34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

A New Antenna System for Microwave Non-invasive Hyperthermia Lipolysis

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Abstract— **In this paper, we present an antenna system for microwave non-invasive hyperthermia lipolysis. The antenna system consists of a circular waveguide antenna radiating electromagnetic waves, AlN(Aluminum Nitride) radome and heat sink. The AlN radome with heat sink helps to extract heat from the skin to keep skin temperature not to rise during heating the lipolysis. The antenna was designed to be operated with TE_{21} mode to maintain uniform temperature over wider area. The usability of the proposed system was verified by performing numerical simulation and hyperthermia lipolysis experiments on rats.**

I. INTRODUCTION

For many years, ultrasound and microwave radiators have been used for hyperthermia treatment in many medical or biological areas such as cancer treatment, muscle therapies, and other diseases. The hyperthermia treatment or therapies exploit the fact that most biological tissues are stimulated, damaged or even dead at the temperature of over 41°C [1], [2]. In case of cancer treatment, the cancer cells can be killed by raising the cell temperature to over 41°C. The muscle treatment can be done by stimulating the muscle with temperature of above 41°C [3].

Recently, methods using ultrasound waves or microwaves to reduce subcutaneous fat without piercing the skin have been introduced as a painless solution to prevent obesity that may lead to diabetes, hyperlipidemia, arthritis and etc.

One of the challenges of these non-invasive methods is that the temperature of the skin enclosing the fat rises up faster than those of targeted fat because the skin always locates closer to the source of waves. The temperature rise of the skin may results in skin burn which may cause infections of other diseases or leave defects on skin beauty. This remains as a critical problem to both ultrasound and microwave non-invasive treatment methods. Otherwise, invasive method needs to be used, but it will also leave scars on the skin that may cause infections and skin defects.

In order to overcome this challenge, we propose an antenna system that can be used in microwave non-invasive hyperthermia lipolysis without leaving any skin burn. The antenna system consists of a circular waveguide antenna with AlN(Aluminum Nitride) radome that helps to extract the heats from the skin to the antenna heat sink during hyperthermia treatment. This confines the skin temperature to a certain temperature and thus, helps to avoid the skin burns. And the proposed antenna can make the temperature distribution in subcutaneous fat layer uniform by using TE_{21} mode instead of the fundamental mode(TE_{11}), which means that we can expand effective area for hyperthermia treatment and design a more compact antenna over conventional antennas [4]. We could treat subcutaneous fat of wider area only with a single antenna. With the proposed antenna system, hyperthermia experiment was performed on rats in order to prove the usability of the system.

II. ANTENNA DESIGN

The proposed antenna system consists of a circular waveguide antenna with a AlN radome at the aperture of the antenna and a heat sink at the back of the antenna as shown in Fig. 1(a). The bulk AlN has high electrical insulation (10^{14} $\Omega\cdot$cm) with high thermal conductivity (285 W/K/m). By contacting the AlN radome to the skin, we can electrically insulate between skin and antenna while extracting heat from skin to antenna efficiently so that it can protect from both an electric shock and thermal burn on skin while the system is operated. The heat collected by the radome from the skin will go to heat sink through the metal body of the antenna to air. The circular waveguide antenna was designed at 7.875GHz to propagate and radiate TE_{21} electromagnetic waves rather than the dominant TE_{11} mode to generate more uniform temperature distribution over the wide area. Fig. 1(b) shows both simulated and measured return loss of the antenna system. Since the aperture of the antenna was closed by bulk AlN whose dielectric constant is 8.8 and live body whose average dielectric constant is 45, the bandwidth in impedance wise is narrower compared to normal waveguide antenna.

In order to obtain temperature distribution, we have used commercial EM and thermal simulation tool based on FDTD numerical technique for a simplified rat body model. The simplified rat body model consists of three planar layers, skin, subcutaneous fat and muscle, whose thickness was assumed to be 2 mm, 7 mm and 15 mm, respectively, as shown in Fig. 2(a).

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*This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (2011-0007797).

