Study of blood flow velocity in epicardial microwave ablation of atrial fibrillation

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Abstract

Purpose: Atrial Fibrillation is the most common clinically cardiac arrhythmia. At present, microwave ablation has been widely used in the treatment of atrial fibrillation, but the effect of microwave ablation on blood flow velocity is not enough, and blood flow velocity is closely related to the ablation effect of atrial fibrillation. In order to study this problem, the temperature field of microwave ablation in atrial fibrillation was numerically simulated.

Methods: This research is based on the finite element method and COMSOL Multiphysics software for numerical simulation. In this study, a three-dimensional fat-myocardium-blood model is constructed, involving numerical simulation of electromagnetic field, temperature field and flow field. The microwave frequency was 2450 MHz, and fat thickness was 1 mm, myocardial thickness was 3 mm. The ablation power was 100 Wand the ablation time was 15s.The blood convective heat transfer coefficient were 0 W/(m^2·℃), 1417 W/(m^2·℃), 3350 W/(m^2·℃), 7100 W/(m^2·℃).

Results: In this simulation, the ablation area is hemispherical. When the blood convective heat transfer coefficient were 0 W/(m^2·℃), 1417 W/(m^2·℃), 3350 W/(m^2·℃), 7100 W/(m^2·℃), the maximum temperature were 192℃, 186℃, 184℃, 183℃, the transverse width were 7.5 mm, 7.2 mm, 7 mm and 6.8 mm, and the axial length were 3.7 mm, 3.4 mm, 3.3 mm, 3.2 mm respectively. The maximum temperature, transverse width and axial length decrease with the increasing convective heat transfer coefficient.

Conclusions: A thin cryogenic layer forms between the Myocardium and the blood . The maximum temperature of the ablation zone decreases with the increasing convective heat transfer coefficient, and the position of the effective ablation zone (≥50℃) moves to the fat layer.

Keywords: microwave ablation; numerical simulation; blood; convective heat transfer coefficient

1. Introduction

Atrial fibrillation(AF) is the most common persistent arrhythmia in clinic. It ranks the second in arrhythmia and has a high fatality and disability. At present, drug therapy is the most commonly method to cure AF. But 10% to 15% of patients have side effects after taking the drug [1] [2]. In non-drug treatment, surgical treatment has become the main means, but it has a greater risk. In recent years, minimally invasive ablation, such as microwave ablation, radiofrequency ablation[3] and cryoablation[4], has been widely used on the basis of maze surgery. Microwave ablation is a kind of high-frequency electromagnetic wave, which generates heat by inducing the vibration of water molecules in tissues and heating tissues directly, independent of the current passing through the probe. microwave ablation can achieve greater ablation depth, especially in the treatment of ventricular tachycardia. Microwave energy attenuates very little when it passes through fat and blood, so it has strong tissue penetration.

But the heart is rich in blood, and the blood flow varies greatly in different heart locations. the greater the velocity of blood flow, the greater the heat transfer coefficient of blood convection, and the more heat it takes away.

In order to reflect the epicardial ablation, this study constructed a fat-myocardium-blood model to explored the influence of blood flow velocity, and simulated the temperature field atrial fibrillation.

2. Methods

2.1 Geometric model

The numerical simulation of this study is based on COMSOL Multiphysics Software.

The structure of microwave antenna comes from the literature[5]. Based on the basic requirements of electromagnetic wave simulation, the material of antenna is defined as copper, and the part between inner and outer conductors was set as Teflon. The structure of THE microwave antenna was shown in Figure 1. The antenna, fat, myocardium and blood model were established. The front end of the microwave antenna was perpendicular to adipose tissue. The thickness of fat was 1 mm, the thickness of myocardium was 3 mm, and the thickness of blood was 2 cm. The model was shown in Figure 2. In this study, the convective heat transfer coefficients at the boundary of blood and myocardium are applied to simulate the blood flow velocity. The coefficients of different atrial parts were shown in Table 1.

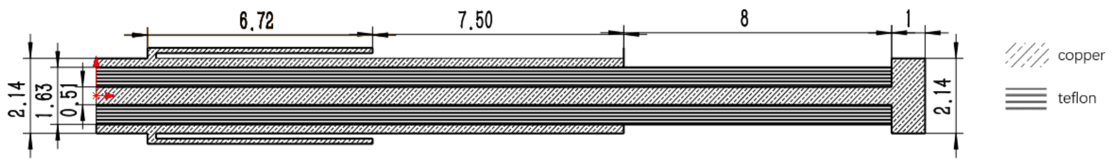

Figure 1. Structure of microwave ablation antenna

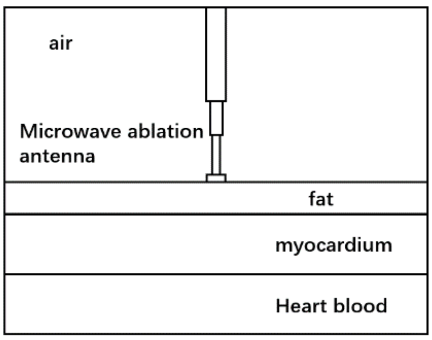

Figure 2. Section drawing of numerical simulation model for microwave ablation of epicardial atrial fibrillation

