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# Experimental Study of Microwave Ablation in Ex Vivo Tissues

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**Abstract**. Cancer is one of the leading causes of morbidity and mortality worldwide. Microwave ablation is a minimally invasive treatment procedure that uses heat from microwave energy to destroy cancer cells. The effectiveness of this technique is associated to the microwave power input and heating time of treatment during the process, as well as the type of cancer tissue. The microwave power absorbed of each cancer tissue type is different and effect on the choice of treatment conditions. This research aims to investigate the effects of tissue type and microwave power input on the temperature profile and the efficiency of cancer treatment during microwave ablation. An experiment in ex vivo different tissues of porcine during microwave ablation via microwave antenna is studied. The types of tissue studied include skin tissue, liver tissue and lung tissue. The microwave power input of 60 W, 80 W and 100 W are investigated. The heating time of 360 s is selected for the study. An infrared thermometer camera is used to measure the temperature profile of tissues. The results reveal that the temperature profile and the ablation size in the case of skin tissue are higher than the liver tissue and lung tissue, respectively. In addition, the temperature profile of all tissues increases with greater microwave power. This research provides the essential aspects for a fundamental understanding of heat transfer within porcine tissues in microwave ablation process and can be used as a guideline to improve the efficiency of cancer treatment.

## 1. Introduction

Nowadays, there are many people diagnosed with cancer and several factors contributing to the increase in cancer. In 2015, the death rate of cancer patients worldwide is as high as 8.8 million. For Thailand, cancer is the major cause of death among Thais for decades. The most common cancer is liver cancer, which has 6,596 cases of patients. Men have a higher incidence of liver cancer than women [1]. Smoking habits are the main cause of lung cancer. For one particular category of smoker, it is found that there is a 10 % chance of lung cancer [2]. There are many ways to treat cancer such as surgical resection [3], chemoembolization therapy [4] and radiation therapy [5] etc. All of the above methods have different advantages and limitations. Microwave ablation techniques have become an extensive choice for the treatment of cancer [6-7]. The key advantages of microwave ablation are consistently higher intratumoral temperatures, larger tumor ablation volumes and shorter treatment times include less susceptibility to the cooling heat-sink effects of air and blood flow [8]. There are few side effects in treatment and spent shortly time recuperating after treatment and the patient has a high opportunity of survival. The principle of microwave ablation is to pass the microwave energy to the tumor that needs to be removed by using a small microwave antenna insert into tissue that is cancerous. The new microwave ablation technique for cancer treatment is different from traditional treatments. The goal of microwave ablation treatment is to raise the temperature of the unwanted tissue (tumor) to therapeutic value of 50 °C to kill cancerous tissues within the body and affect metastases without the danger in nearby tissue [9]. Therefore, the topic of heat transfer as well as temperature distribution in human tissue for improved efficiency of microwave ablation treatment of cancer has been of interest for several years.

Research and academic papers on the process of destruction of cancer cells using microwave energy are widely. The research involved is divided into three groups are 1) Research and study on the destruction of cancer cells using microwave energy by tissue experiment 2) Research and study on the destruction of cancer cells using microwave energy by computer simulation and 3) Research and study on the destruction of cancer cells using microwave energy by tissue experiment and computer simulation. Research paper in the first group, such as Peralta H et al. [10] compared the surgery microwave ablation in ex vivo and in vivo with a similar microwave frequency. The experiment based on microwave power input of 50 W, 100 W and 150 W at heating time of 8 min. It was found that the size of the wounds from the microwave ablation in vivo surgery is larger than ex vivo surgery. In 2016, Liu W [11] reported a multi coaxial-slot antenna to form a figure-of-eight ablation area during microwave ablation. The microwave antenna worked at 2.45 GHz and also has a good impedance matching. In addition, the microwave antenna can solve the specific shape of the tumor and to realize a large ablation pattern, meanwhile has lesser damage to body (for the outer radius of the coaxial-slot antenna is less than 4 mm). Amabile C et al. [12] studied the microwave ablation of primary and secondary liver tumours with ex vivo, in vivo and clinical characterization. The experimental results found that the ex vivo data on bovine liver was more predictive of the actual clinical performance on liver malignancies than an in vivo porcine. The study of destroying liver cancer cells using microwave energy in the tissue to control the temperature distribution and monitor the impact on the tissues was proposed by Lopresto V et al. [13].