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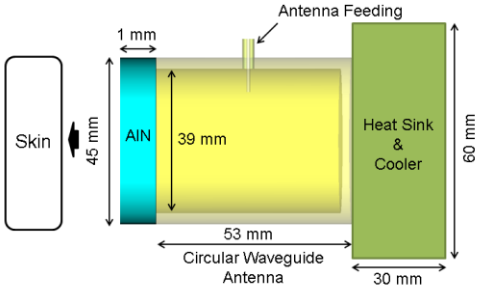
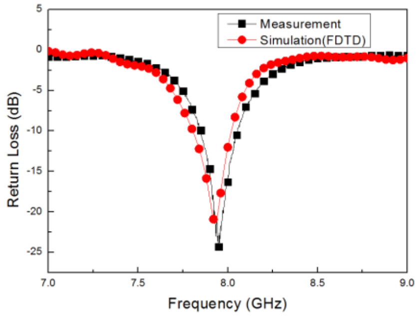
978-1-4577-1787-1/12/$26.00 ©2012 IEEE

In the figure, we can confirm that the skin temperature does not rise higher than fat temperature due to the cooling effect of the radome and heat sink. Fig. 2(b) shows the simulation result of the temperature distribution in the subcutaneous fat for both TE_{11}(Normal W/G antenna) and TE_{21}(Proposed antenna) modes for a comparison purpose. The asymmetry in thermal distribution is due to the asymmetry of feeding structure as shown in Fig. 2(a). In order to measure the uniformity of temperature we have defined a quantity, L_x and L_y, to be a distance between two 90% points of peak temperature in temperature profile in both orthogonal directions at the cross-section of the fat as shown in Fig. 2(c), assuming EM wave propagates into the (-)z-direction. By multiplying L_x and L_y, we can define an effective area with thermal distribution of Fig. 2(b) and Fig. 2(c) shows that the proposed antenna has 1.5 times wider uniform temperature area compared to that of normal waveguide antenna.

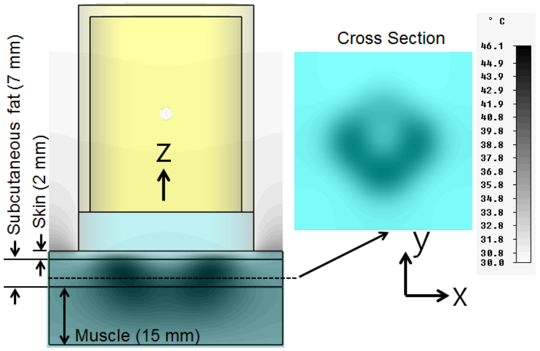


(a) Proposed antenna

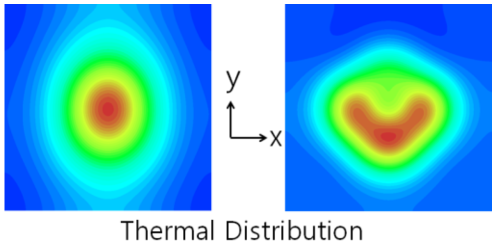


(b) Return Loss

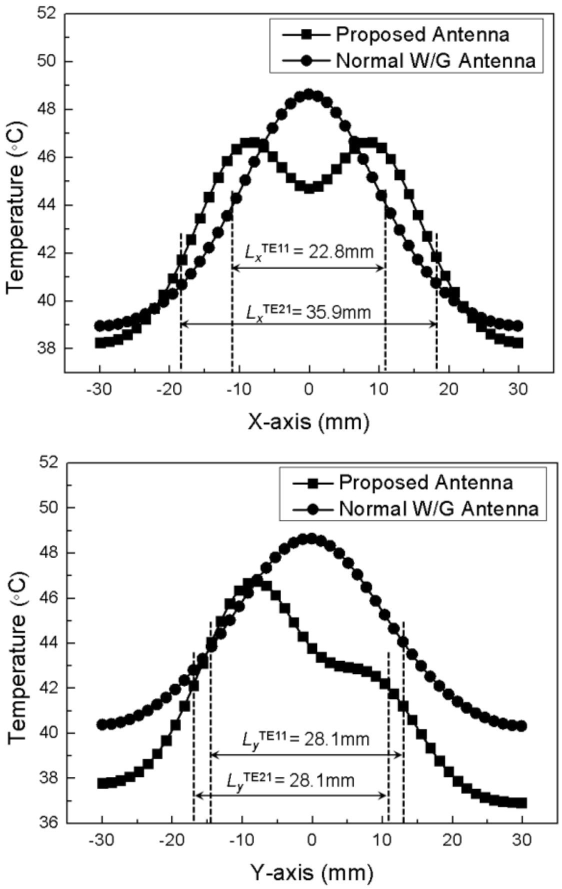
Figure. 1. Structure of proposed antenna for heating subcutaneous fat and return loss



