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Microwave Hyperthermic Lipolysis Using External RF Antenna

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Abstract – In this paper, we propose a microwave hyperthermic lipolysis method to reduce subcutaneous fat without skin burn using external RF antenna. Since skin is closer to the antenna and has higher conductivity compared to the fat beneath, the temperature of the skin rises higher than that of the fat when the external antenna illuminates EM energy into a body, which may cause skin burn. In order to avoid the damages on skin, a skin cooling system is employed to the external antenna. The operating frequency is set at 5.8 GHz which is one of the ISM bands, to concentrate EM power efficiently on fat and not to heat up the muscle behind the fat. The operation time and RF power level has been determined based on experimental results with pork. The feasibility of the proposed method was shown by applying the method to the rat.

Keywords: Non-invasive hyperthermia, Lipolysis, Dielectric heat of adipose tissue

1. Introduction

Obesity has become more of a considerable issue nowadays due to lack of exercise, overeating, and genetic reasons. It can easily lead to diabetes, hyperlipidemia, arthritis, and even to cancer. Due to such high medical complication and for aesthetic reasons, hyperthermic lipolysis techniques using ultrasound wave [1], low frequency wave [2], and high frequency wave have been developed to treat obesity. Among these waves, high frequency wave is known to be safe due to its short periods in oscillation because it attenuates significantly before it reaches to internal organs and such characteristic allow treatments with least effects on internal organs as well as sensory or motor nerves during the treatment [3]. However, the use of high frequency wave has a drawback that the tissue closer to the wave source absorbs more energy and is heated up more rapidly than the target tissue, which results in the necessity of invasive treatment in order to avoid any skin burn.

We propose an non-invasive method to treat obesity by illuminating EM energy with a designed antenna which directly applies the energy to the fat layer without causing any damage on the skin. When electromagnetic waves reach the fat layer, vibration occurs within molecular level of the cells which increases temperature approximately over 41℃. Such temperature could increase blood flow and vascular dilation which improves metabolism and excretion of body wastes. The temperature above 41℃ could also destruct the fat tissue which later could be discharged through vessels or lymphs [4].

In this paper, we used pork to determine the appropriate input power for the proposed antenna and observed the temperature of the fat and skin. Later in the experiment, we used laboratory rats to determine whether this method of lipolysis is effective.

2. Design of antenna system

2.1 Frequency selection

In order to determine an appropriate frequency of the system, we calculated power loss density (PLD) at each layer of skin, fat and muscle using backward propagation matrix in multi-layered media [5] with an assumption that body consists of three planar layers, skin, fat and muscle. Fig. 1 depicts the three layer medium of body model. Muscle layer was assumed to be semi-infinite so that there exists only a transmitted field and no reflected field at the end plane of the muscle layer. This assumption is valid when the operating frequency is in microwave range because the fields will attenuates rapidly due to high lossy characteristic of muscle. In the simulation, the thickness of skin and fat was assumed 3mm and 20mm, respectively. Once the electric fields in all layers are obtained, the PLD in each material voxel can be calculated as

$$PLD = \frac{\sigma\left|\vec{E}\right|^2}{2} \tag{1}$$

where σ is the conductivity of the material voxel and E is the electric field in the material. The simulation was performed at three ISM band frequencies, 0.915 GHz, 2.4 GHz and 5.8 GHz with 1 V/m of an incident electric filed intensity for comparison purpose. The complex dielectric constants at each frequency are shown in the Table 1. Fig. 2 shows the PLD distribution in fat and muscle layers at the

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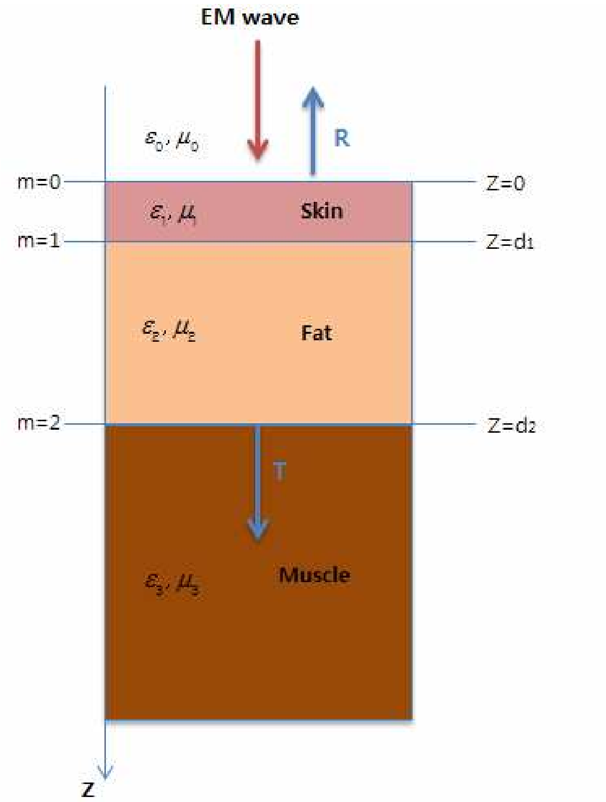

