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FEM Analysis of Microwave Ablation for Snoring Therapy by Using Real Image

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Abstract. This study presents an analyze of blending coaxial open-tip antenna for microwave snoring ablation using real-image with three-dimensional finite element analysis verified by *in vitro* experiment. Treatment of soft palate tissue in mouth cavity of the body and had curve-shape. We performed a blending coaxial open-tip antenna characteristic of antenna get power delivery of 50 W for 60 second and coagulation volume of 1.028 cm^3 .This treatment is a new approach to surgery.

Keywords: Microwave ablation, finite element analysis, snoring therapy, soft palate tissue.

1. Introduction

Snoring is one of a sleep disorder syndrome in which bothering human health only patient himself but also impact to his or her spouse unavoidable. In a long term, this chronic effects seriously to healthy and also mentally of people. Treatment of snoring using resection of somnoplasty is an effective choice in many cases [1,2]. Radiofrequency or microwave range ablation is also widely accepted in this medical maneuver and investigate by many research [2-6]. Heat generated from an electromagnetic wave coagulate a soft tissue and cause tissue necrosis. Upper soft palate or small part possible to be reshaped by this technique. Figure 1 shows an insertion of microwave applicator into soft tissue region the following by microwave emission at preset treatment time and power. The key success factor of this technique depends on controlling of size of a destructive area in soft tissue [6-9]. This process relies on an absorption power, time and temperature distribution of microwave energy. Prediction of those factors using simulation solver seem to be a promising way in microwave ablation system design [7-9].

In this research work, we present a simulation of microwave ablation in a phantom model of human mouth cavity. The new design of open-tip bending applicator was introduced as a microwave antenna. Characteristic in term of VSWR was also identified for an impedance matching at 2.45 GHz frequency range. For mimic phantom of mouth cavity model, real image from CT images set was applied and guided during CAD modelling process. Full 3D finite element method (FEM) was implemented by using COMSOL solver to obtain a distribution pattern of SAR and temperature [6-9]. The simulation output not only shows a promising result of destructive area in 3D space tissue space through the mimic soft palate model but also guide us to validate these results with our full experimental setup system in near future.

This paper is presented as following. An introduction and microwave antenna structure is presented in section 1 and 2 respectively. Modelling from real CT image and an implementation of finite element method in mouth cavity phantom model is in section 3 and 4. Section 5 is our simulation results while discussion and conclusion is proposed in section 6.

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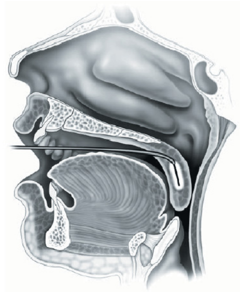


Figure 1: Insertion of microwave antenna into soft palate region.

2. Structure of Bended Antenna

Consideration to an anatomy of human mouth cavity, upper soft palate forms as a curve plate region. Then, as a preliminary, we intently design our applicator as a bending tip antenna in order to fit with this shape [10]. Figure 2 shows this bending antenna structure. L_1 (45 millimetres) is a straight part while L_2 (25 millimetres) is bended as a small curve. Bending angle (B_θ) is trailed at 75 degree. Dimension and material of this antenna are shown in Table I. This antenna was also tested for a return loss factor by using site Analyzer Bird's SA6000 EX at microwave frequency 2.3 GHz to 2.6 GHz and its response is shown in Fig. 3 and blending coaxial open-tip have VSWR : 1:1.1 (very low VSWR desirable because it can drive more energy into tissue). Thus one antenna can potentially be used in microwave ablation of soft palate tissue.

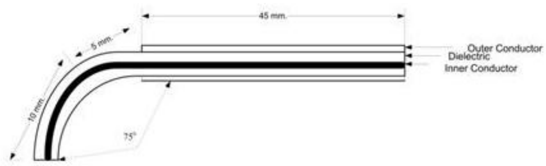


Figure 2: Antenna structure.

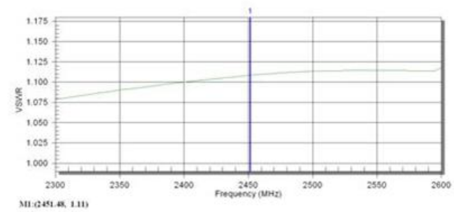


Figure 3: VSWR(Voltage Standing Wave Ratio) characteristic of open-tip bended antenna.

