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Effect of Phase Difference in Multi-antenna Microwave Thermal Ablation for Breast Cancer Treatment

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Abstract— **It was realized that cancer in breast is one of the most health hazards threatening women around the world for many years. Thermal ablation by using microwave energy is another alternative surgical maneuver due to its minimally invasive therapeutic technique. In this research, we investigate an effect of phase difference between three adjacent opened-slot coaxial probes in a multiple antenna alignment of microwave thermal ablation system for breast cancer treatment. FEM by using COMSOL is an implementation tools to simulate for 0, 45, 90, 135 and 180 degree of phase difference. 3D Simulation results show that temperature distribution pattern, destructive volume and SAR in breast tissue are affected from those phase-shift utilization in multi-antenna system significantly.**

I. Introduction

Breast cancer is known as an important health hazard to women around the world for many years. Surgery by using a conventional technique such as mastectomy or lumpectomy as breast conservation is also widely accepted as a gold standard for this malignant tumor treatment [1,2]. Beside from those medical maneuvers, thermal ablation by using electromagnetic energy at 2.45 GHz microwave frequency is emerged as an another alternative therapeutic method especially for an inoperable patient [3-5]. Minimally invasive, less pain and shorter recovery time seem to be a main advantage of this technique over the classical method [6-9]. However, implementation of microwave ablation (MWA) by applying a multi-antenna alignment in breast cancer is still a challenging investigation particularly for a large size of malignant cell. Multi-antenna MWA ablation provides a larger ablation zone due to an energy phase combination from each probe within a lower treatment power without any over heat effect as in a single antenna. In this paper, we propose an investigation of phase difference effect in multi-antenna MWA for breast cancer treatment by using FEM simulation. Design of an opened slot coaxial antenna for each ablation probe was presented both dimension and material firstly. Following by a configuration of three antennas as an array alignment system in breast CAD model. Our breast model was designed as a mammalian tissue as a homogeneous glandular tissue. In this preliminary stage, we have set a phase shift criteria of an initial emitting phase at 0°, 45°, 90°, 135°, 180° and 225° for each difference case. By using COMSOL solver, FEM simulation results were post-processingly analyzed with respect to bioheat equation and interaction between an electromagnetic wave to living tissue for a total distribution pattern of tissue temperature, specific absorption rate (SAR) and an estimation destroyed tissue. These 3D results were then computationally compared in term of ablated tissue volume for each phase difference case. Consideration to a treatment of large breast cancer cell with thermal ablation, this investigation provides us an effect of phase difference on emitting power for each antenna to a total ablation result.

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This paper composes as following. An introduction and a design of a single opened-slot microwave antenna are presented in section 1 and 2 respectively. In section 3, an analysis by using FEM as property of material, CAD modeling, configuration of multi-antenna system, governing equation and simulation condition are described in detail. Our simulation results of phase difference effect for each case ares in section 4. Section 5 proposes a discussion and conclusion finally.

II. Design and Structure of Opened-Slot Antenna

Each single antenna in our multi-antenna ablation system was designed basing on an opened-slot coaxial antenna (OSC) as shown in Fig. 1. Opened-slot part is trial at 0.5 centimeter. Table I shows a dimension and material of this opened-slot antenna. For a symmetrical comparison, our multi-antenna array was supposed to compose of only three OSC in breast tissue model as shown in Fig.2.

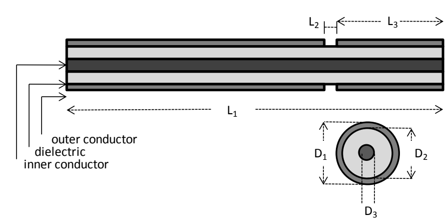


Figure 1. OSC antenna structure.