Fig. 1. Body Model with the Incident Wave

Table 1. The complex dielectric constant of ISM band

Frequency [GHz]	Skin	Fat	Muscle
0.915	41.3290 - j*17.1324	5.4596 - j*1.0103	54.9970 - j*18.6340
2.4	38.0630 - j*10.7954	5.2853 - j*0.7669	52.7910 - j*12.7759
5.8	35.1140 - j*11.5250	4.9549 + j*0.9089	48.4850 - j*15.3837

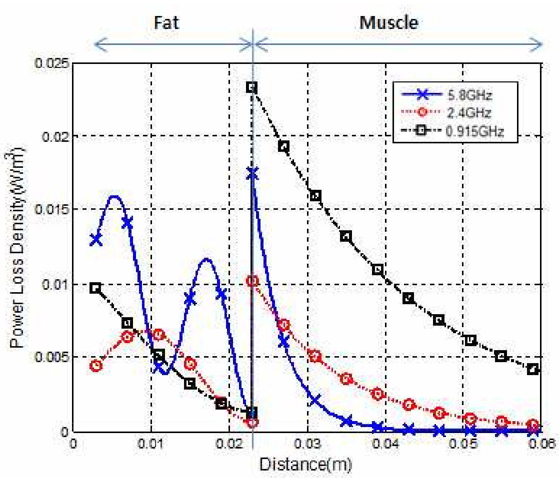

Fig. 2. Power Loss Density of Body Model

three frequencies. In the figure, we can observe that the PLD at 0.915 GHz and 2.4 GHz are lower than that at 5.8 GHz in the fat layer. In muscle layer, PLD at 5.8 GHz is smaller than those at other frequencies because lower frequency wave can penetrate further than higher frequency. Therefore, 5.8 GHz is the best frequency among the three ISM frequencies because it gives higher PLD at fat layer and lower PLD at muscle layer. Further simulation showed 5.8 GHz is the best frequency if the fat thickness is less than 30mm while 2.4 GHz is the best one if the fat is thicker than 30mm. For the rat experiment, 5.8 GHz is chosen as the operating frequency.

2.2 Proposed antenna system

When an external antenna illuminates EM energy into a body, the EM energy travels through the skin layer to reach the fat layer. Since the skin has higher complex permitivity than the fat as is shown in Fig. 3, the skin easily absorbs more EM energy than the fat does. This indicates that the temperature increase rate of the skin is greater than that of the fat, which can cause thermal damage on the skin. In order to prevent such possible damages on the skin layer, we need to add an air cooling system in the antenna to lower the temperature of the skin below a certain level while keeping the temperature of fat in an appropriate range of temperature.

