


Effects of Water-Cooled Loop Monopole Antenna on Microwave Ablation Efficiency

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Abstract: This work compares the effect of a monopole antenna without cooling unit on a biological tissue and a monopole antenna with cooling unit. Computer simulation was done using a computer software named COMSOL Multiphysics™, input power was varied from 10W to 120W, with an interval of 10W, at different times, from 60s to 120s at an interval of 60s. It was observed that the diameter of the lowest power (20W) decreased by -17.2% at 5mins, the length decreased by -32.9% and aspect ratio for the two antennas increased by 23.40%. For medium power (60W), at 5mins, the diameter decreased by -9.89%, length decreased by -37.9%, and aspect ratio decreased by 45.24%. The p-value obtained from diameter for low power showed no significant difference for ablation without water cool ($p > 0.005$), but showed significant difference with water cool ($p < 0.005$), diameter for medium power showed no significant difference, $p > 0.005$ in both simulations, there was no statistically significant difference in the diameter for high power (110W and 120W) for both simulations, p -value > 0.005 . The result showed that inclusion of cooling unit reduced backward heating of microwave antenna, ablation length, and ablation diameter of simulated tissue.

Keywords: Aspect ratio, Closed loop, Microwave ablation, Significant difference.

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Introduction

There is a wide spread of cancers today, hence, various treatment modalities such as the use of radiations (like x-ray, gamma ray), ablation, ultrasound and others have been developed to approach different form of cancer cases. However, minimally invasive tissue ablation has become of central importance in the modern surgery armamentarium, because it does not involve the use of ionizing radiation which can be damaging to healthy tissues if not properly managed, it is also less invasive. In the treatment of benign or malignant tumors, it is important to achieve ablation of the undesirable tissue in a well-controlled and precise way without affecting the surrounding healthy tissue. As an alternative to surgical resection, numerous thermal and non-

thermal ablation modalities are available, including: radiofrequency (RF) ablation, microwave ablation, cryoablation, high-intensity focused ultrasonography (US), laser ablation, irreversible electroporation, chemical ablation (with ethanol and acetic acid), and brachytherapy (Hinshaw et al., 2014; Simon, et al., 2005; Açıkgöz and Türer, 2014; Shock et al., 2004). These ablation therapies make use of different antennas: slot, dipole, cap-choke, sleeve and monopole (Kaur and Maini, 2007; Lin and Wang, 1996). However, monopole antennas are frequently use in tumor ablation (Bertram et al., 2006), this article focuses on effect of a closed loop monopole water cool antenna on microwave ablation efficiency.

Material and Methods

Material

A computer software (COMSOL Multiphysics™) was used for computer simulation. A 2.45GHz solid-state MW generator (SAIREM SAS 200W, NeyronCedex France), with a variable output power from 20 to 120W in step of 10W was used to generate power for different time durations. Monopole antenna was designed from a 50 Ω UT-0.085' semi rigid coaxial cable (RG405 Coax, Pasternack Enterprises Inc, Los Angeles, CA), the inner conductor was made from silver-plated copper clad steel, while the outer conductor was made of copper, and the coaxial dielectric used was a low-loss solid polytetrafluoroethylene (PTFE). The Polytetrafluoroethylene (PTFE) thread seal tape was used to enclose antennas to prevent adhesion of the probe to desiccated ablated tissue and to ensure easy removal of the antenna. A water-cooled syringe pump was used to pump cool water to the antenna, to cool the system and prevent backward heating. Channel Data logging Thermometer (SPER Scientific Ltd) was as well used to measure the temperature of the system. Micrometer screw gauge and ruler were used to measure the diameter of the antennas.

Methods

Computer simulation was done using a computer software named COMSOL Multiphysics™, input power was varied from 10W to 120W, with an interval of 10W, at different times, from 60s to 120s at an interval of 60s.

Antenna Fabrication

Monopole antenna were designed from 50 Ω UT-0.085' semi rigid coaxial cable (RG405 Coax, Pasternack Enterprises Inc, Los Angeles, CA). The antennas consist of thin coaxial cables with internal and external conductor made of copper, and their tip soldered. The water-cooled antenna was enclosed in a sleeve (catheter) made of PTFE (polytetrafluoroethylene a biocompatible dielectric

material) through which a cooling water could flow through. The antenna was operated at 2.45 GHz, a frequency widely used in microwave coagulation therapy.

Experimental Validation

Experiments were performed with a custom-designed microwave applicator on ex-vivo bovine liver (cattle liver) obtained from a local abattoir. The applicator used for all experimentation was a 2.45 GHz, 200-Wmicrowave device with an active 5.7-mm-diameter radiator, powered by a magnetron generator. The antenna was connected to the microwave generator (SAIREM SAS 200W, NeyronCedex France), and the generator output was set properly to ensure appropriate power delivery and to compensate for cable losses. ASP-1800 syringe pump was used to pump water through the water-cooled antenna.

Tissue Coagulation Process

Input power and the slot size were set, other quantities such as reflection coefficient, total power dissipation, ablation diameter, ablation length and were determined. The parameters from the computer simulation were measured and recorded and the power generated by the simulation with the aid of a divider and a ruler. The ablated tissues were sliced along the antenna axis to determine the diameters and lengths of ablated zone. Each ablated zone was photographed for further analysis with ImageJ software. The aspect ratio was determined by dividing the measured tissue diameters by the tissue lengths.

