Computational Modeling of Electrode with Saline Irrigation for Radiofrequency Cardiac Ablation

J. W. Ahn[1], Y. J. Kim[1], S. A. Lee[1], H. C. Jung[1], S. H. Lee[1], J. H. Moon[1*]
1. Osong medical innovation foundation, medical device development center, Cheongju-Si, South Korea

Introduction

•RadioFrequency Catheter Ablation(RFCA) is safe procedure to eliminate cardiac tissue caused arrhythmias.

•During RFCA, thrombus formation can occur if the electrode-tissue interface temperature reaches around 80℃[1].

•To prevent this phenomenon, the saline irrigable electrodes have been developed and can inject saline into blood-tissue interface through holes around electrode tip.

•We investigate the computational modeling electrode with saline irrigation including the flow problem about the blood circulation and the saline irrigation flow.

Problem Definition

- The problem we wish to solve is the temperature distribution of cardiac tissue, electrode and blood when the saline is injected through the electrode including 6 irrigation holes.
- The thermal lesions are identified by the 50 ℃ isotherm contour and determined by their characteristic dimensions: Maximum depth(D), maximum width(MW), depth at the maximum width(DW)[2].

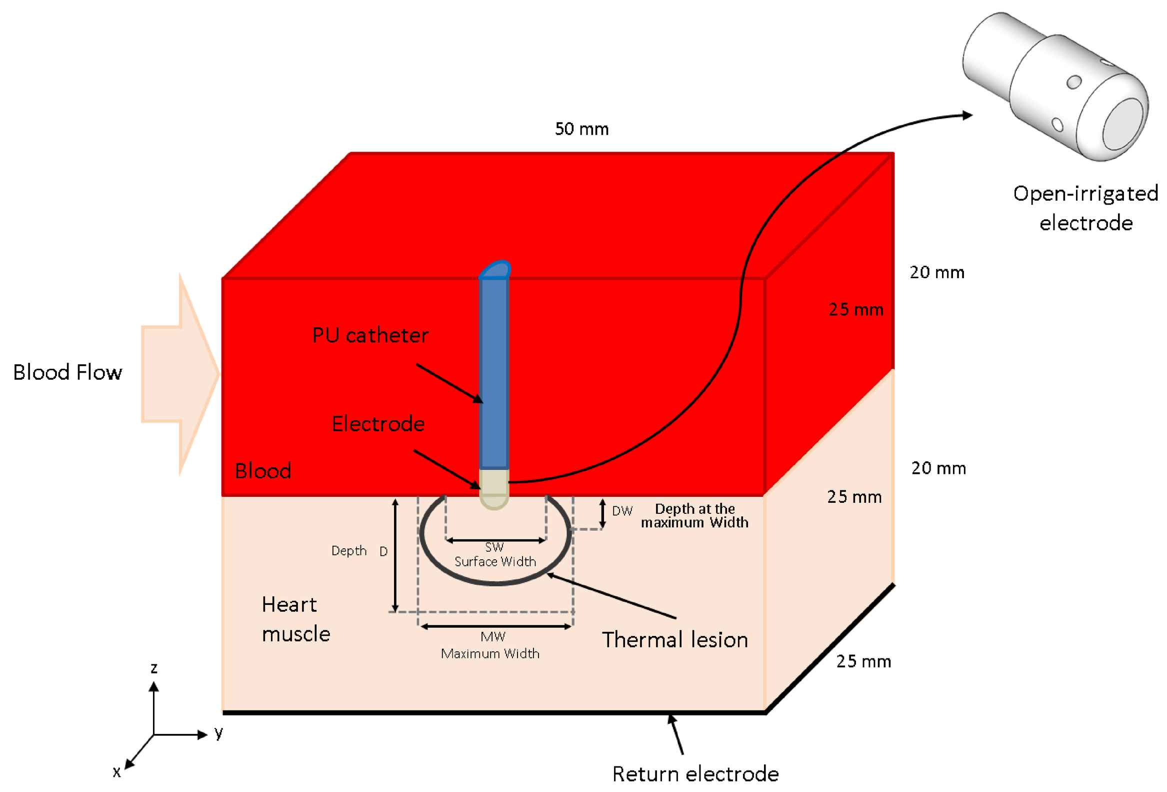

Figure 1. Definition of the numerical model.