In the computational studies, the Pennes bioheat model is widely used for modeling the heat transfer in human tissues during microwave ablation due to simplification approach [14]. Wu X et al. [15] evaluated the effect of high frequency microwave antenna at 6 GHz and 18 GHz applied to liver cancer therapy against conventional microwave antenna at 915 MHz and 2450 MHz by a finite element model coupled electromagnetic field and bio-heat transfer equation. Tissue damaged region, temperature rise and distribution characteristics were analyzed. The results showed that the high frequency microwave antenna can cause less collateral damage, more concentrated ablation region and better material response than conventional microwave antenna. A thermoelastic deformation model of tissue contraction during thermal ablation was presented by Park C S et al. [16]. A finite difference method was considered to quantify the tissue contraction for a typical temperature distribution during thermal ablation.

Some previous studies on the destruction of cancer cells using microwave energy by tissue experiment and computer simulation were presented. Curto S et al. [17] developed a three-dimensional model of electromagnetic-thermal bioheat transfer with the finite element method to characterize power deposition and thermal ablation with asymmetrical insulated dipole antennas (single-antenna and dual-antenna synchronous arrays). Simulation results were validated against experiments in ex vivo tissue. In 2017, Deshazer G et al. [18] examined any differences of specific absorption rate (SAR) profile between predicting by simulation and computing from experimentally measured temperature profiles with an infrared (IR) camera. The SAR profile during the experimental microwave ablation changed, which were not present in simulation, suggesting inaccuracies in dielectric properties. In 2018, Ibitoye A Z et al. [19] studied the characteristics and features of four antennas (monopole, single slot, dual slot and sleeved antennas) for microwave ablation therapy to compare their efficiencies using analytical and experimental methods. The simulation was done to evaluate its reflection coefficient, power dissipation distribution, power dissipation density, SAR distribution and temperature distribution in tissue. The experiment was done on ex vivo bovine livers using 50 W lasting for 5 min and 10 min to determine ablation diameters, ablation lengths and aspect ratio. The sleeved antenna provided the best localization with the highest aspect ratio, the highest temperature distribution, large ablative diameter and the lowest backward heating.

Even though there are many researchers studied about microwave ablation in many years ago, a few studies on the effects of difference of tissue types and microwave power input in order to determine the efficiency of microwave ablation process by calculating ablation zone have done. In this study, the effects of tissue types and microwave power input on the temperature profile and the efficiency of cancer treatment during microwave ablation are presented. The variations in three tissue types: skin tissue, liver tissue and lung tissue of porcine are investigated. The microwave power input of 60 W, 80 W and 100 W for the duration of 360 s are studied. The obtained values will provide a basis for the development of microwave ablation process for tissues and organs.

## 2. Experimental Study

This section divided into two parts explains about the experiment consisting of experimental equipment and tissue samples and experimental setup.