Statistical Analysis

SPSS was used to analyze the data's, and paired t test was used to obtain the p-values, standard deviation was used to show the variation and relation relationship between the obtained values. Also, the percentage differences in the ablation coagulation diameters, lengths and aspect ratios of the data were compared.

Results

In the study, a total of 36 computer simulations were carried out and experimental validation was also done with bovine liver. Comparison the results of ablation with close looped monopole water cooled microwave antenna and result with monopole antenna that has no water cool system

was made. The powers were 20, 30, 50, 60 and 110, 120 representing low, medium and high power respectively. The initial and final temperatures for every simulation was recorded. Thereafter, the diameter and length were measured to calculate the aspect ratio.

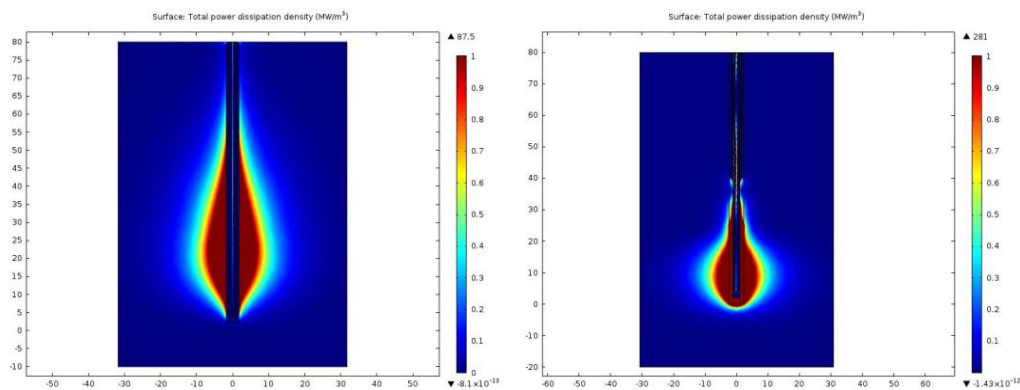


Figure 1a i and ii Result of 20W for 3min without water cool and with water cool respectively.

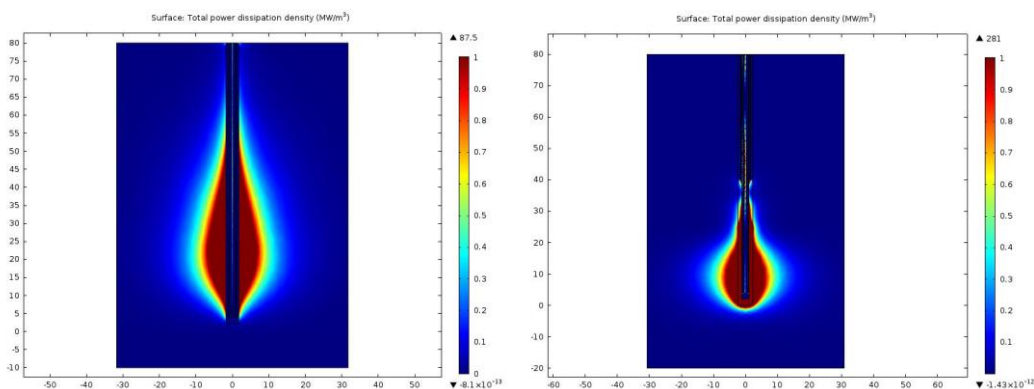


Figure 1b i and bii 20W for 5mins without water cool and with water cool respectively.

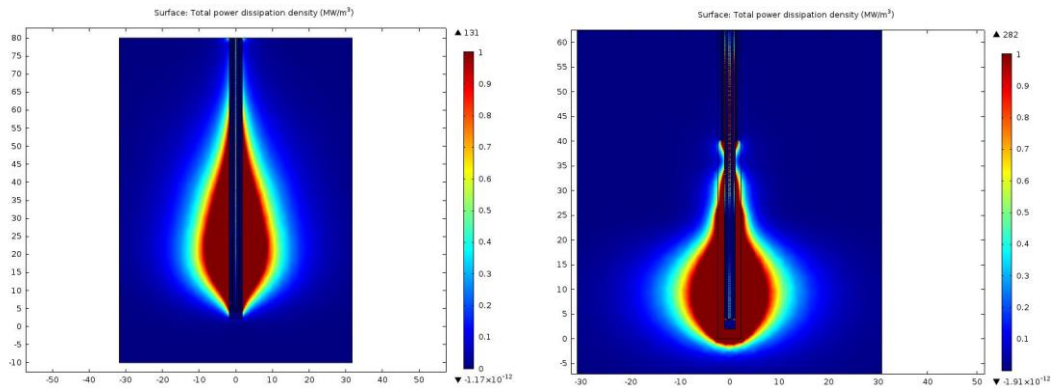


Figure 1c i and ii for 10min without water cool and with water cool respectively.