Table 1. Convective heat transfer coefficient in different applied location[6][7]

position	Convective heat transfer coefficient
within 10mm above the mitral valve on the lateral wall	1417W/(m^2·℃)
CS， Ventricular AP	3350 W/(m^2·℃)
AV node， Atrial AP， RV outflow VT	7100 W/(m^2·℃)

2.2 Bio-heat equation

During ablation of atrial fibrillation, the thermoelectric coupling effect is controlled by Pennes' bio-heat transfer equation[8]. The formula is as follows

$$\rho C\frac{\partial T}{\partial t} = k\nabla^2 T + q - Q_b + Q_m \tag{1}$$

T(℃), ρ（kg/m^3）, C（J/kg·K）, K (W/m·K) and Q (W/m^3) are temperature, density, specific heat, thermal conductivity and power density, respectively. Q_b and Q_m represent blood perfusion and metabolic heat, respectively. They are neglected for far less than that generated by microwave ablation .

3. Results and Discussion

The temperature distribution and data of ablation zone were studied under different convective heat transfer coefficients (0 W/(m^2·℃), 1417 W/(m^2·℃), 3350 W/(m^2·℃), 7100 W/(m^2·℃). The ablation power was 100W. And the heating time was 15s. The axial ablation region is parallel to the ablation region of the microwave antenna, and the transverse ablation region is perpendicular to the ablation region of the microwave antenna. According to the tissue and physical characteristics, 50℃ is the threshold temperature for the formation of ablation blockade line caused by myocardial injury. Table 2 shows the experimental data at different heat transfer coefficient.

Table 2. Experimental data

convective heat transfer coefficient W/(m^2·℃)	0	1417	3350	7100
transverse width/mm	7.5	7.2	7	6.8
axial length/mm	3.7	3.4	3.3	3.2
maximum temperature/℃	192	186	184	183

As can be seen from Figure 3, with the increase of heat transfer coefficient, the maximum temperature deceases, while the lateral width and axial length decrease too. When the convective heat transfer coefficient was 0 W/(m^2·℃), 1417 W/(m^2·℃), 3350 W/(m^2·℃) and 7100 W/(m^2·℃), the transverse width of the ablation zone was 7.5mm, 7.2mm, 7mm and 6.8mm, and the axial length was 3.7mm, 3.4mm, 3.3mm and 3.2mm, respectively. The maximum temperature of the ablation zone was 192℃, 186℃, 184℃ and 183℃, respectively. The presence of blood flow lowers the maximum temperature, decreases both the axial length and the transverse width, but the amplitude is very small.

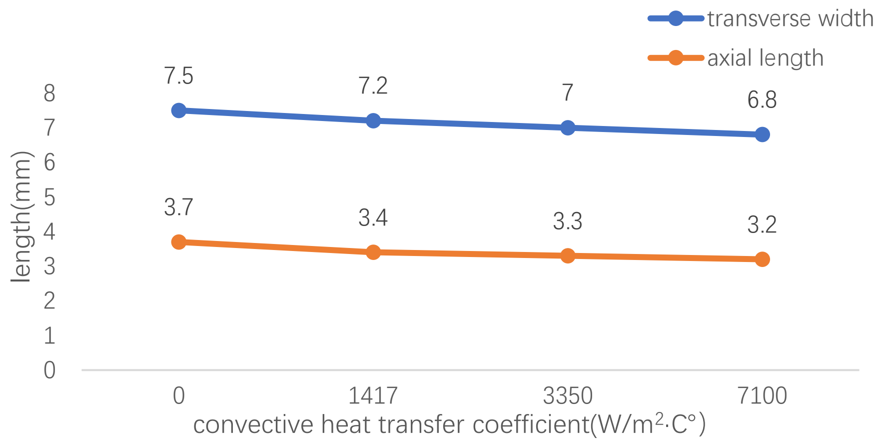

Figure 3. Changes of cardiac tissue length with convective heat transfer coefficient

4. Conclusion

This study simulated the effect of blood flow on microwave ablation of atrial fibrillation in a simple three-layer myocardial model. The results showed that the maximum temperature of ablation region decreased with the increase of convective heat transfer coefficient, and the transverse width and axial length decreased, but the amplitude was small.

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