OPTIMIZATION OF A NOVEL MICROWAVE TUMOR ABLATION SYSTEM IN AN *IN VIVO* PORCINE LIVER MODEL.

Andrew S. Wright MD, Fred T. Lee Jr. MD, David M. Mahvi MD
Departments of Surgery and Radiology, University of Wisconsin Hospital

Background

Radiofrequency (RF) ablation is commonly used in the treatment of surgically unresectable hepatic tumors. It is amenable to open[1], laparoscopic[2], or percutaneous application[3], it makes use of well-understood principles of electrical and thermal heating of tissue[4], and it is readily available. However, local recurrence rates following RF ablation are as high as 39%[3].

Microwave (MW) ablation is a novel therapy that has several theoretical advantages over RF ablation, including a larger zone of active heating, higher temperatures, and the capacity for ablation with several, simultaneously active probes. Currently MW ablation is in clinical use in a number of Asian centers[5, 6]. However, more widespread adoption has been prevented by a relatively small lesion size, requiring as many as 46 overlapping ablations to treat a single tumor[7]. This appears to be due to a high level of power reflected back from the liver, causing heating of the probe, cable, and generator and limiting duration of MW application to 30-90 seconds.

Recently, advances in antenna design have led to a new MW ablation system in which power feedback is markedly reduced, allowing for longer times of application, greater power deposition, and larger ablation lesion sizes. This study was designed to determine the optimal parameters of this prototype microwave ablation system in an *in vivo* porcine liver model.

Methods

All ablations were performed using a prototype Microwave Ablation System (Figure 1, Vivant Medical Inc., Mountain View, CA). The microwave probe is a 13g, 15cm dipole coaxial antenna with a choke limiting feedback of microwave energy. The distal 3.2cm is the actively radiating portion of the antenna. The generator is capable of producing 50 Watts of power at 915MHz, and is controlled by customized LabView software (National Instruments Corporation, Austin TX). The two parameters that can be controlled are duration of application, and power applied.

A total of 59 microwave ablations were performed in 10 cross-bred swine. All were performed during laparotomy under general anesthesia. Power settings were 30, 40, or 50 watts. Lesions were performed for 1 minute following signs of tissue heating on ultrasound (hyperechoic changes or evidence of water vaporization), or for 5, 10, 15, or 20 minutes total time of application. Four lesions were performed at each of the 15 different combinations of power and duration settings, except only 3 lesions were made at 30 Watts for 1 minute following signs of tissue heating. Temperature recordings were made for selected ablations with a fiberoptic thermosensor (Model 790, Luxtron Corporation, Santa Clara, CA).

Animals were heparinized and sacrificed immediately following completion of surgery, and livers were removed and fixed in formalin. Lesions were sectioned at regular 3mm intervals, and each section was scanned at 300 dpi. Lesion dimensions (length, minimum cross-sectional diameter, and volume) were measured using ImageJ software (NIH, Bethesda, MD). Analysis of Variance (ANOVA) testing was used to determine significance. This research was approved by the University of Wisconsin Animal Care Committee, and guidelines for the ethical care and treatment of animals were strictly followed.

Results

All lesions were hyperechoic on interoperative ultrasound, with evidence of microvascular bubbles (Figure 2). The first signs of tissue heating occurred within 30 seconds at 40 and 50W, but took between 90-180s at 30W ($p<0.001$). On gross inspection, microwave ablation lesions had a central pale necrotic zone surrounded by a red hyperemic zone (Figure 3). Microscopic analysis confirmed the presence of complete coagulative necrosis in the pale areas of the lesions. Temperature was significantly higher at 50W than at 30W (135 ± 31^{o}C vs. 105 ± 24^{o}C, $p<0.02$, Figure 4), but there was no significant difference between 40W and 50W.

Lesion diameter was significantly greater at 50W than 30W ($p<0.03$), and there was a trend towards greater lesion diameter at 50 compared to 40W ($p=0.07$, Figure 5). Lesion length at 30W was significantly less than at 40W ($p<0.02$) and 50W ($p<0.02$, Figure 6). Volume was significantly greater at 50 than 30W ($p<0.01$) and there was a trend towards significantly greater volume at 50 than 40W ($p=0.054$, Figure 7). While there was no significant interaction between duration of application and lesion diameter, length, or volume, there was a trend towards greater volume with increasing time ($p=0.07$). Reflected power increased significantly with power ($p<0.001$) but not time ($p=0.9$, Figure 8).