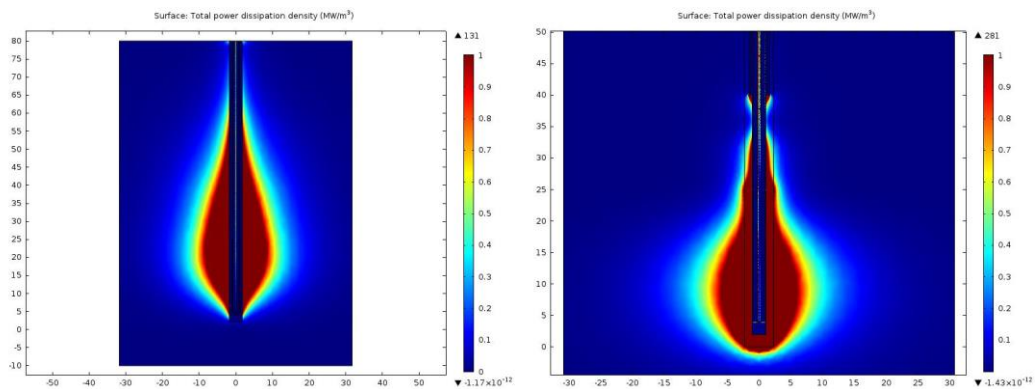


Figure 1d i and ii 30w for 3mins without water cool and with water cool respectively.

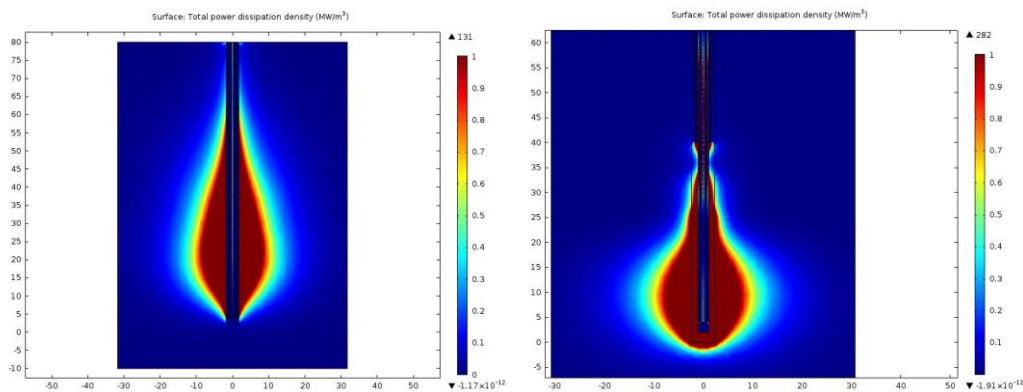


Figure 1 e i and ii 30w for 5mins without water cool and with water cool respectively.

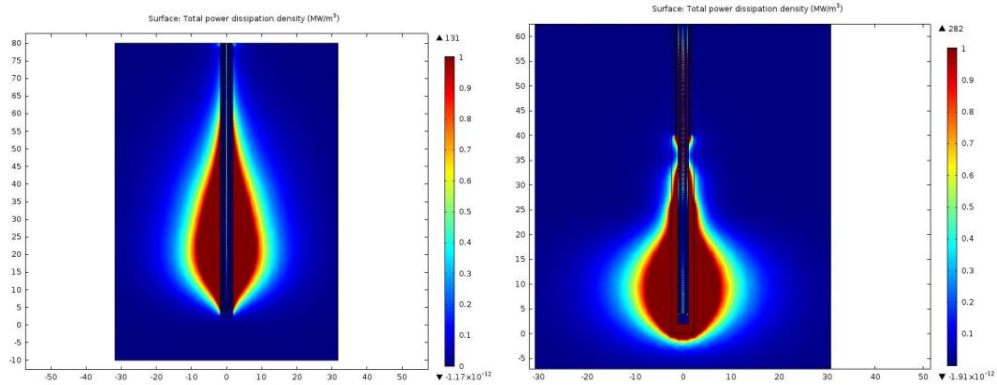


Figure 1 f i and ii 30watts 10mins without water cool and with water cool respectively.

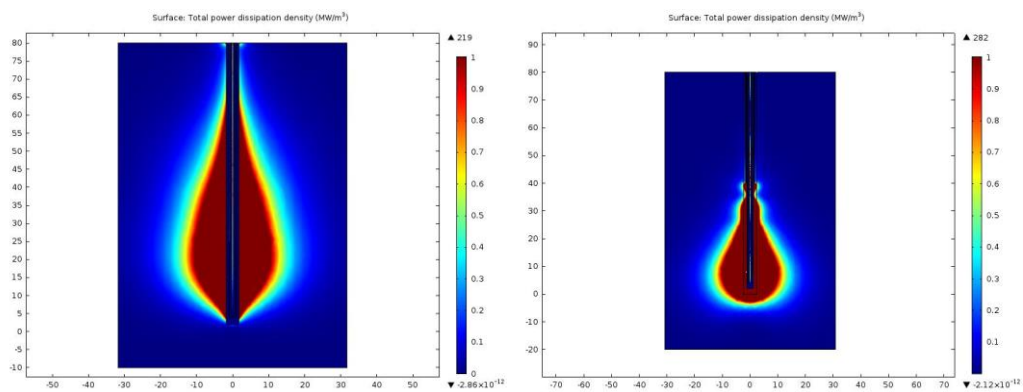


Figure 1 g i and ii 50w for 3mins, without water cool and with water cool respectively.