TABLE I. Dimension And Materials of Each Single Opened-Slot Coaxial (OSC) Antenna

Part	size	Part	size
Diameter of outer conductor – D1 (Silver plated copper clad steel)	3.581 mm.	Length of total antenna (L1)	60 mm.
Diameter of dielectric – D2 (Solid PTFE)	2.985 mm.	Length of opened slot (L2)	3 mm.
Diameter of inner conductor - D3 (Silver plated copper clad steel)	0.912 mm.	Length of end to slot (L3)	20 mm.

III. IMPLEMENTATIONS OF FEM

The simulation using finite element method is concerned about a separation of a complex geometry model into small elements for a partial differential equation system and following by an evaluation at each nodes or edges. This implementation composes of many steps, at first, a physical property of breast tissue and OSC antenna was defined then CAD Modeling was created according to our interesting problem. The overall validation of our simulation depending on a main governing equation and a boundary condition setting. Those procedures are described as following.

A. Property of Materials

Material property of breast tissue and OSC antenna was defined according to their physical characteristics as shown in Table II [10,11].

TABLE II. PHYSICAL PROPERTY OF BREAST TISSUE AND OSC ANTENNA

Tissue Material	**Conductivity** (S/m)	**Permittivity** (F/m)
Glandular tissue	1.9679	57.201
Dielectric	0	2.03

B. Multi-Antenna Array Modeling

As described above, we intend to design the multi-antenna ablation system as a three antenna in-line array for a symmetrical alignment. Figure 2 shows a configuration of each single OSC antenna to compose as a 3 probes array alignment in breast CAD model. A distance between each single antenna is approximately 1 centimeter. For the breast tissue model, we intently design the breast model in this simulation as a homogeneous tissue. It composes only glandular tissue layer. The OSC antenna was supposed to be inserted into the center of this glandular tissue layer to investigate an ablation phenomenon at this region.

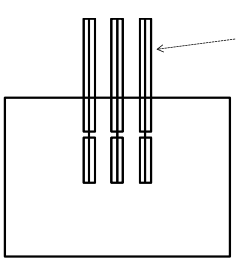


Figure 2. Alignment of multi-antenna for breast ablation system.

C. Governing Equations

The governing equation in our FEM analysis was strictly derived with respect to a bioheat effect, SAR criteria and microwave interaction in a general living tissue as following.

$$SAR = \frac{\sigma \cdot E^2}{\rho} \quad (1)$$

where

σ is a conductivity of tissue (S/m)
E is an electric field (V/m)
ρ is a density of tissue (kg/m^3).

In this research, 2.45 GHz was set as the microwave ablation frequency according to an ISM band regulation. At this frequency, SAR term generally is used to indicate a heating ability of microwave antenna. It implies as heat generated by an electric field in living tissue. In our ablation case, this term can be applied as an external heat source in bioheat consideration and then derived into bioheat equation as shown in (2) and (3) [11].

$$Q_{ext} = \rho \cdot SAR \quad (2)$$

$$\rho\, C\, \frac{\partial T}{\partial t} + \nabla \cdot (-k\, \nabla T) \;\; = -Q_p + Q_{met} + Q_{ext} \quad (3)$$

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 $(°C)$
Q_p is an energy of blood perfusion (W/m^3)
Q_{met} is an energy from metabolic process (W/m^3)
Q_{ext} is an external heat source (W/m^3)

When electromagnetic wave propagate from conducting antenna into breast tissue, Joule heating or thermal energy increases due to a microwave energy dissipation from electric current flowing. This phenomenon defines as Q_{ext} or an external heat source from antenna applicator. In general, an internal heat source from our tissue metabolism process is quite very small comparing to a heat from antenna, then this natural amount can be ignored in this simulation. Consideration to a cooling term or Q_p, this term indicates a blood perfusion effect surrounding an ablated tissue. It can be defined as $h_b(T_b - T)$ when h_b is a convective heat transfer coefficient (kg/m^3) and T_b is a blood temperature $(°C)$ and

D. Simulations Process

By using a general CAD modeler, multi-antenna ablation system which composes of three OSC antennas and multi-layer breast tissue was geometrically created then export IGES format into our simulation solver. In this simulation, we use COMSOL Multiphysics (version 3.5a) as a FEM simulation solver. RF module with a harmonic propagation and also heat transfer module were induced with respect to a living tissue effect under an electromagnetic exposure. A meshing refinement was defined as an automatic initial mesh in tetrahedral shape. A number of meshing elements was compromisingly refined at 74,754 elements. Degree of freedom is ordered at 515,663. Meshing refinement of our multi-antenna array system is shown in Fig. 3.