Conclusions

Microwave ablation was successfully performed in an *in vivo* porcine liver model. The lesions were easily visualized by intra-operative ultrasound, and all lesions resulted in clearly defined areas of coagulation necrosis. Lesion size increased with applied power and tended to increase with duration of application, however reflected power also increased at the highest power setting. This increase in reflected power at 50W may explain the greater variability in lesion volume seen at this power setting. Reflected power did not increase with time, allowing longer ablations than have been used in previously reported studies of MW ablation.

Microwave ablation has a number of theoretical advantages over conventional RF ablation. First, MW ablation can reach much higher temperatures than RF ablation, as it is not limited by tissue charring and boiling at temperatures greater than 100^{o}C, as is RF. Second, RF relies primarily on passive thermal conduction for tissue heating, while MW ablation has a much larger zone of active heating. A large zone of active heating may allow for more uniform tumor kill within a lesion and improve tumor kill next to blood vessels. Third, microwave ablation is relatively straightforward and does not require expandable arrays or tip cooling to achieve clinical useful lesion sizes, as does RF. Fourth, unlike RF ablation, MW ablation may be performed with multiple probes simultaneously. Many large tumors require multiple overlapping ablations for complete coverage[8], so simultaneous multiple probe ablation would allow for more efficient and potentially more effective therapy.

In this initial investigation of a prototype MW system, lesions were regular and reproducible. The relatively high power feedback at 50W indicates that, as clinical Phase I trials of MW ablation proceed, ablation should be performed at 40W power in order to maximize lesion size while minimizing reflected power. Although lesion diameters achieved were somewhat smaller than offered by conventional RF devices, this will likely be overcome by further refinements of the MW antenna and generator. Also, the ability to use multiple overlapping MW antennas should allow for the creation of ablation lesions that are both large and controlled, in less time than required to create a series of sequentially placed overlapping RF lesions.

Selected References

1. Curley SA, Izzo F, Delrio P, et al. Radiofrequency ablation of unresectable primary and metastatic hepatic malignancies: results in 123 patients. [see comments]. *Annals of Surgery* 1999;230(1):1-8.

2. Siperstein A, Garland A, Engle K, et al. Laparoscopic radiofrequency ablation of primary and metastatic liver tumors. Technical considerations. *Surg.Endosc.* 2000;14(4):400-405.

3. Solbiati L, Livraghi T, Goldberg SN, et al. Percutaneous Radio-frequency Ablation of Hepatic Metastases from Colorectal Cancer: Long-term Results in 117 Patients. *Radiology* 2001;221(1):159-166.

4. Goldberg SN, Gazelle GS, Dawson SL, Rittman WJ, Mueller PR, Rosenthal DI. Tissue ablation with radiofrequency: effect of probe size, gauge, duration, and temperature on lesion volume. *Academic Radiology* 1995;2(5):399-404.

5. Lu M-d, Chen J-w, Xie X-y, et al. Hepatocellular Carcinoma: US-guided Percutaneous Microwave Coagulation Therapy. *Radiology* 2001;221(1):167-172.

6. Shibata T, Niinobu T, Ogata N, Takami M. Microwave coagulation therapy for multiple hepatic metastases from colorectal carcinoma. *Cancer* 2000;89(2):276-284.

7. Sato M, Watanabe Y, Ueda S, et al. Microwave coagulation therapy for hepatocellular carcinoma. *Gastroenterology* 1996;110(5):1507-1514.

8. Dodd GD, III, Frank MS, Aribandi M, Chopra S, Chintapalli KN. Radiofrequency Thermal Ablation: Computer Analysis of the Size of the Thermal Injury Created by Overlapping Ablations. *Am. J. Roentgenol.* 2001;177(4):777-782.