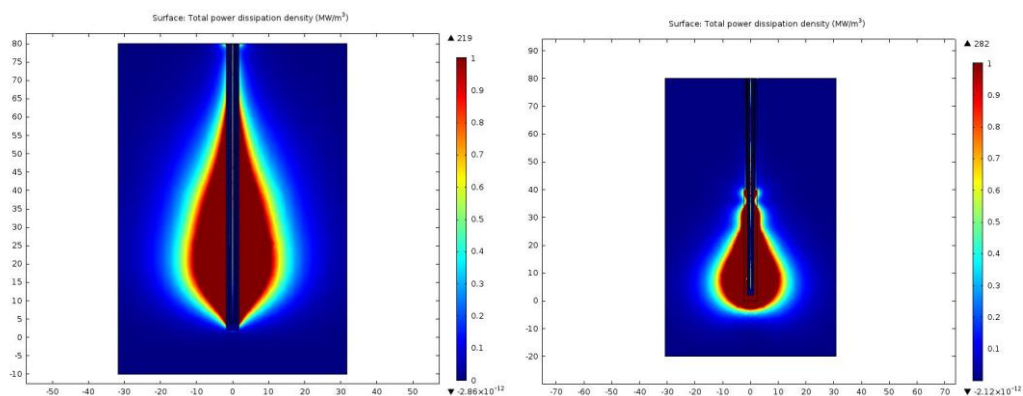


Figure 1 h i and ii 50w for 5mins, without water cool and with water cool respectively.

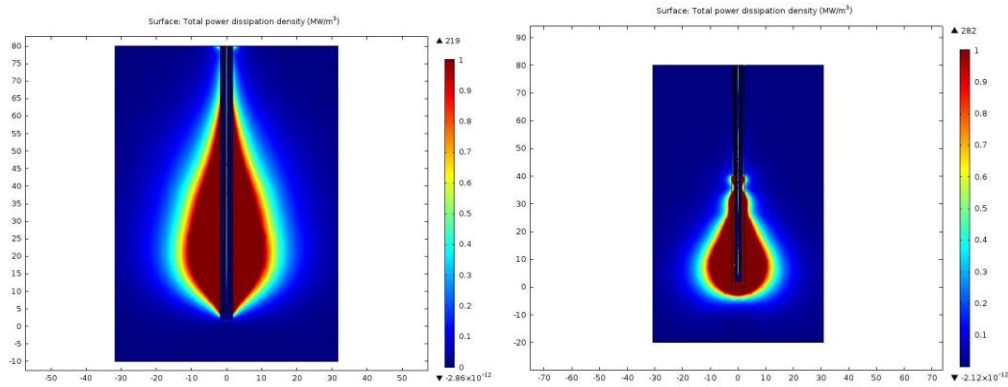


Figure 1 I i and ii 50w for 10mins without water cool and with water cool respectively.

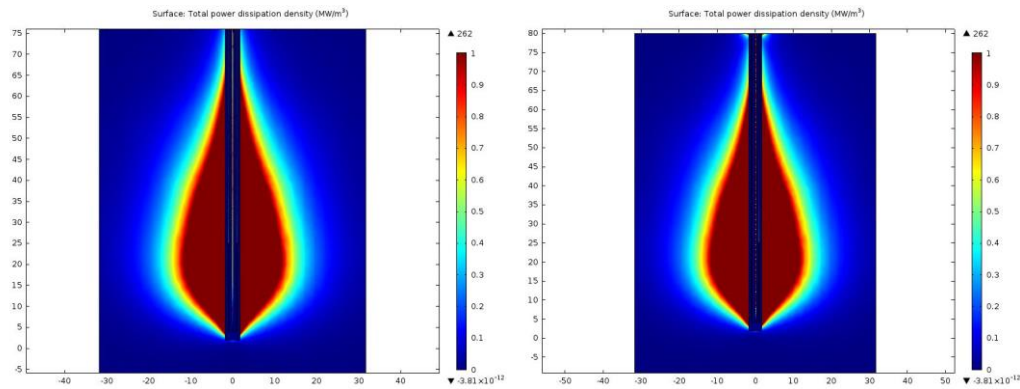


Figure 1j ii and ii . 60w for 3mins without water cool and with water cool respectively.

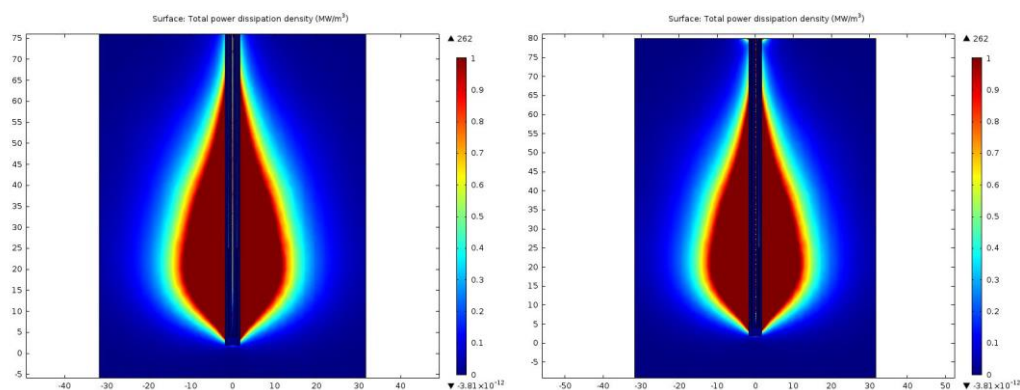


Figure 1k i and ii 60w for 5mins, without water cool and with water cool respectively.