### *2.1. Experimental equipment and tissue samples*

Experiments are performed in ex vivo porcine skin tissue, liver tissue and lung tissue with a microwave applicator. The experimental equipment used in the experiment is as follows: 1) Microwave ablation system: is a microwave generator (Acculis, AngioDynamics, 60-140 W, 2.45 GHz) as shown in Figure 1. Microwave generator is connected to the microwave antenna. Microwave energy generated by microwave generator propagates in microwave antenna into the tissue from the slot to destroy cancerous tissue. 2) Microwave antenna: is a device for transporting microwave energy to a region where required to heat. The temperature of unwanted tissue (tumor) at a level above of 50 °C can effectively kill cancer cells [20-21]. The microwave antenna used in this experiment (Accu2i PMTA Applicator) is 19 cm length operating with internally cooled system for releasing internal heat as shown in Figure 2. 3) Fiber optic thermometer: is a temperature-measuring instrument. It has many advantages: capable of measuring the temperature in microwave heating process without any reaction and noise, capable of measuring the temperature in localised region and can show the difference between each measured points. In this experiments, fiber optic thermometer (FOT Lab Kit, LUXTRON) is 4-channel optic sensor which is 4-20 mA or 0-10 VDC output and able to measure the temperature in range of -100 °C to 330 °C and record data in PC software. 4) Infrared thermometer camera: is a device that captures infrared radiation (IR) emitting from an object to surroundings and forms a heat zone image. In the image, the hotter region is represented by dark color and the cooler region is represented by bright color. IR is a result of atom and molecular vibration and behaves like visible lights. The more molecules move will result in more temperature increases. Infrared thermometer camera will show a temperature profile of tissues after microwave ablation process. In addition, 5) Other devices include computer for recording data, thermometer knife and chopping board and temperature controlled ice bucket.

**Figure 1.** Microwave ablation system
(at Center of Scientific Equipment for Advanced Research, Thammasat University).

**Figure 2.** Microwave antenna.

In this research, the effects of three tissue types i.e. skin tissue, liver tissue and lung tissue on the temperature profile and the efficiency of cancer treatment during microwave ablation are studied. Each type of tissues has three samples for three microwave power inputs setting. Required each piece of tissue sample used is shaped as a rectangular prism with dimensions of 6 cm x 8 cm x 6 cm. Tissue samples are cooled to 10 °C in a temperature controlled ice bucket.

### *2.2. Experimental setup*

Microwave ablation experiments are performed in ex vivo porcine tissue i.e. skin tissue, liver tissue and lung tissue. The experiment starts with the preparation of the tissue sample with size of 6 cm x 8 cm x 6 cm as shown in Figure 3. Then, immerse it in temperature controlled ice bucket that the initial temperature is equal to 10 °C. To validate the fiber optic, measure the temperature of water by the thermometer and the fiber optic cable to compared the temperature results as shown in Figure 4. For microwave ablation, a microwave antenna is inserted into a tissue sample to release microwave energy. Microwave antenna is inserted to a depth of 7.5 cm as shown in Figure 5. Microwave generator (Acculis, AngioDynamics) supplied microwave energy at the frequency of 2.45 GHz, which is amplified microwave power input of 60 W, 80 W and 100 W to the tissue sample. Connect the fiber optic cable to the tissue sample, set microwave antenna on the tissue sample and placed tissue sample in a bath. Then, turn on the microwave generator. For ex vivo experiments, microwave power input of 60 W, 80 W and 100 W are applied to each tissue for duration of 360 s as shown in Figure 5. The position of fiber optic cable is shown in Figure 6. Read and record the temperature from the fiber optic cable. After the microwave ablation process, take a temperature profile with infrared thermometer camera. Measure the ablation diameter and compute the ablation size. The experimental diagram is shown in Figure 7.

**Figure 3.** Prepare tissue sample.

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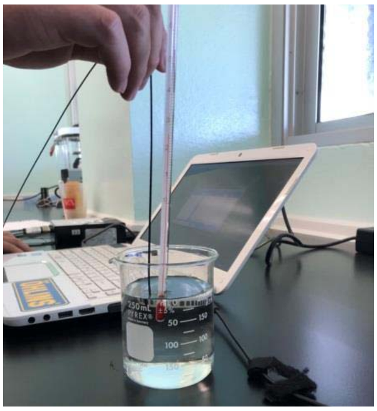


