Airflow Analysis of Radiofrequency Ablation for Asthma Therapy by using 3D Finite Element Method

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***Abstract*—The research aimed to present airflow analysis of radiofrequency ablation for asthma therapy by using three-dimensional finite element method. We study a solution for asthma therapy by using radiofrequency ablation method. Airflow is main factor for asthma therapy. Asthma patients have shortness of breath, coughing, wheezing, and chest tightness that influence a daily life of patients. All symptoms cause to die, especially in severe symptom patients. Asthma therapy by using radiofrequency ablation is a new alternative maneuver to the patient and hopefully may extend his lifetime, reduce using of medicines in asthma treatment and also save money on medical care. The simulation results obtained from our three-dimensional finite element method show airflow that will directly affect the temperature distribution by using radiofrequency ablation technique. These simulation results also guide us to develop an advance asthma treatment in the future.**

***Keywords*— Radiofrequency Ablation, Asthma Therapy, Finite Element Method, Temperature, Airflow.**

I. INTRODUCTION

Asthma is a chronic airway inflammation, with over 300 million people in worldwide who suffer from disease [1]. Asthma symptom is shortness of breath, coughing, wheezing, and chest tightness. All symptoms cause to die, especially in severe symptom patients. Therapy method based on severity of disease. Medical therapies cannot reduce a permanent narrowing of airway smooth muscle dimension in an airway wall. The persistent airflow can be difficult to control with medical therapies. We study solution to treat asthma by using radiofrequency ablation method because this method can reduce airway smooth muscle dimension. Patients who cured by this technique are supposed to have a fewer shortness of breath symptoms, and taking medicine in low-dose.

Previously, studies on radiofrequency ablation for asthma therapy. By the year 2004, Danek et al, [2-3] studied in non-asthmatic dogs. Treatments applied RF energy at 65°C or 75°C delivered to airway wall in lung. After therapy, airway hyperresponsiveness decreased significantly. Treatments effect persisted 3 years. Jarrard et al, [4] studied electro-thermal finite element analysis model in 2010. Catheter electrodes were designed as D-shaped wires. Model was designed to simulate the delivery of temperature controlled RF energy to airway wall.

Recently, the airflow simulations in airways have been based on dimension of airway. Johari et al, [5] define the accuracy of simplified models versus actual human airways. Simplified model depends on regions with complex geometry. Salleh et al, [6] studied effect of stenosis to the airflow pattern in the trachea and main bronchi. Press drop is one effect of healthy model.

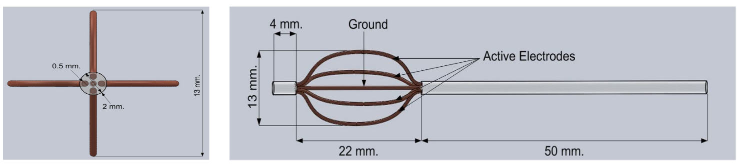
In this paper, we argue that radiofrequency ablation for asthma therapy. Radiofrequency delivers 380 kHz. RF probe temperature is controlled to 65-70°C at 22 volt for 10 seconds [3]. Velocity is equal to 0.066 m/s.

II. METHOD

A. Structure of RF Probe and Airway Model

The structure of RF probe is designed basing on a tractable electrode. Electrodes are intently designed similar to an ellipse shape. This RF probe control heat to airway wall. Zone of active tissue heating from RF probe is limited to a few millimeters surrounding this active electrode, with the remainder of the ablation zone is supposed to be heated via a thermal convection [7].

Airway is simply designed as a human smooth muscle airway in lung in which a phenomenon of muscle spasm due to an asthma symptom frequently existing. The airway model consists of lumen part, airway wall and parenchyma [4]. Fig. 1 and Fig. 2 display structure of RF probe and an airway model in this research. Material at the tractable wire part is stainless steel. Dimensions of structure of RF probe are shown in table I.



(a) Front view (b) lateral view

Figure 1. Structure of RF probe.

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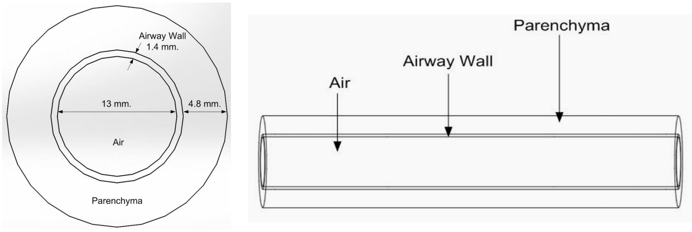


(a) Cross-section view (b) Perspective view

Figure 2. Airway model.