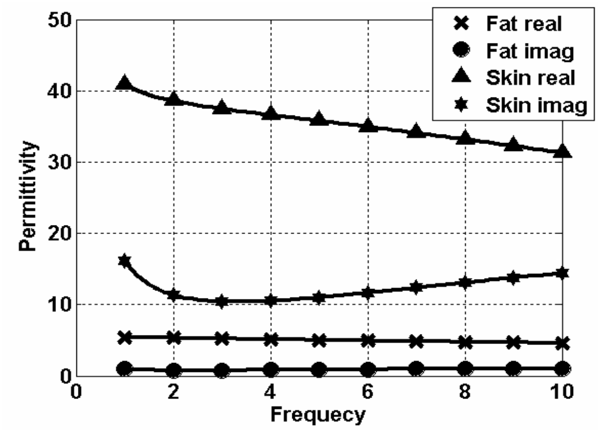

Fig. 3. Relative permitivity of fat and skin

For this, a special antenna was designed with a fan along with a motor on its back as shown in Fig. 4. It has a lot of small holes for effective air flow. The hole size and quantity was selected such that the leakage power through the holes is less than 0 dBm when the input power from the antenna feed is 30 dBm. In this study, we punched 9 holes in a wavelength whose diameter is 3 mm, which gives more than 30dB shield effectiveness. The feeder is designed with a loop antenna. The TE11 mode is propagated in circular waveguide antenna. The antenna has to be in direct contact with the skin to minimize power leakage through the gap between antenna and skin. In order to avoid electrical conduction from the antenna to the skin, antenna was coated with thin insulating paint. Fig. 5 shows the return loss of the antenna and the resonance frequency which is 5.83 GHz when the antenna was directly contacted to the body. Fig. 6 shows power density distribution around the antenna. The simulation was performed using a FDTD tool.

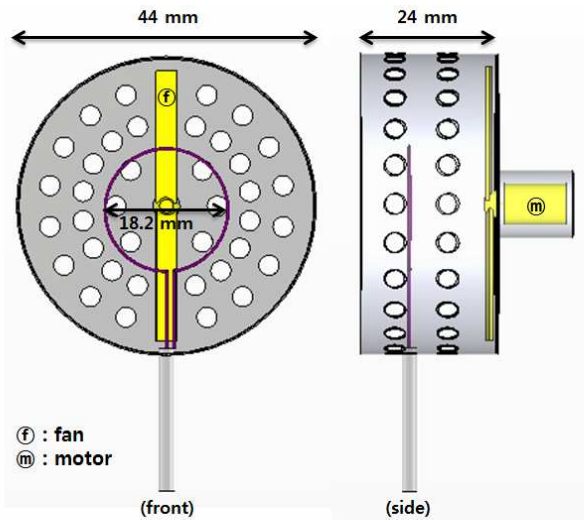

Fig. 4. Waveguide antenna with cooling system: (a) Front; (b) Side

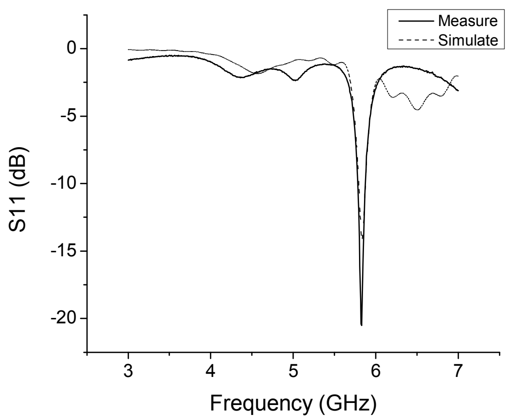

Fig. 5. Return loss of the antenna on the body

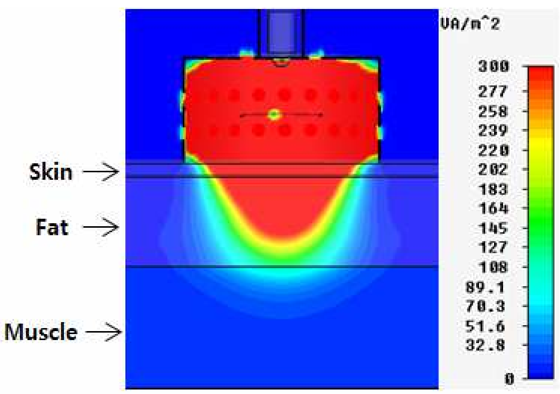

Fig. 6. Power density distribution of body model

3. Experiment using pork and rats

3.1 Pork experiment

Pork was used for initial feasibility of fat decomposition with the proposed antenna. Fat decomposition could be determined by comparing the weight of fat after extracting liquidized fat with the initial weight of the fat since the fat tissue melts with thermal heating. Since it is known that melting point of the fat is about 41℃ and the temperature over 45℃ may cause normal tissue destruction, the fat temperature was kept between 41℃ and 45℃ during treatment. After the treatment, the pork was squeezed to remove liquidized (decomposed) fat and weighed to see the difference from the initial weight.

In order to find an effective RF power that needs to be illuminated by the antenna, the temperature of the fat was measured with thermocouples while changing the input power of the antenna from 3 watts to 6 watts by one watt step. The result is shown in Fig. 7. The temperature did not reach 40℃ with 3 watts even for 35 minutes of heating. The temperature with powers more than 4 watts reaches to 41℃ within 30 minutes. Considering the safety of live tissue and keeping the temperature between 41℃ and 45℃ for a while, we chose 4 watts as illuminated power for further experiments.