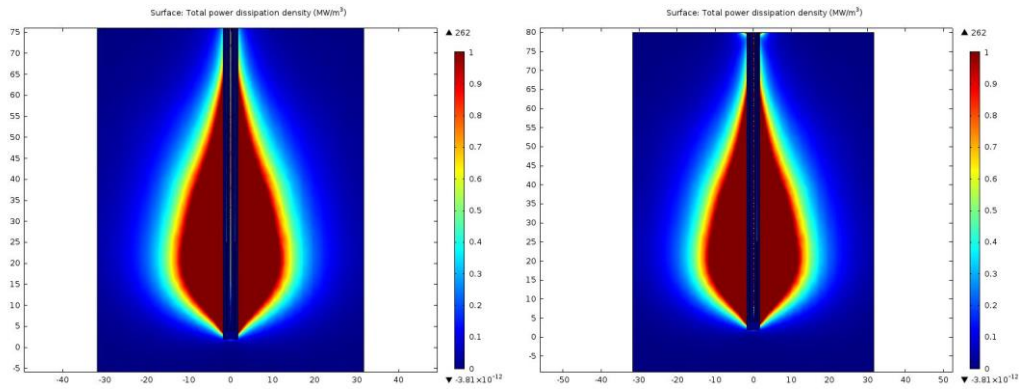


Figure 1L i and ii 60w for 10mins without water cool and with water cool respectively.

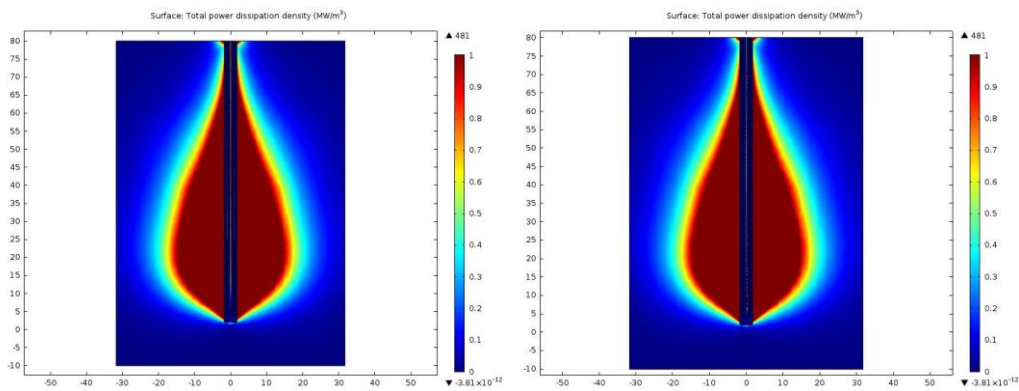


Figure 1 m i and ii 110w for 3mins without water cool and with water cool respectively.

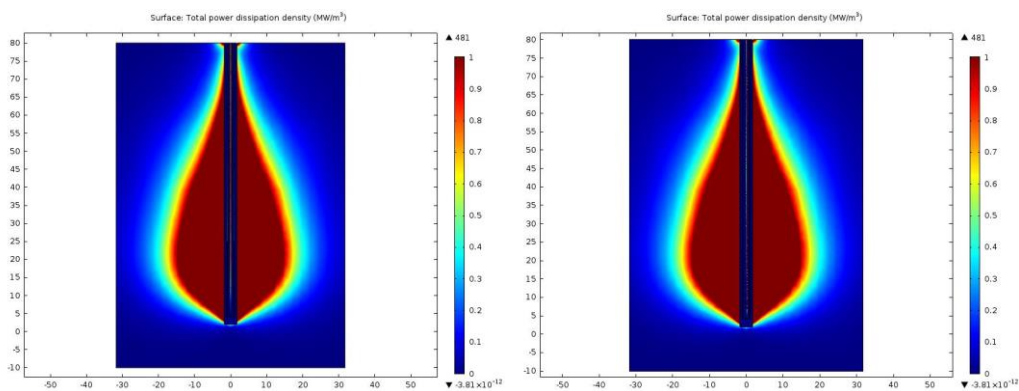


Figure 1 n i and ii 110w for 5mins without water cool and with water cool respectively.

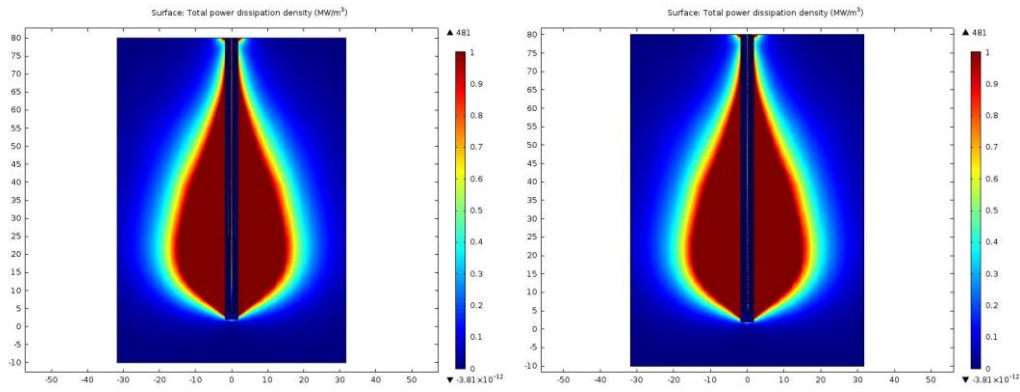


Figure 1 O i and ii 110w for 10mins without water cool and with water cool respectively.