Figures

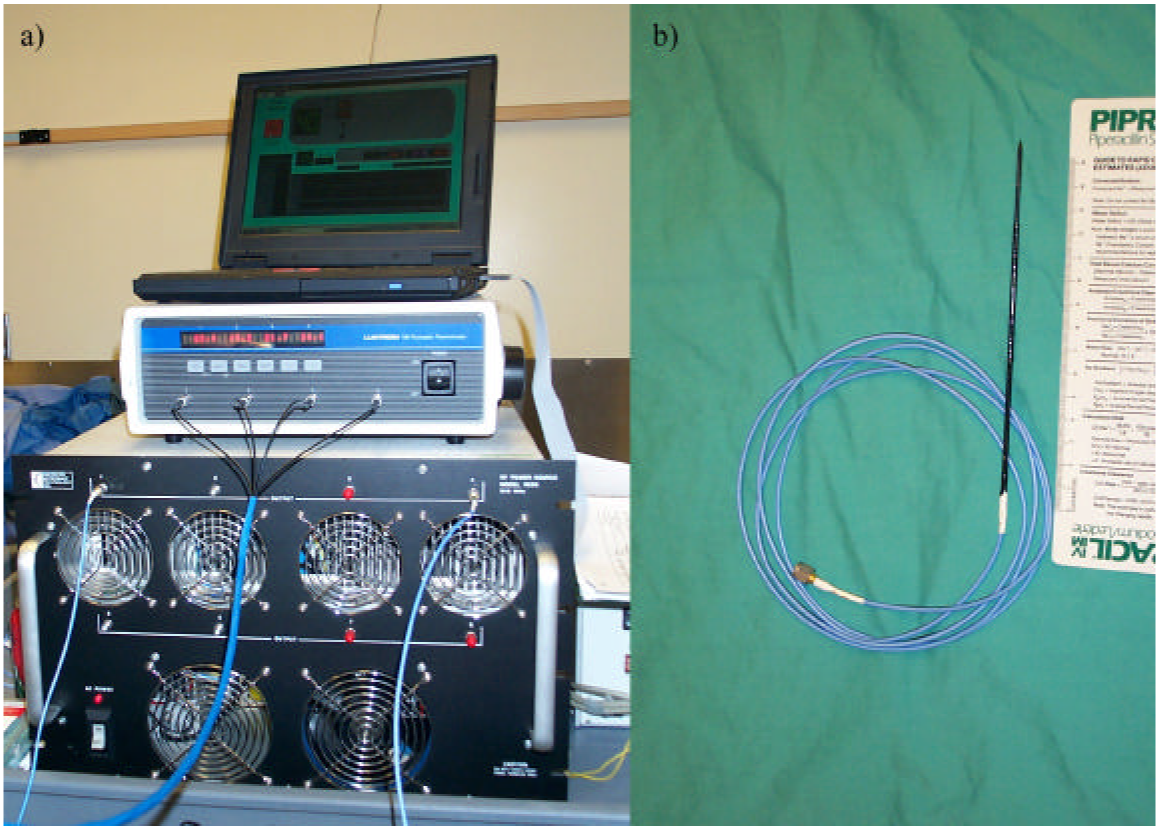

Figure 1: a) Prototype microwave generator capable of producing 50 Watts at 915 MHz. b) 13 gauge dipole microwave antenna.

