마이크로파 에너지를 이용한 열 치료용 링-모노폴 안테나

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Modified Monopole Antenna for Microwave Thermal Therapy

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Modified coaxial-slot antenna for minimally invasive microwave thermal therapy for liver tumor is studied in this paper. Minimally invasive microwave antenna in medicine are applied for hyperthermia for medical treatment for cancer, cardiac catheter ablation for ventricular arrhythmias treatments, microwave treatment of Benign prostatic hypertrophy, and so on. Microwave hyperthermal ablation for liver tumors is expected for enthusiasts as an alternative to curative surgical resection. Tumors have to heated up to 60 degree C to coagulate cancer cells but less than 100 degree C to avoid evaporation. Temperature dependence of properties of the tissues should be considered for wide range of treatment. Electrical properties of liver tissue were measured for different temperatures. SAR distribution around the antenna into the liver are simulated using Remcom's XFDTD.

1. Intorduction

One of applications using electromagnetic energy is microwave thermal therapy. These microwave thermal therapies are microwave interstitial hyperthermia and microwave coagulation for medical treatment for cancer, cardiac catheter ablation for ventricular arrhythmias treatments, and microwave treatment of Benign prostatic hypertrophy, and so on. Hyperthermia is alternative to cancer treatment to heat tumor up to therapeutic temperatures(between 42-45 deg. C) without overheating the surrounding normal tissues.

For liver tumors, surgical resection has been established treatment modality offering potential for cure. However, resection is dependent on tumor volume, lesion location, extrahepatic metastasis, and limited hepatic function as a result of the degree of liver cirrhosis. Systemic Chemotherapy, External Beam Radiation or Chemoembolization are three other options that are either used in conjunction with resection or used as alternatives. Enthusiasts view hyperthermal ablation as an alternative to curative surgical resection.

Hyperthermal ablation are Radio Frequency Ablation(RFA), Microwave Ablation(MWA), Laser

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Ablation, and High Focused Ultrasound Ablation. RFA and MWA require local anesthesia, percutaneous approach. 15 to 17 GA needle electrodes are used and Greatest kill zone for RF is 3.5 cm with one insertion. For RFA and MWA can use single electrode or multi-electrode array. For liver cancer, volumetric tissue coagulation including large volumes treatment, small electrode sizes, and more power is required.
modified coaxial slot antenna for minimally invasive microwave thermal therapy can be applied to both microwave interstitial hyperthermia and MCT. As for hyperthermia treatment, temperature of the tumor must be kept between 42 and 45 degree C without overheating the surrounding normal tissue while tumors must be heated up to at least 60 degree C but less than 100 degree C not to evaporate tissue in the MCT treatment.

2. Monopole antenna

Modified coaxial antenna structure is shown in Fig. 1. This antenna is composed of a thin coaxial cable which outer diameter is approximately 4 mm. Several conductor rIngs which are connected to inner conductor are lied on the outer conductor. The antenna is embedded into a catheter for medical safety.
In thermal therapy, SAR(Specific Absorption Rate) is commonly used as one of the indices evaluating the heating ability of the equipment. The SAR indicates the heat generated by the electromagnetic fields inside the human body.

$$SAR = \frac{\sigma}{\rho}|\boldsymbol{E}|^2$$

where σ : conductivity, ρ : density, E: electric field

Table 1. Electrical properties of the human body

	Skin	Fat	Muscle	Blood
Relative permitivity	47.0	5.0	53.0	-
Conductivity [S/m]	1.0	0.09	1.41	-
Specific Heat [J/Kg · K]	3500	2300	3500	3960
Density [kg/m^3]	1000	900	1020	1060

3. Analysis and simulation

The FDTD method is used to analyze monopole antenna. FDTD applied to the rotationally symmetric coaxial line in a cylindrical coordinate system. Monopole antenna is assumed to be immersed in a homogeneous medium. By symmetry, $\frac{\partial}{\partial \phi} = 0$, and E_r, E_z, and H_ϕ components are exist.
From Maxwell equations, we obtain H_ϕ,

$$-\frac{\partial}{\partial z} = \left(\frac{\partial H_\phi}{\partial z}\right) - \frac{\partial}{\partial z}\left[\frac{1}{r}\frac{\partial}{\partial r}(rH_\phi)\right] = \omega^2 \mu \varepsilon H_\phi$$

where, $\varepsilon = \varepsilon_0 \varepsilon_r - j\sigma/\omega$

The FDTD is used to solve equation with a trial solution for H_ϕ over one triangular finite element.

$$H_\phi = \sum_{i=1}^{3} u_i N_i(r,z)$$

where, u_i : unknown complex component

$N_i(r,z)$: 1st order interpolating functions

Over one finite element, above equation can be cast in the following

$$\sum_{i=1}^{3} u_i \int\int\left[Y\left(\frac{\partial N_i}{\partial r}\frac{\partial N_j}{\partial r} + \frac{\partial N_i}{\partial z}\frac{\partial N_j}{\partial z} + \frac{1}{r}N_i\frac{\partial N_i}{\partial r}\right) + ZN_i N_j\right]dr\,dz$$

$$= \int E_t N_j\, dl \quad where\ j = 1,2,3$$

where, $Y = (\sigma + j\omega)^{-1}$

$Z = j\omega\mu$

E_t : tangential component of the elemental boundary electric field

$H_\phi(r,z)$ can be decomposed into incident and reflected waves at the feed boundary.
Electric field is derived from

$$E_r = -\frac{1}{j\omega\varepsilon}\frac{\partial H_\phi}{\partial z}$$

$$E_z = \frac{1}{j\omega\varepsilon}\left(\frac{1}{r}\frac{\partial}{\partial r}rH_\phi\right)$$