**Figure 4.** Compare the temperature of water from the thermometer to the fiber optic cable.

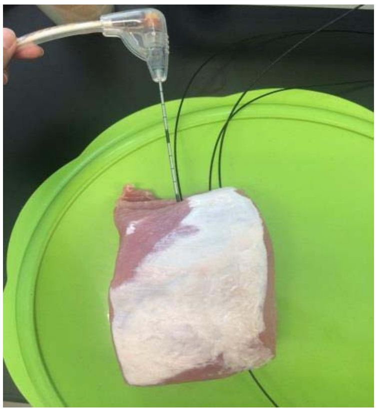


**Figure 5.** Tissue sample during experiment.

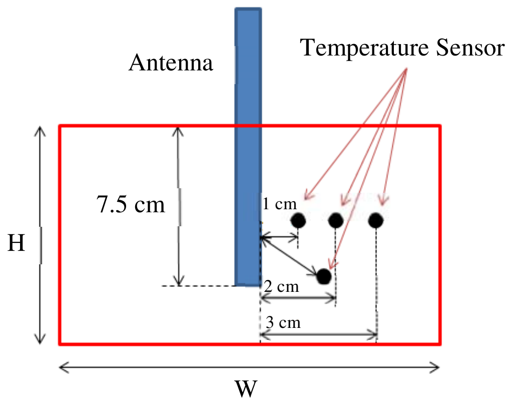



**Figure 6.** Position of antenna and fiber optic cables.

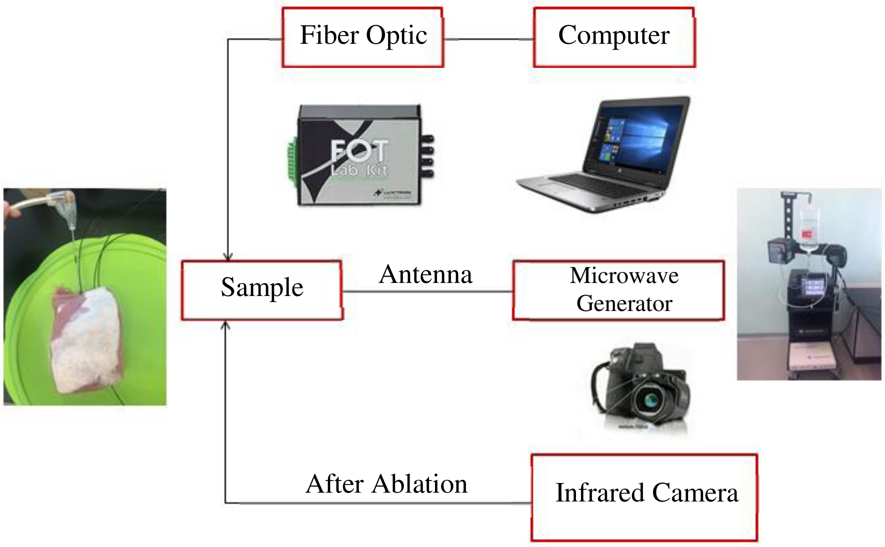



**Figure 7.** Experimental diagram.

In addition, the dielectric properties of skin tissue, liver tissue and lung tissue are measured using network analyzer (E5063A ENA Series) at frequency of 2.45 GHz in this study. The dielectric properties of skin tissue, liver tissue and lung tissue are exhibited in Table 1.

**Table 1.** The dielectric properties of skin tissue, liver tissue and lung tissue at frequency of 2.45 GHz.

| Tissues | Dielectric Properties | |
|---|---|---|
| | Dielectric Constant, $\varepsilon'$ (F/m) | Dielectric Loss Factor, $\varepsilon''$ (F/m) |
| Skin Tissue | 54.20 | 17.97 |
| Liver Tissue | 48.90 | 14.44 |
| Lung Tissue | 30.01 | 7.10 |

## 3. Results and Discussion

In this study, the effects of the two parameters, namely, the types of tissue (skin tissue, liver tissue and lung tissue) and the microwave power input (60 W, 80 W and 100 W) have been investigated. A parametric study has been performed to estimate the effects of each of these variables and analyze their contributions in the temperature profile and the efficiency of cancer treatment during microwave ablation. Due to the actual ablation zone covers tissue areas where temperature exceeds 50 °C [20-21], the temperature of 50 °C as a threshold as tissue discoloration could be visually observed and measured for calculating the ablation size. In addition, the target ablation diameter of 2 cm and target ablation volume of 4.2 $cm^3$ are considered in this study [22].