As a preliminary, phase difference between each single antenna was varied from 0°, 45°, 90°, 135°, 180° and 225°. The initial emitting phase of electromagnetic wave at the middle antenna was set at zero as a reference phase while a positive phase and negative phase is set at left and right antenna, respectively. Simulation process was tested by setting an ablation microwave output power for each antenna and treatment time at 20 Watts and 180 seconds, respectively. FEM simulation was implemented then 3D distribution pattern of temperature, SAR and an estimated destructive volume was analyzed post-processingly for each phase difference case.

This simulation was performed on a personal computer with CPU Core-i5 2.5 GHz under 64 bits Microsoft Window 7 platform and 16 GB of RAM memory. Solution time is 1,800 seconds approximately.

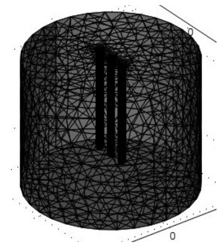
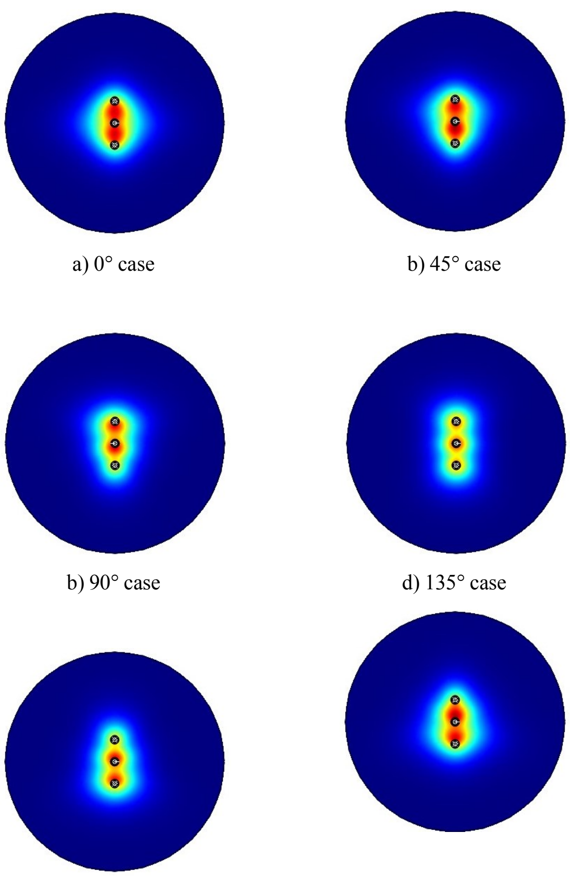


Figure 3. Meshing refinement of multi-antenna system in breast model.

IV. SIMULATION RESULTS

Figure 4-6 shows all simulation results. A distribution pattern of temperature and SAR is shown in Fig. 4 and 5. Figure 6 shows an estimated destructive shape in which defined as a tissue area absorbing temperature higher than 60 degree of Celsius or non-reversible damaging from heat [11]. This destructive tissue is numerically estimated and also compared for each phase difference case as in Table III.