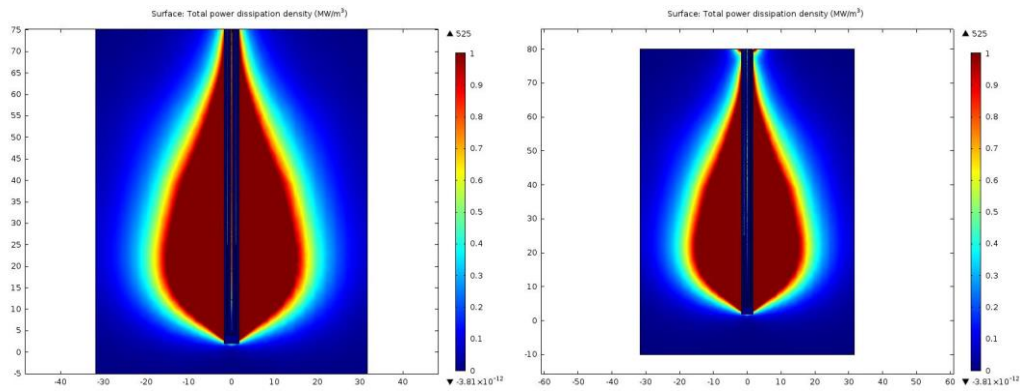


Figure 1 P i and ii 120w for 3mins without water cool and with water cool respectively.

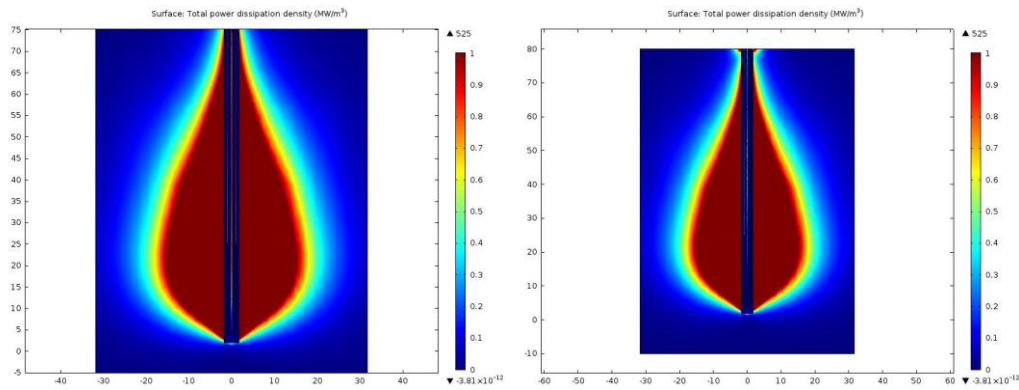


Figure 1Q i and ii 120w for 5mins without water cool and with water cool respectively.

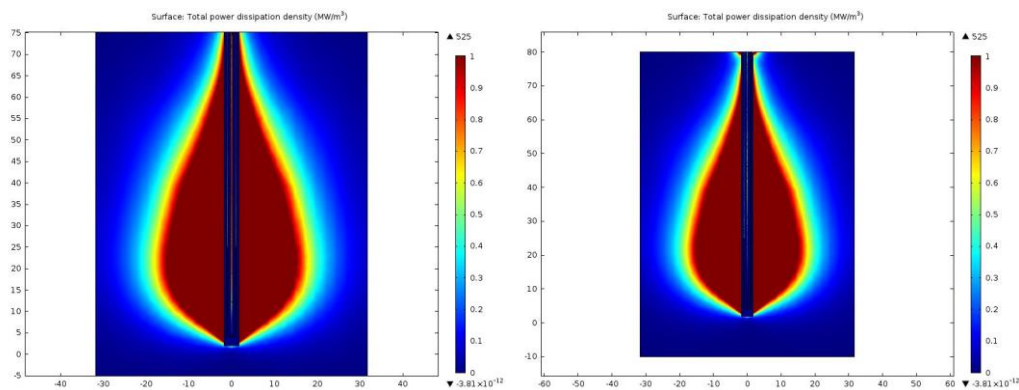


Figure 1 R i and ii 120w for 10mins without water cool and with water cool respectively.

Table 1. Simulation reading of time and diameter of antenna without cooling unit

Time	D ₀ 20W (mm)	D ₀ 30W (mm)	D ₀ 50W (mm)	D ₀ 60W (mm)	D ₀ 110W (mm)	D ₀ 120W (mm)
60	8.45	12.1	13.3	18.8	20.78	20.75
120	14.27	18.35	20.5	27.52	28.1	28.98
180	17.95	22.38	23.5	29.88	32.68	33.58
240	20.65	25.14	27.2	33.58	36	37.42
300	23.05	28.04	28.7	36.38	36.68	41.78
360	24.9	29.71	31.2	38.54	40.18	42.78
420	26.27	31.58	31.8	40.48	42.18	43.48
480	27.44	32.94	33.15	42.08	42.82	44.9
540	28.48	33.94	34.4	43.36	44.92	46.34
600	29.28	34.6	34.7	44.38	46.02	46.98