The ablation zones in ex vivo skin tissue during microwave ablation with a single microwave antenna operating at 2.45 GHz at different microwave power inputs for duration of 360 s are shown in Figure 8. Figure 8(a)-8(c) show the ablation zones of the skin tissue at the microwave power inputs of 60 W, 80 W and 100 W, respectively. These figures illustrate the volumetric heating effect expected from microwave ablation, where a hot spot zone occurs at the position near the end tip and the slot of the microwave antenna. Microwave delivered from the antenna propagates inside the tissue and is transformed into the thermal energy by electromagnetic heating. The ablation zone curves form a nearly ellipsoidal shape around the slot and its highest value of temperature near the antenna slot. It then decreases with the distance from the antenna. The ablation zones within the skin tissue in the case of a higher microwave power provides a broader area of heat dissipation to the surrounding tissue near the slot of the antenna compared with result in the case of lower microwave power. Table 2 shows the dimensions of measured ablation diameter and ablation volume for different microwave power inputs in ex vivo skin tissue during microwave ablation.

The surface temperature profiles in ex vivo skin tissue during microwave ablation with a single microwave antenna operating at 2.45 GHz at different microwave power inputs for duration of 360 s are shown in Figure 9. Figure 9(a)-9(c) display the surface temperature profiles of the skin tissue at the microwave power inputs of 60 W, 80 W and 100 W, respectively. These figures show that the surface temperature profiles which correspond to the ablation zones quite well. The temperature profile within the skin tissue in the case of a higher microwave power provides a broader area of heat dissipation with higher temperature to the surrounding tissue near the slot of the antenna compared with result in the case of lower microwave power correspond to characteristic of the ablation zone.

The effects of microwave power input on the ablation zones in ex vivo liver tissue during microwave ablation with a single microwave antenna operating at 2.45 GHz for duration of 360 s are shown in Figure 10. Figure 10(a)-10(c) illustrate the ablation zones of the liver tissue at the microwave power inputs of 60 W, 80 W and 100 W, respectively. In the same way with the skin tissue, the ablation zone curves form nearly ellipsoidal shape around the slot. The highest value of temperature near the antenna slot and decreases by distance from the antenna. The ablation zones within the liver tissue in the case of a higher microwave power provides a broader area of heat dissipation to the surrounding tissue near the slot of the antenna compared with result in the case of lower microwave power. Table 2 lists the dimensions of measured ablation diameter and ablation volume for different microwave power inputs in ex vivo liver tissue during microwave ablation correspond to the skin tissue. It is however found that the experiment results of ablation zones and temperature pattern of skin tissue has a higher ablation volume of heat dissipation than the liver tissue. This is because the dielectric properties of skin tissue are higher than the liver tissue that becomes the reason of higher absorption of microwave energy as shown in Table 1.

Figure 11 shows the surface temperature profiles in ex vivo liver tissue during microwave ablation with a single microwave antenna operating at 2.45 GHz at different microwave power inputs for duration of 360 s. Figure 11(a)-11(c) show the surface temperature profiles at the microwave powers of (a) 60 W, (b) 80 W and (c) 100 W, respectively. These figures show that the surface temperature profiles which correspond to the ablation zones quite well. The temperature profile within the liver tissue in the case of a higher microwave power is higher than the case of lower microwave power that corresponds to in case of skin tissue. It is found that the temperature profiles in case of liver tissue have the same pattern with temperature profiles when compared with results for skin tissue. However, the temperature profiles for skin tissue provides a broader area of heat dissipation compared with results for liver tissue because the dielectric properties as shown in Table 1.