Table I Dimensions And Materials of Bended Antenna

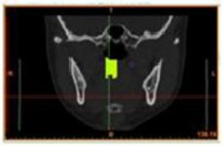
Material	dimension
Diameter inner conductor (Silver Plated Copper Clad Steel)	0.912 mm.
Diameter of dielectric (Solid PTFE)	2.985 mm.
Diameter of outer conductor (Silver Plated Copper Clad Steel)	3.581 mm.
Length of antenna (L_1)	45 mm.
Length of opened tip (L_2)	15 mm.
Bending angle (B_θ)	75°

Table II: Physic Properties of Materials in Fem Model

Material	value
density of tissue (ρ)	1,040 (kg/m^3)
specific heat of tissue (C)	3,700 (J/mK)
thermal conductivity of tissue (k)	0.5 (W/mK)
temperature of tissue (T)	37 ($°C$)
temperature of blood (T_b)	37 ($°C$)
relative permittivity of tissue (ε_{tissue})	53.573
relative permittivity of dielectric (ε_{diel})	2.03

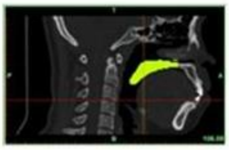
3. Real image Geometry Model

In FEM analysis, a correction of model geometry plays an important role in simulation. In this study, a set of real image from CT sliced was introduced to enhance a human mouth cavity modelling design. CT image in sagittal view, axial view and coronal view were imported and rebuilded to obtain a mouth cavity in CAD file model with *iges* format. This implementation was succeeding by using general mimic type program and also manually segmentation. This maneuver provides us a soft palate model in which reassemble to human anatomy. Figure 4 shows a mouth cavity obtains from this technique.



(a)Coronal view

(b)Axial view



(c)Sagittal view

(d)CAD model

Figure 4. Mouth cavity from real CT image.

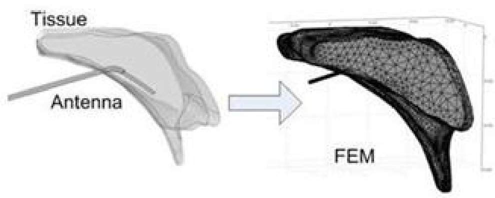


Figure 5. Soft palate model and meshing refinement.

4. Implementation of Finite Element Analysis

The finite element method (FEM) involves dividing a complex geometry model into small elements for a system of partial differential equation then evaluate at nodes or edges. In this study, two governing equations as bioheat equation and SAR distribution equation were carefully concerned due to a natural phenomenon of electromagnetic wave in living tissue [11].

4.1. Bioheat Equation

Analysis of heat generated in soft tissue due to an electromagnetic wave was employed by using a general bioheat equation as following. Solution obtains from this equation indicate a thermal distribution in soft palate tissue

$$\rho\, C\, \frac{\partial T}{\partial t} + \nabla \cdot (-k\, \nabla T) = h_b(T_b - T) + Q_{met} + Q_{ext} \quad (1)$$

ρ = density of tissue (kg/m^3)
C = specific heat of tissue (J/mK)
k = thermal conductivity of tissue (W/mK)
T = temperature of tissue $(°C)$
T_b = temperature of blood $(°C)$
h_b = convective heat transfer coefficient(kg/m^3)
Q_{met} = energy from metabolic process (W/m^3)
Q_{ext} = external heat source (W/m^3)

Generally, term Q_{met} in (1) is an energy from metabolic process inwhich can be negligible and excluded from FE Model during ablation simulation. As a preliminary study, we also can omit h_b due to our simulation is an *in vitro* study.

4.2. SAR Distribution

In general, an energy which absorbs by living tissue when body is exposed by electromagnetic field at radiofrequency range can be measured in term of a specific absorption rate (SAR). This value indicates an absorption power per mass of living tissue or in Watts per kilogram (W/kg). SAR distribution is widely used in order to indicate a heating ability of microwave antenna. Heat generated by an electric field in living tissue can be shown as SAR as in (2).

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

where

ρ	= density of tissue (kg/m^3)
σ	= conductivity of tissue (S/m)
E	= electric field (V/m)

In this research, heat generated by antenna as SAR can be applied as an external heat source in bioheat consideration and derived as shown in (3), a heat equation.

$$\rho\, C\, \frac{\partial T}{\partial t} + \nabla \cdot (-k\, \nabla T) = h(T_b - T) + \rho \cdot SAR \tag{3}$$