TABLE I. DIMENSIONS OF STRUCTURE OF RF PROBE

Component	Dimensions (mm.)
Diameter of electrode	0.5
Diameter of catheter	2.0
Width of electrode	13
Length of electrode	22.0
Overall length of RF probe	76.0

B. *Bio-heat Equation*

Joule heating arises when an electric current passes through a conductor. Electromagnetic energy is converted into heat. The heating of tissue during RF ablation is governed by the bio-heat equation in (1) and convective term in (2):

$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot kT + J \cdot E - h_{bl}(T - T_{bl}) - Q_m \qquad (1)$$

$$h_{bl} = \rho_{bl} c_{bl} \omega_{bl} \qquad (2)$$

Where

ρ = Density of tissue [kg/m^3];
c = Specific heat of tissue [$J/kg \cdot K$];
k = Thermal conductivity of tissue [$W/m \cdot K$];
J = Current density [A/m^2];
E = Electric field intensity [V/m];
T_{bl} = Temperature of blood;
ρ_{bl} = Density of blood [kg/m^3];
h_{bl} = Convective heat transfer coefficient accounting for the blood perfusion;
Q_m (W/m^3) = Energy generated by metabolic processes and was neglected since it is small compared with the other terms.

In the Pennes model described in the bioheat equation, the energy exchange between blood and tissue is modeled as a nondirectional heat source. One major assumption is that the heat transfer related to perfusion between tissue and blood occurs in the capillary bed, which turned out not to be fully correct. The main thermal equilibrium process takes place in the precapillary or postcapillary vessels. Nevertheless, the Pennes model describes blood perfusion with acceptable accuracy, if no large vessels are nearby [8-10]. The blood perfusion in airway wall (smooth muscle) used in the FEM was $\omega_{bl} = 0.6 \times 10^{-3}\ s^{-1}$ [4].

We can compute the electric field intensity by solving the Laplace equation is shown in (3)

$$\nabla \cdot \sigma \nabla V = 0 \qquad (3)$$

and the current density can be computed from (4)

$$J = \sigma E = -\sigma \nabla V \qquad (4)$$

where

V = potential distribution;
σ = electrical conductivity [S/m].

Then, (1) is solved for the temperature distribution. The temperature dependence of tissue electrical conductivity was incorporated in the model and required that the equations be coupled [4].

Electrical properties are specified at body temperature. Thermal properties of tissues are modified from animals [4]. We apply trachea properties for airway wall due to a similarity structure and property. Material properties used in FE models are shown in table II .

TABLE II. MATERIAL PROPERTIES USED IN FE MODELS

Material	Conductivity (σ) [S/m]	Thermal conductivity (k) [W/m · K]	Specific heat (c) [J/kg · K]	Density (ρ) [kg/m^3]
Air	0.01	0.030	1009	0.995
Airway wall	0.359	0.5	3000	1500
Blood	0.748	0.52	4176	1060
Parenchyma	0.15	0.451	1643	199
Stainless Steel	1.39×10^6	16.2	500	8030

C. Navier-Stokes and Energy Transport Equation

The model uses chemical engineering module to simulate the problem: weakly compressible Navier-Stokes equations and an energy transport equation with both convection and conduction. The weakly compressible Navier-Stokes equations can be used to simulate variable density flows; see equation (5):

$$\rho(u\cdot\nabla)u = \nabla\cdot\left[-pI+\eta\left(\nabla u+(\nabla u)^{T}\right)-\left(\frac{2\eta}{3}\right)(\nabla\cdot u)I\right]+\rho g \qquad (5)$$

and the energy transport equation with both convection and conduction can be computed from (6)

$$\rho C_p u\cdot\nabla T-\nabla\cdot\left(k\nabla T\right)=0 \qquad (6)$$

Where

u	=	Velocity [*m/s*];
p	=	Pressure [*Pa*];
η	=	Viscosity [*kg/(m·s)*];
C_p	=	Heat capacity [*J/(kg·K)*].

Airflow parameters are shown in table III [5].