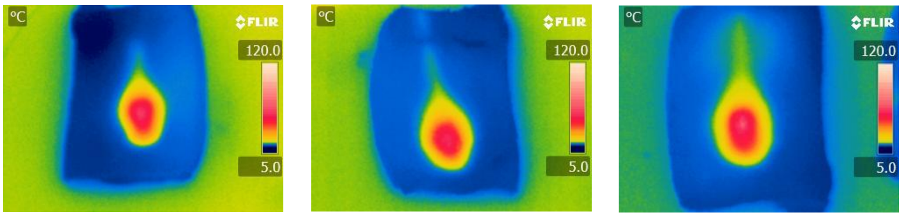
The last section discusses the effects of input microwave power on the ablation zones in ex vivo lung tissue during microwave ablation with a single microwave antenna operating at 2.45 GHz for duration of 360 s are shown in Figure 12. Figure 12(a)-12(c) illustrate the ablation zones of the lung tissue at the microwave power inputs of 60 W, 80 W and 100 W, respectively. Similar to the case of skin and liver tissues, the ablation zones of ex vivo lung tissue curves form nearly ellipsoidal shape around the slot. The highest value of temperature nears the antenna slot and decreases with the distance from the antenna. The higher microwave power generates the broader area of heat dissipation occurs. Table 2 illustrates the dimensions of measured ablation diameter and ablation volume for different microwave power inputs in ex vivo lung tissue during microwave ablation correspond to the skin and liver tissues. From Table 2, it can be seen that the ablation zones and temperature pattern of skin tissue has a higher ablation volume of heat dissipation than the liver tissue and lung tissues, respectively. This is due to the skin tissue has higher dielectric properties than the liver tissue and lung tissues, respectively which are the reason of highest absorption of microwave energy as shown in Table 1.

The surface temperature profiles in ex vivo lung tissue during microwave ablation with a single microwave antenna operating at 2.45 GHz at different microwave power inputs for duration of 360 s are shown in Figure 13. Figure 13(a)-13(c) indicate the surface temperature profiles of the lung tissue at the microwave power inputs of 60 W, 80 W and 100 W, respectively. These figures show that the surface temperature profiles which correspond to the ablation zones quite well. The temperature profile within the lung tissue in the case of a higher microwave power provides a broader area of heat dissipation with higher temperature to the surrounding tissue near the slot of the antenna compared with result in the case of lower microwave power correspond to characteristic of the ablation zone. Once again, the findings revealed that the temperature profiles in case of lung tissue have the same pattern with temperature profiles in case of skin and liver tissues. When comparing temperature profiles in three tissues, it is observed that the temperature profiles for skin tissue provides a broadest area of heat dissipation compared with other tissues due to the dielectric properties as shown in Table 1. The comparison of the ablation zone size and ratio of ablation for each cases are illustrated in the Table 2.

The results in this Table 2 exhibit that the ablation volume in the case of skin tissue is higher than liver tissue and lung tissue, respectively, at the same microwave power input. In addition, the ablation volume of tissues increases with greater microwave power.

(a) (b) (c)

**Figure 8.** The ablation zones in ex vivo skin tissue operating at 2.45 GHz for duration of 360 s at different microwave power inputs of (a) 60 W, (b) 80 W and (c) 100 W, respectively.

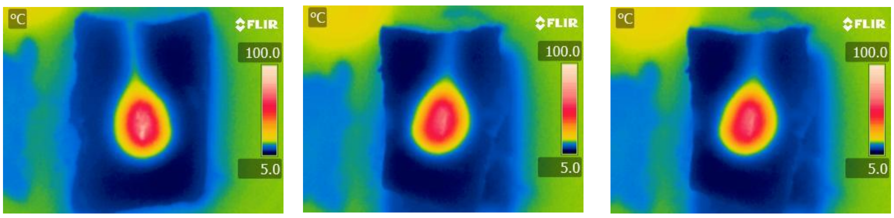



(a) (b) (c)

**Figure 9.** The surface temperature profiles in ex vivo skin tissue operating at 2.45 GHz for duration of 360 s at different microwave power inputs of (a) 60 W, (b) 80 W and (c) 100 W, respectively.

