A Basic Investigation of Cancerous Breast Microwave Ablation Using Opened-tip Applicator and *Ex Vivo* Experiment.

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1 Introduction

Cancer in female breast was realized as one of the main health hazard that threatening women around the world for many year [1]. Besides from a conventional intervention surgery, thermal ablation in microwave frequency range was widely accepted as an another alternative medical treatment due to its minimal invasive maneuver and using only bipolar antenna probe technique [2,3]. Some research groups propose their studies both in simulation phase and only a few with a real experiment [2-5]. In this research, we propose an analysis of FEM and a valid *ex vivo* real experiment of an opened-tip microwave antenna for using in breast cancer ablation. Consideration to a tissue destructive shape, we intently design our microwave applicator as a conventional opened-tip antenna [6, 7]. At first, materials, dimensions and characteristic in term of VSWR of this antenna was investigated. Then, a complicated CAD model of cancerous breast tissue was originally proposed by our group in this research in which compose of a tumor cell in a multi-layer mammalian tissue. By using FEM of COMSOL solver, we have analyzed a distribution pattern of SAR, temperature and estimated destructive breast tissue region with respect to bioheat effect and phenomenon of an electric field in living tissue. These all implementations were able to show in true full 3D tissue space. Furthermore, we also confirm our simulation by an *ex vivo* real ablation of female swine breast with enhancing an applicator insertion by ultrasound-guided image. During ablation process, temperature generated from microwave heat was also monitored and finally a burning lesion of swine tissue was declared.

2 Finite Element Analysis Implementation

The implementation of FEM was primarily performed to an applicator design then following by cancerous breast phantom modelling and definition of governing control equation.

2.1 Opened-tip Applicator Design

Coaxial opened-tip antenna type (COT) was selected as an applicator in our microwave ablation since its propagation pattern is quite predictable to a desire destructive area. Figure 1 shows an antenna structure while the dimensions and materials are shown in Table 1. Return loss factor was also simulated at microwave frequency range and show voltage standing wave ratio (VSWR) response in Fig.2.

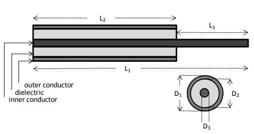

Fig. 1. Applicator structure.

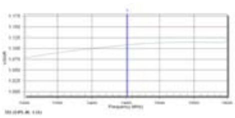

Fig. 2. VSWR of COT applicator.

Table 1. Dimensions and materials of opened-tip applicator

Dimension/material	size	Dimension/material	size
Diameter of outer conductor – D1 (Silver plated copper clad steel)	3.581 mm.	Length of antenna (L_1)	60 mm.
Diameter of dielectric – D2 (Solid PTFE)	2.985 mm.	Length of outer (L_2)	40 mm.
Diameter of inner conductor - D3 (Silver plated copper clad steel)	0.912 mm.	Length of open slot (L_3)	20 mm.

2.2 Cancerous Breast Model

In this research, cancerous breast phantom model which originally created by our research group was designed by using CAD program. We introduced an ideal to insert a small size (1.5 centimetres in cubic shape) of maglinant tumor in between a multi-layer of female breast tissue [8]. As a preliminary model, this tumor was located at approximately 2 centimetres below breast tissue surface. Then, our opened-tip type applicator was supposed to be inserted through the middle of this tumor. Figure 3 shows subdomain geometry of CAD breast phantom model while meshing refinement is shown in Fig. 4. Table 2 shows main physical properties of breast tissue and materials for FEM simulation [8, 9].

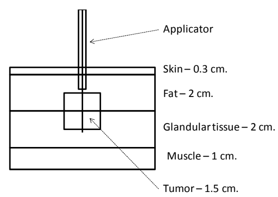

Fig. 3. Cancerous breast tissue subdomain geometry model.

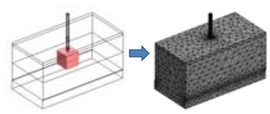

Fig. 4. Breast modelling and meshing refinement.