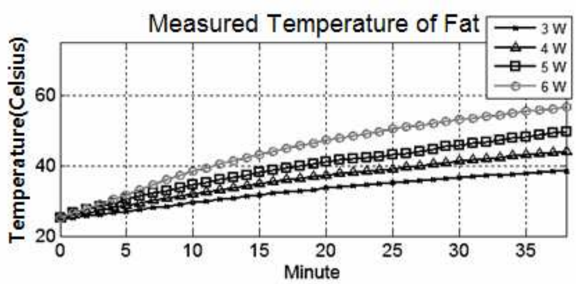

Fig. 7. Temperature curve of the fat with different input power

Not only for the determination of the input power, the pork experiment was used to determine the appropriate amount of time for the treatment. Table 2 shows the weight changes for different exposure time maintaining the fat temperature between 41℃ and 45℃. The first 10 minutes of the exposure time gives higher weight reducing rate of

Table 2. Fat loss versus experiment time when exposed to 41℃

Experiment time [Min]	Initial weight [g]	Final weight [g]
5	50	41
10	50	36
15	50	33
20	50	32

the fat than any longer exposure time. Therefore, the exposure time for further experiments was set 10 minutes at around 41℃ with 4W of antenna input power.

In order to protect the skin from any burn, cooling system was mounted on the antenna. The temperatures of the fat and skin were individually checked with thermocouples. Fig. 8 shows the temperature of the fat and skin during the treatment with a cooling system. The skin temperature was kept around 32℃ while the fat temperature reached around 41℃, which proves the effect of the cooling system.

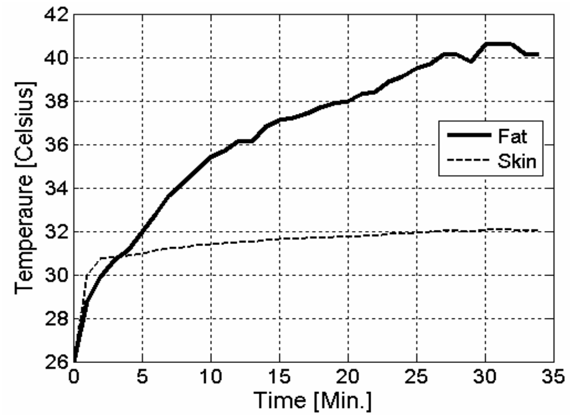

Fig. 8. Temperature Curve of the Fat and the Skin on Pork

3.2 Obese rat experiment

We used a female Zucker rat that is 8 weeks old. The experiment was carried on for two weeks; the first week with 30 minutes of treatment everyday and the second week with weight observation only. The 30 minutes of treatment time includes the rising time to reach at 41℃ of the fat temperature. The rat received obese-induced diet throughout the experiment. The operating frequency was 5.8 GHz and input power was 4W. Fig. 9 shows the setup of this experiment. The skin temperature was monitored using thermocouple to make sure it was kept under 38℃. Fig. 10 shows the weight observation of the rat during the experiment. In the figure, 'without treatment' shows weight gain of normal female Zucker rat provided by Zucker rat seller. Since the rat was not fully grown, the overall weight increase during non-treating period is expected to follow the 'without treatment' curve. The figure shows the weight increase rate is significantly lowered during the period of treatment and slowly back to normal rate after the treatment is stop, which shows the feasibility of the proposed technique.