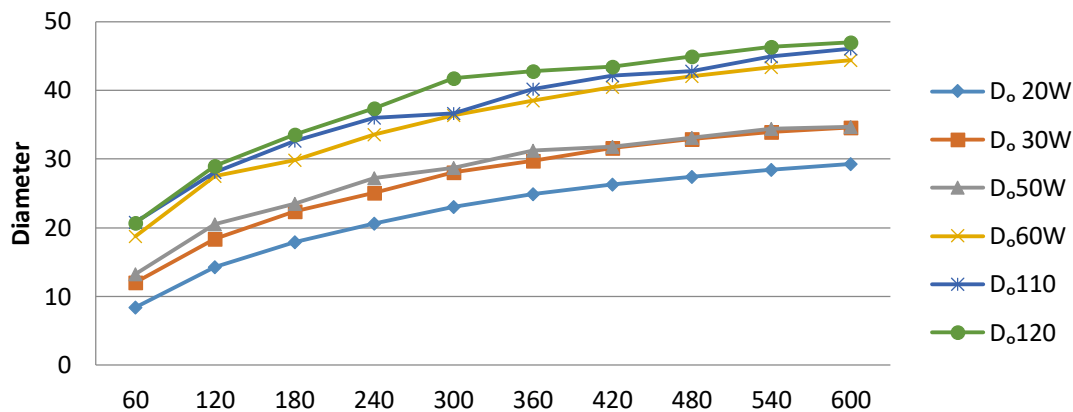


Figure 2. The diameter (mm) against time(s), for simulation without water cooled unit

- The graph shows that ablation diameter increases with time from 60s to 600s, with 600s having the highest diameter.
- It also shows that ablation diameter increases with respect to power from 20w to 120w, with 120w having the highest diameter.

All the mean diameters of simulation with water cool antenna were also tabularized, for ablation of 20W, 30W, 50W, 60W, 110W and 120W at time 60(s) - 600(s) as shown below.

Table 2. Simulation reading of time and diameter of antenna with water cooled unit

Time	D _{0.20W} (mm)	D _{0.30W} (mm)	D _{0.50W} (mm)	D _{0.60W} (mm)	D _{0.110W} (mm)	D _{0.120W} (mm)
60	6.82	10.48	14.78	16.4	19.02	19.02
120	12.10	16.08	21.34	23.4	25.88	25.84
180	15.50	19.86	25.38	27.18	31.50	30.50
240	18.06	22.72	28.48	30.60	33.68	33.68
300	19.08	24.90	30.86	32.78	36	36.22
360	21.40	26.54	32.58	34.94	36.22	38.28
420	22.94	27.90	34.38	36.48	40.10	40.10
480	24.00	29.18	35.58	37.58	41.52	41.5
540	24.78	30.14	36.48	38.88	42.68	42.68
600	25.42	30.7814	37.28	39.9	43.16	43.6

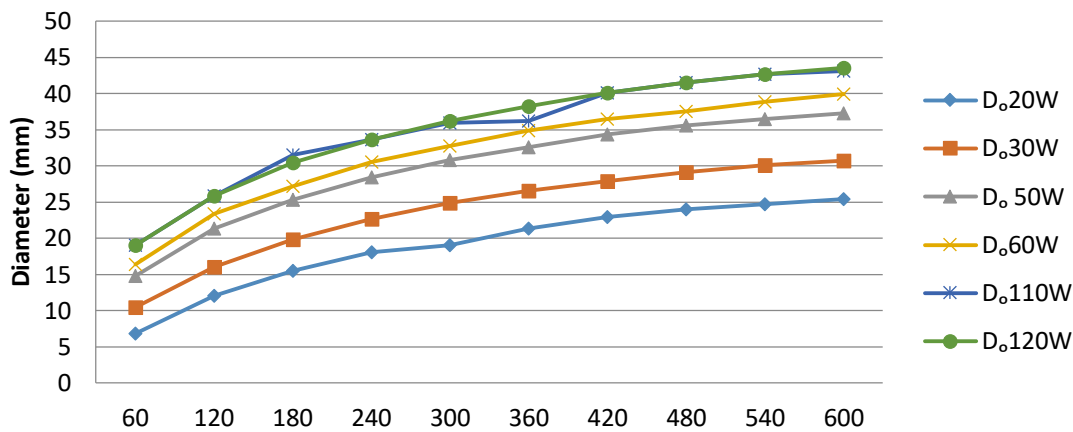


Figure 3. Diameter against time for antenna with water cooled unit

- The graph above shows that as the time increases, the ablation diameter increases, with respect to power from 20 -120W, but the diameter at each power is reduced because of the water cool effect.
- The graph also shows that as the time increases from 60s to 600s the ablation diameter increases.

Discussion

The study compared the result gotten from using a closed loop water cooled monopole microwave antenna with the same monopole antenna without a water cool system. The difference between the loop microwave antennas used in this study and other thermal ablation arrays (multiple prong RF electrodes) involves the ability to completely encircle a tumor with the loop antennas, which effectively creates a cage in which the tumor is entrapped. This has the advantage of providing precise targeting of a specific area for thermal destruction while minimizing collateral damage (Shock, 2004).