Table 2. Physical parameters of breast tissue and applicator for FEM simulation

Tissue / Material	Conductivity (S/m)	Permittivity (F/m)
Skin	1.464	38.007
Fat	0.10452	5.2801
Glandular tissue	1.9679	57.201
Muscle	1.7388	52.729
Tumor	4	50
Dielectric	0	2.03

2.3 Governing Equation

All governing equation in our FEM analysis was strictly derived with respect to bioheat effect, SAR criteria and microwave phenomenon in living tissue. These solutions were presented in (1,2) [7] as following.

$$SAR = \frac{\sigma \cdot E^2}{\rho} \tag{1}$$

Where σ is a conductivity of tissue (S/m), E is an electric field (V/m) and ρ is a density of tissue (kg/m^3). This term generally used to indicate a heating ability of microwave antenna or imply as heat generated by an electric field in living tissue. In this research, SAR can be applied as an external heat source in bioheat consideration and derived into heat equation as shown in (2).

$$\rho \cdot C\,\frac{\partial T}{\partial t} + \nabla \cdot (-k\,\nabla T) = h_b(T_b - T) + \rho \cdot SAR \tag{2}$$

Where C is a specific heat of tissue (J/mK), k is a thermal conductivity of tissue (W/mK), T is a temperature of tissue $(°C)$, T_b is a blood temperature $(°C)$ and h_b is a convective heat transfer coefficient (kg/m^3).

2.4 FEM Analysis

In this research, we use COMSOL Multiphysics (version 3.5a) solver to implement FEM analysis. Simulation module was selected on RF module with a harmonic propagation and also heat transfer module of living tissue. Microwave frequency was preset at 2.45 GHz according to ISM criteria. The simulation was truly performed in full 3D tissue space on Core-i5 2.5 GHz desktop computer and 16 GB RAM.

3 Simulation and *ex vivo* experimental results

The simulation and real experimental results in this research were presented as following.

3.1 Simulation Results

In this simulation, a number of meshing elements was compromisingly refined at 55,396 elements in tetrahedral shape with 334,905 degree of freedoms and the solution time is about 755 seconds. Figure 5, 6 and 7 shows SAR, temperature distribution pattern and estimated destructive tissue shape at opened-slot site in full 3D space after 180 seconds of 2.45 GHz microwave ablation at 50 Watts.

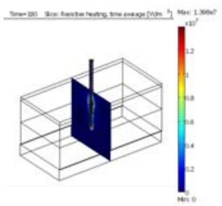

Fig. 5. SAR distribution pattern.

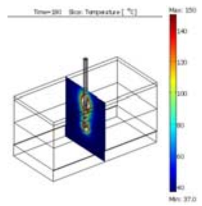

Fig. 6. Temperature distribution pattern.

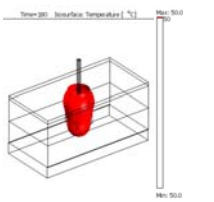

Fig. 7. Estimation of destructive breast phantom model in 3D tissue space.

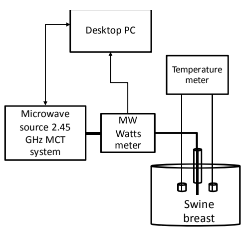

Fig. 8. *Ex vivo* real ablation experimental setup.

3.2 Ablation Experimental Results

To clarify our simulation proposal, we have implemented an *ex vivo* real ablation of our opened-tip applicator to a piece of female swine breast with our in-house microwave ablation prototype system and Bird site analyzer SA-6000EX as shown in Fig.8. The applicator insertion into swine breast was enhanced by using ultrasound-guided viewing (Aloka SSD-1700 Dynaview). Figure 9 shows tissue ablation lesion using 50 Watts at 2.45 GHz for 180 seconds. Rising of heat temperature in swine tissue was also monitored continuously from 2 observed sites by using Fluke 54 II thermometer as shown in Fig. 10.

Fig. 9. Ablation of female swine breast by the bending applicator using 2.45 GHz at 50 Watts for 180 seconds.

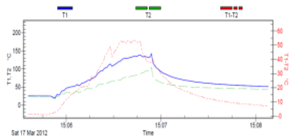

Fig. 10. Monitored temperature during microwave ablation.

4 Discussion and Conclusion

By using FEM, we propose a design of opened-tip antenna and a complicated cancerous breast phantom model in an investigation of breast cancer ablation. Validation of our simulation is also performed with *ex vivo* real ablation in female swine breast. From this proposed research, these outputs not only show a promising result of both simulation and real experiment but also encourage us to develop an advance microwave ablation system for using in breast cancer hyperthermal treatment in near future.

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