4.3. Model Simulation

As described above, a mouth cavity, especially soft palate region was anatomically modelled from a huge of image set of CT. Then, microwave applicator was assumed to be inserted into soft palate region. Destructive area of soft tissue was finally expected to be identified by this simulation study. This aspect is possible to achieve by implementation of full 3D FEM simulation. Figure 5 shows a soft palate model and meshing refinement in this simulation. We selected a microwave frequency as 2.45 GHz at 50 Watts of ideal output power with respect to a specific absorption rate (SAR) and an industrial, scientific and medical (ISM) radio bands. The propagation of heat generated from electric field in electromagnetic wave was analyzed by using FEM of COMSOL Multiphysics (version 3.5a) solver in 3D tissue space. Simulation module was selected on RF module with harmonic propagation and also heat transfer module of living tissue. Basic condition of FEM meshing refinement was defined as an automatic initial mesh of triangular mesh shape. Physic properties of material in our simulation and boundary conditions was assigned as shown in Table II. This simulation was operated on a personal computer with CPU Core-i5 2.5 GHz under 64 bits Microsoft Window 7 platform and 16 GB of RAM memory.

5. Simulation Results

5.1. FEM Results

In this simulation, a number of mesh element was compromisingly refined at 481,803 tetrahedral elements with degree of 721,582 freedoms at 5.6 GB RAM of memory using. The solution time is 1222.7 second. Simulation results of this study are shown in Fig. 6-10. Absorption rate as SAR was shown in figure 6. This distribution was observed at the end of opening tip. Temperature distribution in soft tissue due to heat generated from antenna was also shown in figure 7. The tissue coagulation of soft palate tissue can be estimated from the temperature distribution. Figure 8 shows a volume of destructive area (red color) in 3D volume space of soft palate model from FEM. This volume was observed after 60 seconds of microwave emission. Due to an enhancement of real image from CT data set, this expectation from FEM simulation was merged into CT image at appropriate view and shown in figure 10.

5.2. Experimental Result

Validation of this simulation also implemented as a preliminary study. Chicken breast was preferred as a soft tissue in our case (6). Figure 11 shows a coagulation zone after 60 seconds of microwave emission in which superficial burn was disappear noticeable.

6. Discussion and Conclusion

We propose a preliminary research study of soft palate microwave ablation for snoring treatment. The study was implemented by using full 3D simulation of finite element method from COMSOL solver. New bending type applicator was designed as a microwave antenna in order to anatomically fit with mouth cavity. To obtain a suitable FEM model, we also applied a real image from CT slice of human mouth cavity area to enhance a CAD model design. From the simulation results, SAR and temperature distribution imply a destructive region in 3D volume shape of soft palate noticeably. Real coagulation also performed with *in vitro* experiment in order to support our preliminary study in which this applicator shows a promising result. Our long-term target is to develop a simple microwave ablation for somnoplasty in microwave frequency range, this simulation provide us a useful basic data and encourage us develop a complete system in near future.

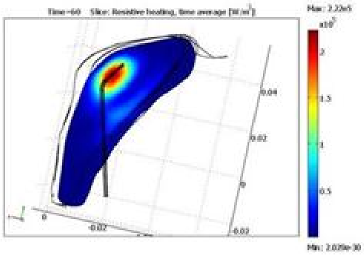


Figure 6. SAR distribution.

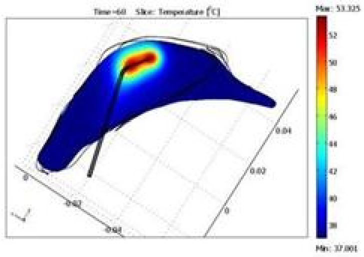


Figure 7. Temperature distribution.

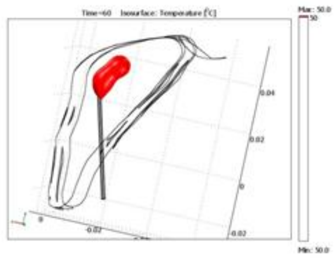


Figure 8. Estimation of destructive tissue in 3D volume space.

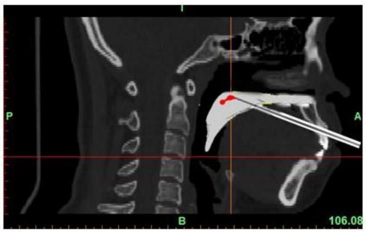


Figure 9. FEM simulation result in real image.

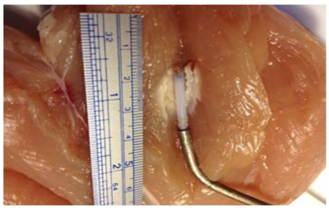


Figure 10. Ablation of chicken breast by the bending applicator.

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