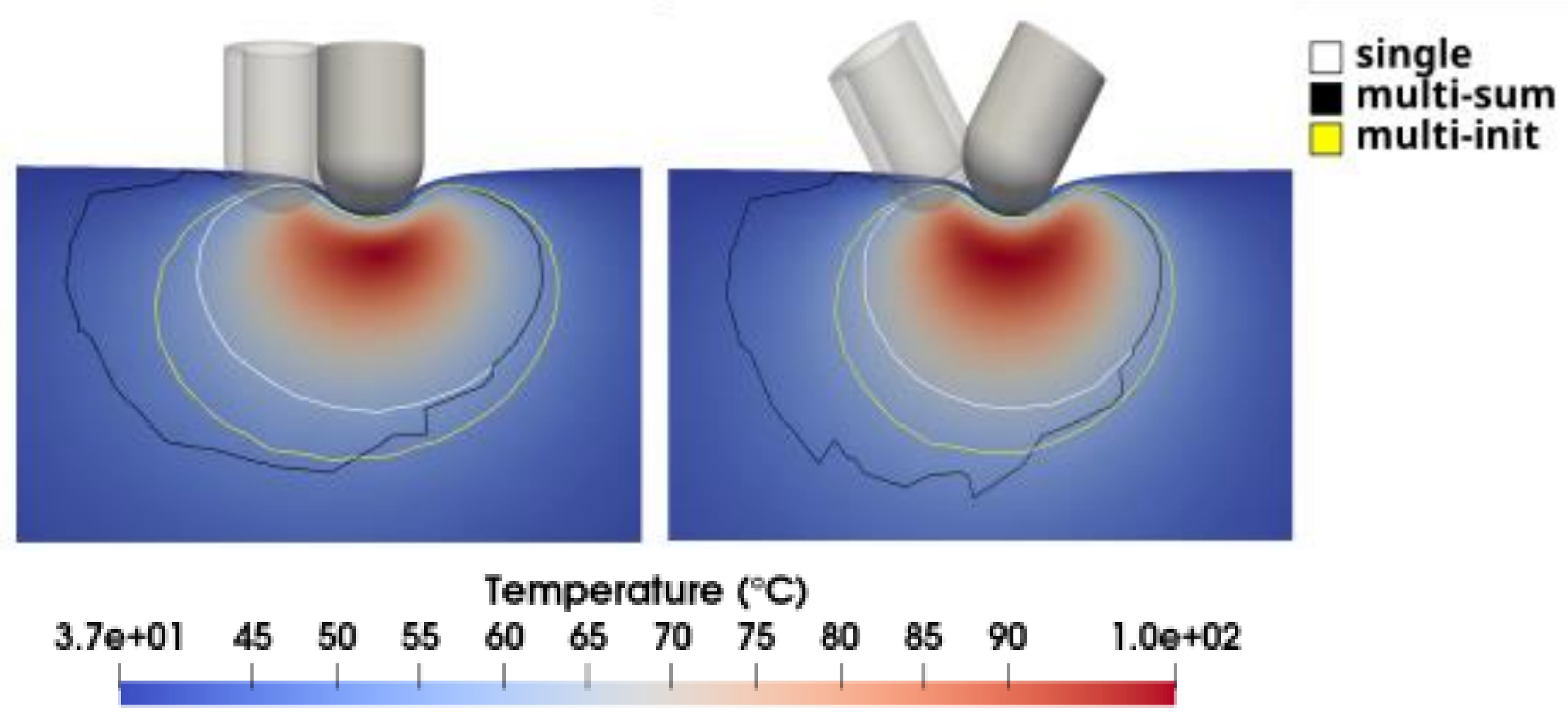

Figure 3: *Temperature distribution for perpendicular catheter indentation (left) and catheter indentation at 30° (right) comparing single-site and multi-site simulations.*

3. Results

Lesion characteristics were measured at site s_2 for single-site (**single**) and multi-site ablation simulations (Tab. 1). Multi-site ablation was modelled either using the delivered temperature at s_1 as initial condition (**multi-init**) or by summing the s_1 and s_2 heat maps (**multi-sum**).

	single	multi-sum	multi-init
R_{s1} = 0°, R_{s2} = 0°			
Width (mm)	7.4	10.5	8.7
Depth (mm)	4.1	5.6	5.1
T_{max} (°C)	90.7	168.3	96.2
R_{s1} = 30°, R_{s2} = -30°			
Width (mm)	6.9	10.1	7.9
Depth (mm)	3.8	5.4	4.7
T_{max} (°C)	78.3	158.2	82.82

Table 1: *Lesion characteristics for single-site and multi-site ablation simulations.*

4. Conclusions and Future Work

The proposed solution demonstrates that **lesion formation** may be significantly **underestimated** if multi-site ablation conditions are omitted. We believe that the proposed algorithm may be proven a useful tool for multi-site ablation simulation that can enable accurate heat distribution prediction and assist decision making during clinical applications.

In future work we will:

- validate the proposed approach using realistic geometric models of the human atria;
- generate heat distribution maps of real ablation protocols delivered to patients

References

1. SKS. Huang et al., *Elsevier Health Sciences*, 2014.
2. F. Akca et al., *Int. Journal of Cardiology*, 179, 2015.
3. A. Petras et al., *Int. Journal for Numerical Methods in Biomed. Eng.*, 35, 2019.

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