TABLE III. AIRFLOW PARAMETERS

Parameter	Airflow
Velocity [m/s]	0.066
Pressure [Pa]	101,325
Density [kg/m^3]	1.225
Viscosity [kg/ms^{-1}]	1.7894×10^{-5}

D. Finite Element method

In this paper, we apply a finite element method of COMSOL Multiphysics program to simulation the radiofrequency ablation in our asthma therapy. Airway model and RF probe are designed firstly by using a general CAD program then imported into the COMSOL solver. RF module, electromagnetics module and chemical engineering module was selected as a radiofrequency thermal ablation. All physics parameter and boundary condition was precisely defined. Number of meshing element is 248,864 at fine Meshing. Fig. 3 shows meshing refinement respectively. This simulation was implement on Intel Core-i7 3.5 GHz and 16 GB RAM on Window platform.

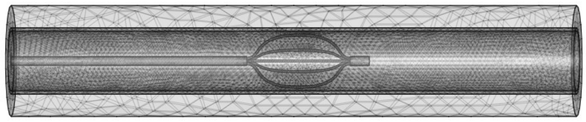


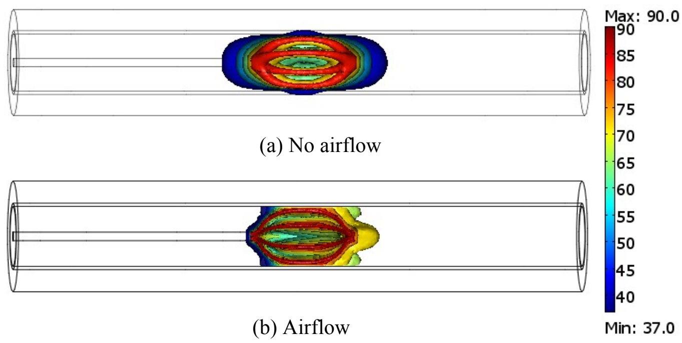
Figure 4. Meshing refinement.

III. RESULTS

From the figures it may be shown that the simulation results of radiofrequency ablation for asthma therapy by using three-dimensional finite element method. Radiofrequency is controlled to 380 kHz for 10 seconds. Velocity is equal to 0.066 m/s. After RF probe operate for 10 seconds, temperature surrounding the active electrode equal to 65-70°C. The airflow will directly affect the temperature distribution. Dilation of an airway wall results in an increasing airflow and increasing temperature distribution during receiving the thermal energy. Models illustrate an increasing of temperature from an origin temperature 37 °C to 90 °C. At 65-70°C, these temperatures are suitable for asthma therapy because these temperatures cannot destroy cell surrounding the airway smooth muscle and proteins including actin and DNA.

IV. DISCUSSION AND CONCLUSION

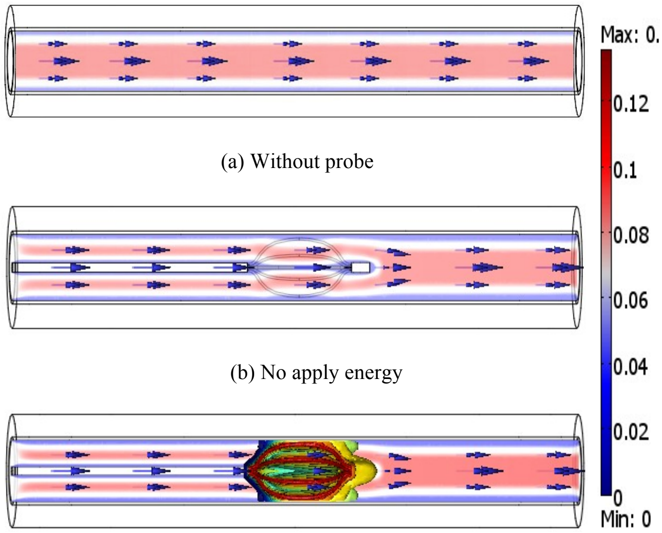
In conclusion, radiofrequency ablation for asthma therapy by using three-dimensional finite element method clearly demonstrates that RF probe control heat that radiate to an airway wall. Airway smooth muscle in airway wall is heated then its thickness becomes narrow cause an airway lumen bigger. Radiofrequency is controlled to 380 kHz at 65-70°C for 10 seconds. Velocity is equal to 0.066 m/s. After receiving the thermal energy, airway wall is dilate dimension. Thus, asthma therapy by using radiofrequency ablation is a new alternative maneuver to the patient and hopefully may extend his lifetime, reduce using of medicines in asthma treatment, save money on medical care, and also guide us to develop an asthma treatment in the future. We plan to apply our treatment system to use with lung cancer, chronic obstructive pulmonary disease, and lung disease in the future.



(a) No airflow

(b) Airflow

Figure 5. Temperature distribution.



(a) Without probe

(b) No apply energy

(c) Apply energy

Figure 6. Airflow.

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