Computational Methods

•The numerical model is based on a coupled electric-thermal-flow problem.

•To solve the coupled problems, we use AC/DC Module, Heat Transfer Module, and CFD Module in COMSOL Multiphysics® software

•The thermal problem – Energy equation

$$\rho c_P \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + q - Q_p + Q_m - \rho c \boldsymbol{u} \cdot \nabla T$$

•Fluid flow problem – Navier-Stokes equation

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho \boldsymbol{u} \cdot \nabla \boldsymbol{u} = -\nabla P + \mu \nabla^2 \boldsymbol{u} + \boldsymbol{F}$$
$$\rho \nabla \cdot \boldsymbol{u} = 0$$

•The electrical problem – Maxwell equation

$$q = \frac{1}{2} \sigma |\boldsymbol{E}|^2$$
$$\boldsymbol{E} = -\nabla \emptyset$$

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korean Government(Ministry of Science, ICT & Future Planning)(No. 2015R1C1A1A02037795 and No. 2017M3A9E2063008)

Boundary conditions

•In velocity boundary conditions, inlet velocity boundary condition is applied on the left surface to impose a blood flow(U_f=0.1m/s).

•A constant temperature of 37 ℃ is fixed on the outer model surfaces.

•The model implemented a proportional-integral(PI) temperature control algorithm in the electrical boundary conditions(K_P=7, K_I=5).

•The temperature of measure point is electrode-tissue interface and called " set temperature".

•The value of T_{set} is 50, 45, 40, 35℃.

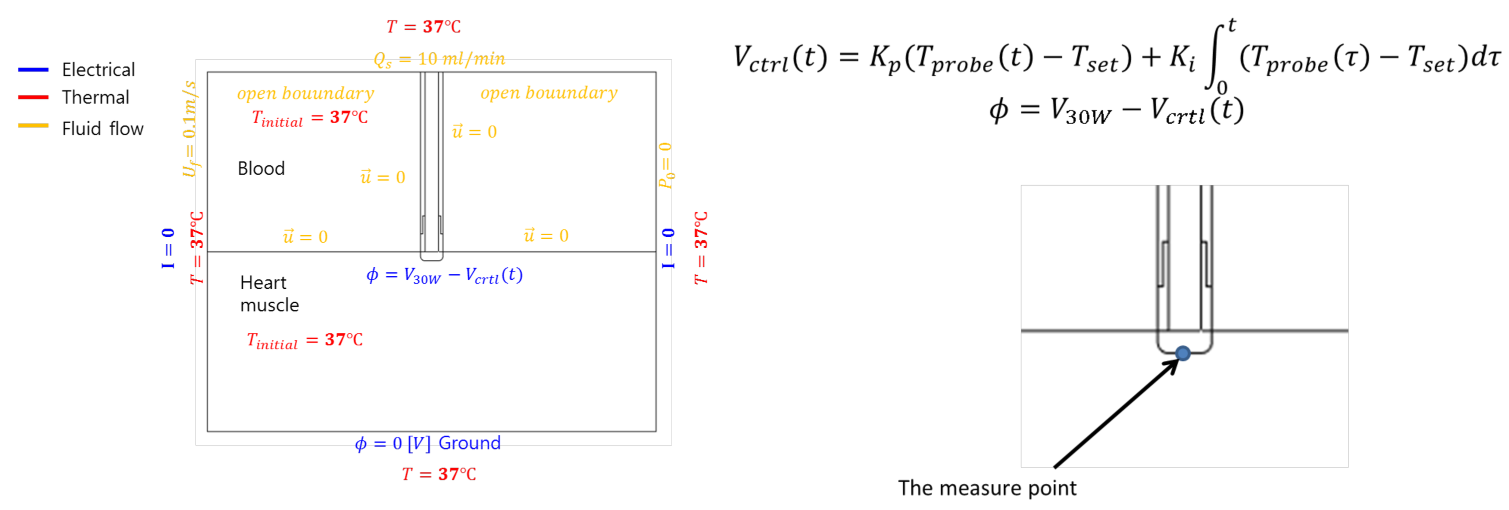

Figure 2. Boundary conditions of the numerical model.