(a) (b) (c)

**Figure 10.** The ablation zones in ex vivo liver tissue operating at 2.45 GHz for duration of 360 s at different microwave power inputs of (a) 60 W, (b) 80 W and (c) 100 W, respectively.

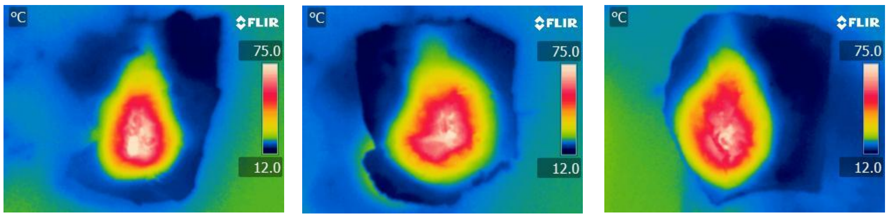


(a) (b) (c)

**Figure 11.** The surface temperature profiles in ex vivo liver tissue operating at 2.45 GHz for duration of 360 s at different microwave power inputs of (a) 60 W, (b) 80 W and (c) 100 W, respectively.

(a) (b) (c)

**Figure 12.** The ablation zones in ex vivo lung tissue operating at 2.45 GHz for duration of 360 s at different microwave power inputs of (a) 60 W, (b) 80 W and (c) 100 W, respectively.




(a) (b) (c)

**Figure 13.** The surface temperature profiles in ex vivo lung tissue operating at 2.45 GHz for duration of 360 s at different microwave power inputs of (a) 60 W, (b) 80 W and (c) 100 W, respectively.

**Table 2.** Comparison of the ablation zone size and ratio of ablation for each cases.

| Tissues | Power (W) | Time (s) | Target Ablation Diameter (cm) | Ablation Diameter (cm) | Target Ablation Volume ($cm^3$) | Ablation Volume ($cm^3$) | Ratio (Ablation Volume/ Target Ablation Volume) (-) |
|---|---|---|---|---|---|---|---|
| Skin Tissue | 60 | 360 | 2.0 | 2.4 | 4.20 | 7.23 | 1.72 |
| | 80 | 360 | 2.0 | 2.6 | 4.20 | 9.20 | 2.19 |
| | 100 | 360 | 2.0 | 2.8 | 4.20 | 11.49 | 2.74 |
| Liver Tissue | 60 | 360 | 2.0 | 2.2 | 4.20 | 5.57 | 1.33 |
| | 80 | 360 | 2.0 | 2.4 | 4.20 | 7.23 | 1.72 |
| | 100 | 360 | 2.0 | 2.6 | 4.20 | 9.20 | 2.19 |
| Lung Tissue | 60 | 360 | 2.0 | 2.0 | 4.20 | 4.19 | 1.00 |
| | 80 | 360 | 2.0 | 2.4 | 4.20 | 7.23 | 1.72 |
| | 100 | 360 | 2.0 | 2.6 | 4.20 | 9.20 | 2.19 |

## 4. Conclusion

In this study, the experimental study of microwave ablation in ex vivo tissues is presented. The outcomes of this study clearly proved that the effects of the differences of types of tissue and microwave power inputs are well-grounded. The temperature profiles and the ablation volume in the case of the skin tissue are higher than the liver tissue and the lung tissue, respectively. Greater microwave power input not only results the broader ablation zone but also higher temperature distribution. This investigation provides the essential aspects for a fundamental understanding of heat transfer within tissues during microwave ablation include thermal treatment and can be applied to use in clinical tumour treatments to predict whether sufficient tissue volume has been ablated. Our future works will include investigation in in vivo and in vitro experiments.

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