(a) Simplified rat model with proposed antenna



(b) Thermal distribution in subcutaneous fat layer



(c) Effective Temperature length

Figure. 2. Electrical field distribution in waveguide, thermal distribution in subcutaneous fat and effective length; electrical and thermal properties are obtained from [5-7], L_x^{TE11} x L_y^{TE11}=640.7 mm^2, L_x^{TE21} x L_y^{TE21}=1008.8 mm^2.

III. EXPERIMENTS

In order to confirm the usability of the AlN radome, we measured the temperatures of fat, between skin and AlN, and antenna as shown in Fig. 3. We used thermocouples(JMTSS-010G-6) made in OMEGA for the temperature measurements. Fig 3 shows the measured temperature changes versus time during the experiment on pork. The thickness of the skin and fat of the pork used in this experiment was 2 mm and 8 mm, respectively. When the cooling fan is off, the skin temperature rises up according to fat temperature. However, when the cooling fan is on, the skin temperature drops down with antenna temperature to below 40°C while the fat temperature of the depth of 7 mm from the interface between the skin and AlN still rises and saturates to about 44°C. By controlling the velocity of the cooling fan, the cooling depth to be effective, from the interface between the skin and AlN, of less than 40°C may be changed.

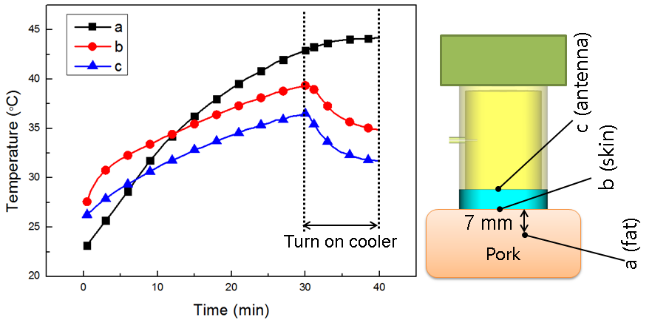


Figure. 3. Temperatures versus time when using pork

In order to set RF power level to support the fat temperature over 41°C, we performed several experiments with different power level on rats with thermocouples inserted into the interface between skin and fat, considering a burn of muscle due to thin subcutaneous fat. Fig. 4 shows the temperature change versus time for different RF power level and the gap between simulation and experimental results. Measuring directly the temperature in the subcutaneous fat of rats during this experiment was difficult. Because of this reason, we firstly found out the optimized power on the simulation with which showed suitable thermal distribution of 41~45°C for hyperthermia treatment. The temperature of the interface between the skin and subcutaneous fat in the simulation was compared with those from the experiment on rats as shown in Fig. 4. The temperature changes as time of using 3.0 watts in the simulation was similar to one of using 3.3 watts in the experiment on rats, so that we chose 3.3 watts for the rat lipolysis experiment.