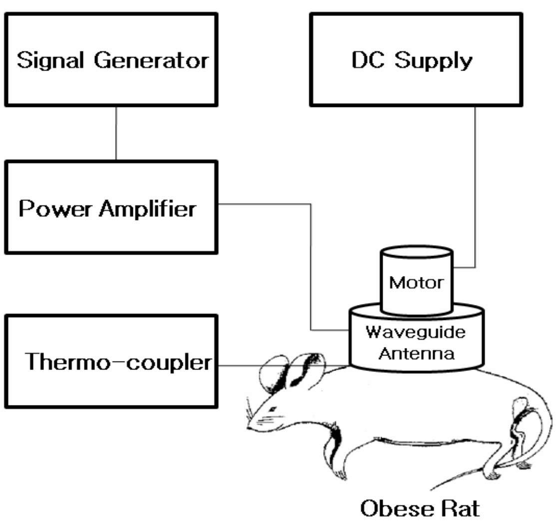

Fig. 9. Diagram of the experiment

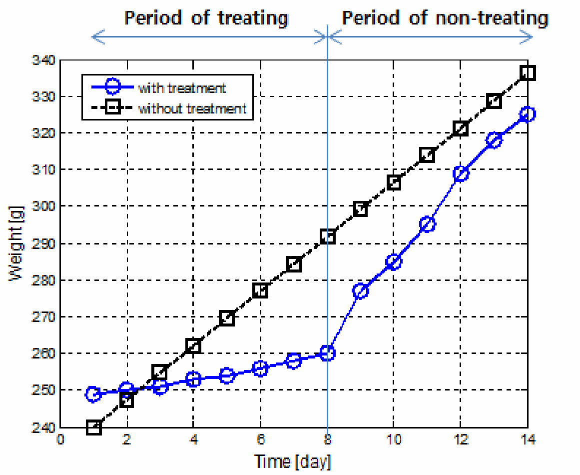

Fig. 10. Weight observation of the obese rat over time

3.3 Three groups of the rats each with specific condition

For further experiment, nine Sprague-Dawley rats, all 8 weeks old from Charles River Laboratory Inc. U.S.A. were divided into three groups evenly. As shown in Table 3, the 1st and 2nd group received the treatment while the 3rd group received only anesthetic. The 1st and 3rd group received normal diet after the treatment but the 2nd group received obese-induced diet throughout the entire experiment. The experiment took 2 weeks. The treatment was given for 30 minutes every other day for the first 7 days along with weight observation and only weight was observed weight for the next 7 days. The weight variation during the experiment is shown in Fig. 11. The 3rd group slightly decreased in its weight only up until the 7th day which may reveal that only given anesthetic could cause

Table 3. Experiment Condition for Each Group

Group	Before Diet	Treat/ Anesthetic	After Diet	Number
1st	Obesity	Treat	Normal	3
2nd	Obesity	Treat	Obesity	3
3rd	Obesity	Anesthetic	Normal	3

the loss of weight due to stress or any other factors. Until the 7th day, both group received treatment decreased their weight more rapidly than the group that received only anesthetic.

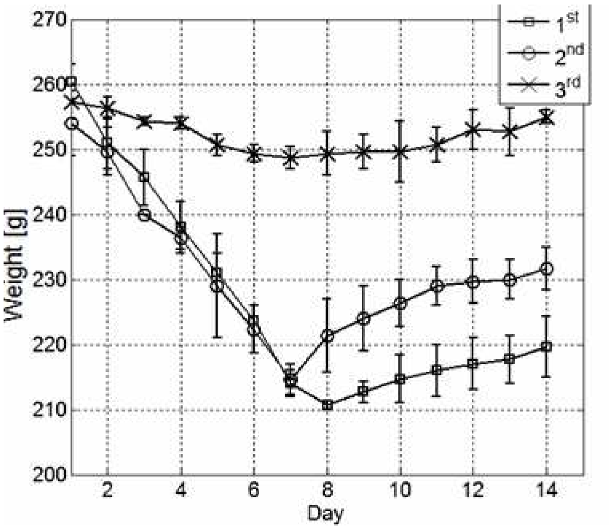

Fig. 11. The Weight Variation of the Three Groups

4. Conclusion

The proposed technique is to decompose the fat tissue by increasing its temperature while the skin is protected with a cooling system. The operating frequency was chosen so that RF power would not invade the inner muscle tissue but the fat tissues right beneath the skin. The purpose of the cooling system is to protect the skin efficiently from thermal damages when the microwave power is applied by the proposed antenna. From the pork experiment, ideal input power of the antenna was chosen by monitoring temperature of the fat and skin of the pork. In experiment with an obese rat, the treatment was given to a Zucker rat for 30 minutes every day for a week, which lowers the weight increase rate of the rat. Lastly, from the experiment with three groups of rats, the treatment group rapidly lost their weight while given the treatment. Therefore, it is clearly shown that this non-invasive hyperthermic lipolysis using microwave is effective.

Acknowledgements

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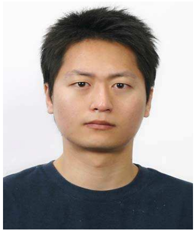

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