Considering the result for computer simulation with cooling unit, the diameters gotten for 20w from 60s – 600s gave a high percentage increase of 246%, this showed that ablation diameter

increased rapidly with respect to time. Also, the percentage increment in power, from 20w-120w, from 60s -20w to 600s -120w showed 455.6%, this as well portrayed that diameter increased with increase in power. Similar increment was found in antenna length, considering 20w at 60s – 600s, the increase gave 119.3%, as the power increased, from 20w to 120w, there was high increment from 20w -60s to 120w – 600s, the percentage increment value was 199.7%. For the water cool, in the result gotten for 20watt for 60s-600s, there was an increment of 272% in diameter, the length also showed an increment of 110%. As the power increases from 20w to 120w there was an increase of 539% in length and 194% in diameter. Using data analysis for the result obtained without water cool, the mean standard deviation gotten for 20w was 26.88 ± 6.78 , at 30w the mean standard deviation was 26.878 ± 6.78 , at the highest power, 120w the mean standard deviation was 38.70 ± 6.78 . It was observed that the standard deviation remains the same (6.78). Also, the result gotten from the water-cooled simulation (4.14), at 20w from 60s to 600s the mean standard deviation was 19 ± 6.05 and at 30w the mean standard deviation was 23.86 ± 6.05 , at the highest power,

120w, the mean standard deviation was 35.14 ± 6.05 , showing that the standard deviation remains the same. The reflection coefficient for simulation without water cool was -17.0882dB, which was the same for all the powers, water cool simulation also

showed the same reflection coefficient (-3.1436dB) for all the powers.

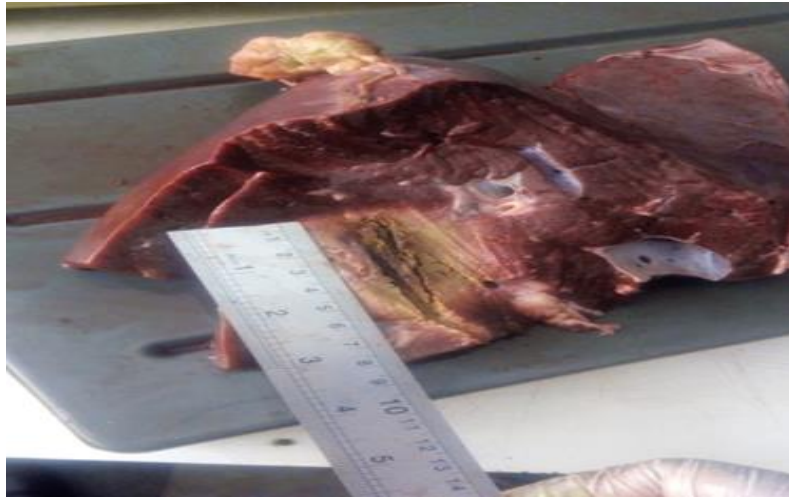


Figure 4. Represents experimental simulation without water cool for 5mins with 60W, the length was 5.8cm, the diameter 5cm and the aspect ratio was 0.862.



Figure 5. Represents experimental work with water-cool 60w at 5mins, the diameter was 4.8cm, the ablated length was 5.5 and the aspect ratio was 0.87.

Comparing the two antennas, antenna without water cooling system has increased diameter and length than antenna with water cooling system. Starting with the lowest watt (20w), at 5mins the diameter decreased by -17.2%, the length decreased by -32.9% and aspect ratio for the two antennas increased by 23.40%. For medium power (60w), at 5mins, the diameter decreased by -9.89%, length decreased by -37.9%, and aspect ratio decreased by 45.24%. The diameter for highest watt (120w), at 5mins, showed a percentage decrease of -13.3%, the lengths for the same watt at the same 5mins showed a percentage decrease of -38.2% and the aspect ratio showed a percentage increase of 40.5%. In the experimental ablation was carried out at 60w and 120w for 5minutes and 10minutes for antenna without water cool and antenna with water cool respectively (Figure 4 – 5), the result as well showed that ablation length and diameter increased with time and power. Using paired sample t-test, the P-values gotten from diameters for low power without water cool and water cool for (20W-30W) were, 0.335 and 0.001 respectively, showing no statistically significant change in diameters for water cooled but significant change in diameters with water cool. There was significant change in diameter of medium power, p-value = 0.001 in both cases. In high power, both simulations showed no significant difference in the diameters. The p values gotten from length for low power showed no significant difference for simulation without cooling unit $p = 0.040$ but showed significant difference for water cool, $p = 0.001$. In medium power, simulation without cooling unit showed significant difference in length, $p = 0.001$, why water cooled showed no significant difference, $p = 0.646$. There was no significant difference in simulation lengths of high power in both water cool and non-water cool.

This study is similar to another work on evaluation of the clinical implementation of triangular and spherical designs for simultaneous multiple-

antenna ablation of human hepatocellular carcinoma (HCC) with a recently engineered microwave coagulation system. The diameters gotten during the study were 16.7, 51.7, and 54.3cm in 3, 5–10minute ablation cycle. It was observed that the ablation with the longest time yielded the most uniformly round ablation shape (Yu et al, 2006).

It as well shared the same sentiment with another research on investigation of the result of microwave heating near large vasculature using coupled fluid-flow and thermal analysis, it was observed that low-flow conditions could cause cytotoxic heating and, therefore, vessel thrombosis and endothelial damage of downstream tissues. This is similar to this study, the effect of water cool antenna was shown in Figure 1, it was observed tissue without water cool could produce high ablation length and diameter, resulting to backward heating, hence, causing endothelial damage (Chiang et al., 2012). Such conditions might be more prevalent in patient with severe cirrhosis or compromised blood flow. High-flow conditions create the more familiar heat-sink effect that could protect perivascular tissues from the intended thermal damage.

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