SAR(Specific Absorption Rate) is obtained from using $E_t^2 = E_r^2 + E_z^2$

$$SAR = \frac{\sigma}{2}|E|^2 = \frac{\sigma}{2}(|E_r|^2 + |E_z|^2)$$

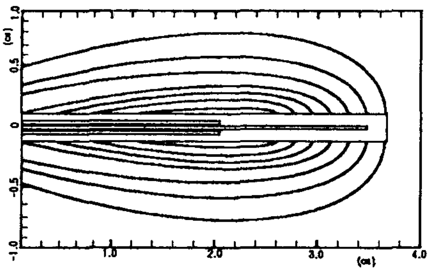
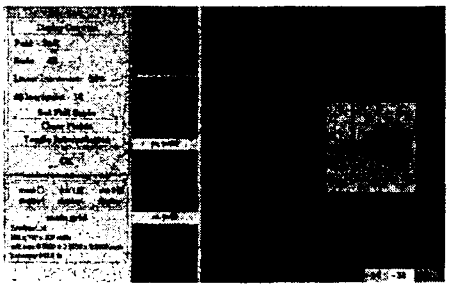


Fig. 1 Normalized SAR distribution

computer simulation is performed for $\varepsilon_r = 76$ using Remcom's xFDTD program. Simulation result shows similar to calculation result.



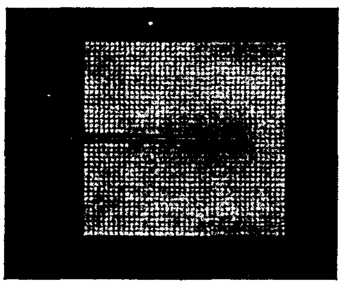


Fig. 2 SAR ditribution simulations for modified monopole antenna($\varepsilon = 76$)

4. Experiments

Liver Ablation experiments are performed for monopole antenna and two other modified monopole antennas. Experimental results show below table.

Modified monopole antennas did not show a significant difference when comparing lesion size. But, Antenna temperature shows higher than other two antennas.

When measurements are made with different step, time duration does not have as much of an effect on lesion size.

Blood flow has a substantial effect on lesion size. There are two options that can overcome this, either more power or a multiple antenna array.

Table 2 Cow Liver Ablation experiment

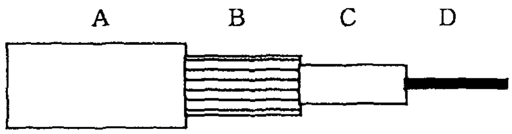
	Ant. A	Ant. B	Ant. C
Duration [Min.]	20	20	10
Fwd Pwr [W]	100	100	100
Cath Temp [C]	25.7	28.0	23.4
Ant Temp [C]	152.6	104.5	121.6
Lesion Length [cm]	6.0	5.0	3.0
Lesion Width [cm]	3.0	2.0	2.5
Lesion Depth [cm]	2.0	2.0	2.5

(a) Antenna A

(b) Antenna B

(c) Antenna C

Fig. 3 Antenna Design



A : Solid PTFE Jacket
B : S.P.C. served wire 38 AWG
C : Expanded PTFE Dielectric
D : S.P.C. Center Conductor

Fig. 4 Cable Specification

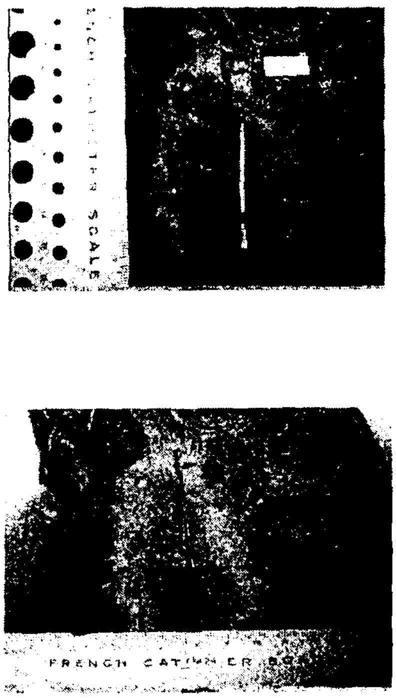


Fig. 5 Microwave Ablation treatment on Cow liver

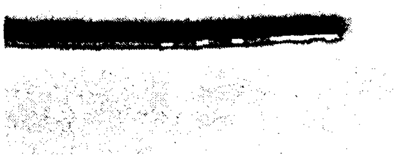


Fig. 6 Modified Monopole Antenna

5. Conclusion

Monopole antenna and modified monopole antenna were tested for liver ablation. The design of microwave ablation antenna requires determination of the electromagnetic fields in the catheter and tissue so that power is efficiently delivered to the liver tumor and not reflected back into the catheterat the design frequency. Other technical difficulties which must overcome include radiation due to leaky wave propagation in the catheter coating and a narrow probe bandwidth. Also, blood flow effect on lesion size so that multiple array antenna can be considered for wide spread of temperature distribution.

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