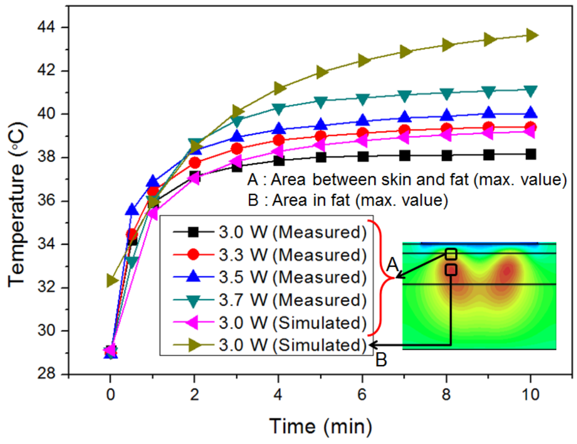


Figure. 4. Temperature change versus time for different RF power level

Fig. 5 shows the experiment set-up. The rat raised using high-fat feed made by Research Diets INC. was positioned on the support to make a good contact to the radome of the antenna system. We used three different Slc:SD strain rats for the experiment; rat A is anesthetized and treated four times for 15 minutes each time, rat B is anesthetized but not treated and rat C is not anesthetized nor treated. This experiment was approved by the Animal care and Use Committee of University of Seoul. Fig. 6 shows the normalized weight changes to the initial weight of the rats versus time. In the figure, the weight of rat A decreases rapidly and does not increase again for a while even after the treatment finishes while the weight of rat B starts increase after the treatment finishes, which means the fat of rat A is resolved and taken out thru metabolism. After the all resolved fat has been taken out, the weight starts increase again. The reason that the weight of rat B decreases during anesthesia is that the rat does not eat as much as when it is in normal due to the anesthesia. However, its weight starts to increase rapidly after the treatment because the fat is still in its body. The weight of Rat C steadily increases because no treatment was made. There was no damage or burn observed on the skin of the treated rat and the rat eats well after the treatment as it does before the treatment.

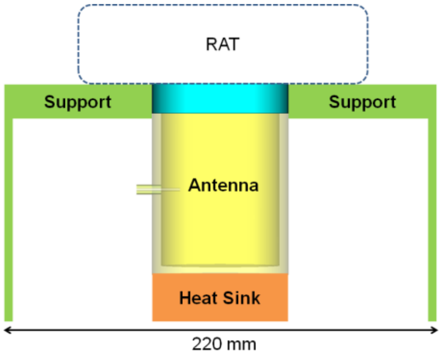


Figure. 5. Experiment set-up

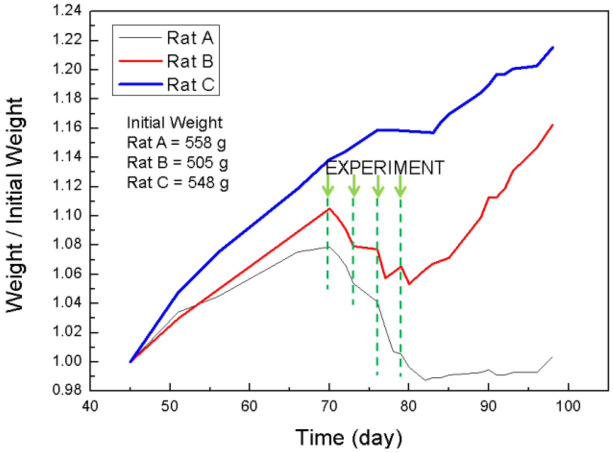


Figure. 6. Normalized weight of Rat A, B and C

IV. CONCLUSION

In this paper, we proposed an antenna system for non-invasive microwave hyperthermia lipolysis without leaving any skin burn by using AlN radome and heat sink at the back of antenna. And the proposed antenna can be applied to superficial cancers and breast cancer with more treatment area of about 1.5 times than normal W/G antenna. In order to verify the system, hyperthermia lipolysis experiment on rats was performed. The treated rat's weight was reduced compared to non-treated rat's weight without any damages on the skin. Although the treated rat eats well after the treatment as it does before the treatment, further biological study is necessary whether its internal organ is still healthy after the treatment. The number of rats for the experiments was not enough but we proved the proposed antenna system could be utilized to hyperthermia treatments.

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