Results

•When the set temperature is increased, the size of the thermal lesion and the maximum temperature show a increase regardless of the flow rate of the saline irrigation.

•In case of the constant set temperature, the thermal lesion show a increase due to convective heat transfer between electrode and saline irrigation flow if the flow rate of saline irrigation is increased.

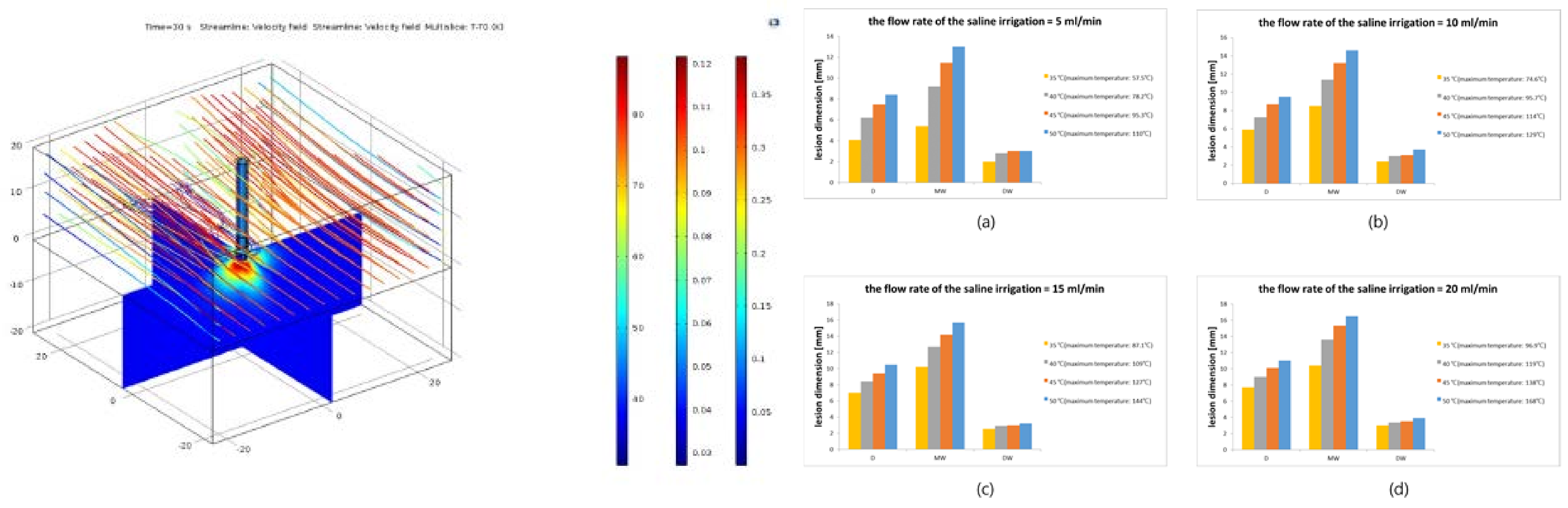

Figure 3. The results of the temperature distribution of 3D model and the thermal lesion.

Conclusions

•To prevent the temperature of cardiac tissue from exceeding 80℃, the set temperature of the electrode tip must be set differently according to the flow rate of the saline irrigation.

•We need to study more the model by varying the contact angle between the electrode and the cardiac tissue.

References

1.Suárez, Ana González, Fernando Hornero, and Enrique J. Berjano. "Mathematical modeling of epicardial RF ablation of atrial tissue with overlying epicardial fat." The open biomedical engineering journal 4.1 (2010).

2.González-Suárez, Ana, et al. "Computational Modeling of Open-Irrigated Electrodes for Radiofrequency Cardiac Ablation Including Blood Motion-Saline Flow Interaction." PloS one 11.3 (2016): e0150356.