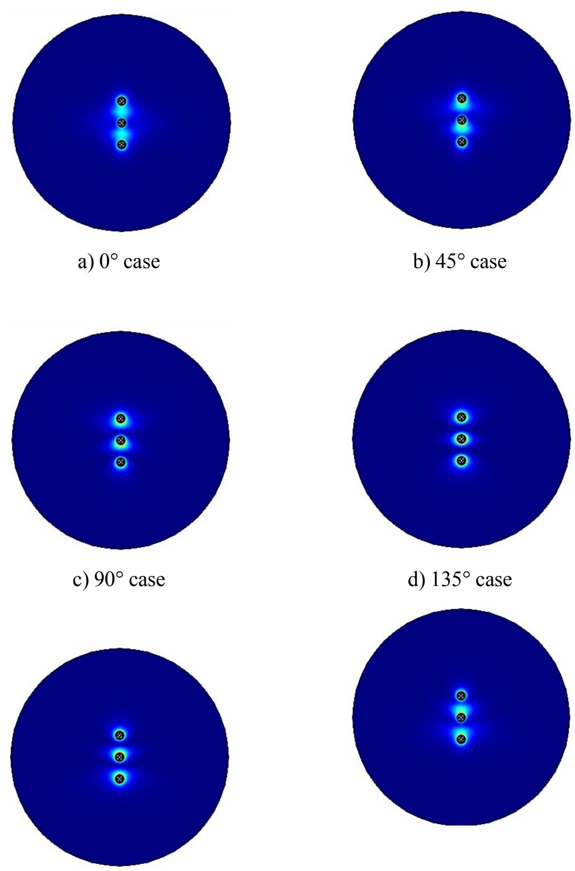


a) 0° case b) 45° case

b) 90° case d) 135° case

e) 180° case f) 225° case

Figure 4. Distribution pattern of temperature.



a) 0° case b) 45° case

c) 90° case d) 135° case

e) 180° case f) 225° case

Figure 5. Distribution pattern of SAR.

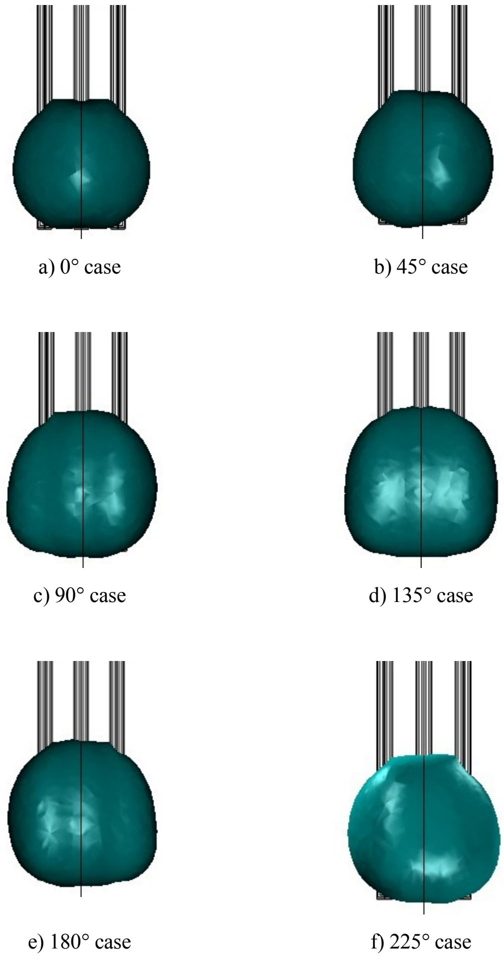


Figure 6. Distribution pattern of destructive volume

TABLE III. ESTIMATED DESTRUCTIVE VOLUME (CM^3).

Phase shift difference	**volume**
0°	41.170
45°	42.185
90°	43.526
135°	44.417
180°	43.731
225°	43.731

V. DISCUSSION AND CONCLUSION

Consideration to the simulation results, the estimated destructive tissue volume was affected significantly from the initial phase difference between each antenna in the multi-antenna array system. Even though, this variation is not quite linear as shown in Table III.

As a conclusion, we have analyzed a total ablation result in multi-antenna system that affect from an initial phase difference of each ablation antenna. This phase shift influences directly to a destructive tissue volume and must be considered carefully as an another controlling parameter.

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