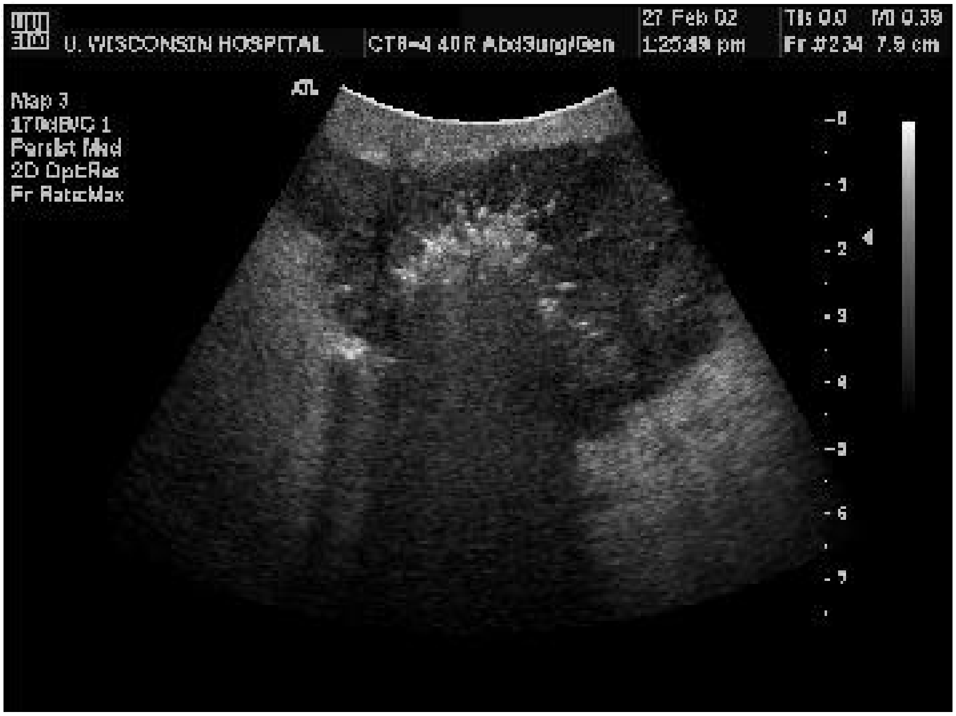

Figure 2: Typical Ultrasound appearance of a microwave lesion.

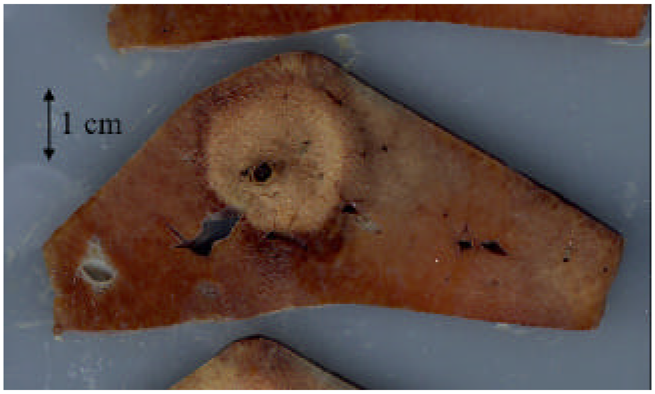

Figure 3: A microwave ablation lesion performed at 40 Watts for 10 minutes. Note the central pale area of coagulative necrosis surrounded by a red hyperemic zone.

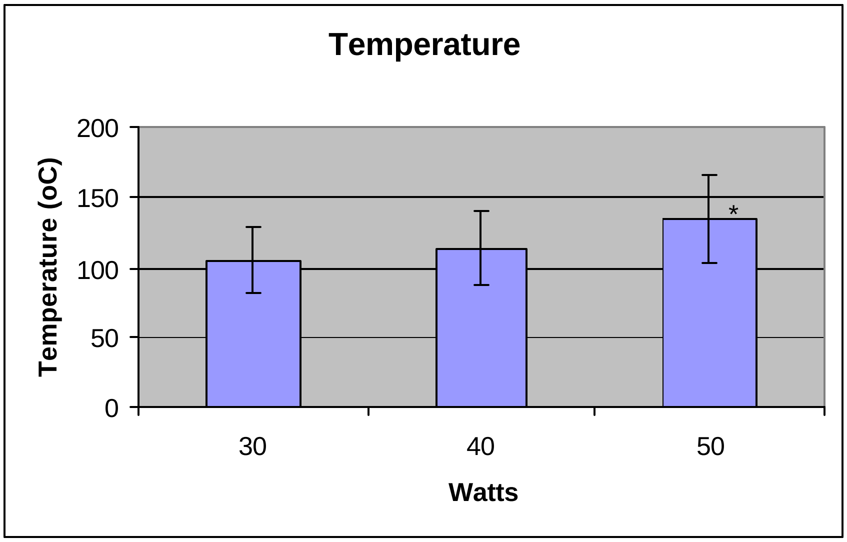

Figure 4: Temperature at center of ablation lesion.

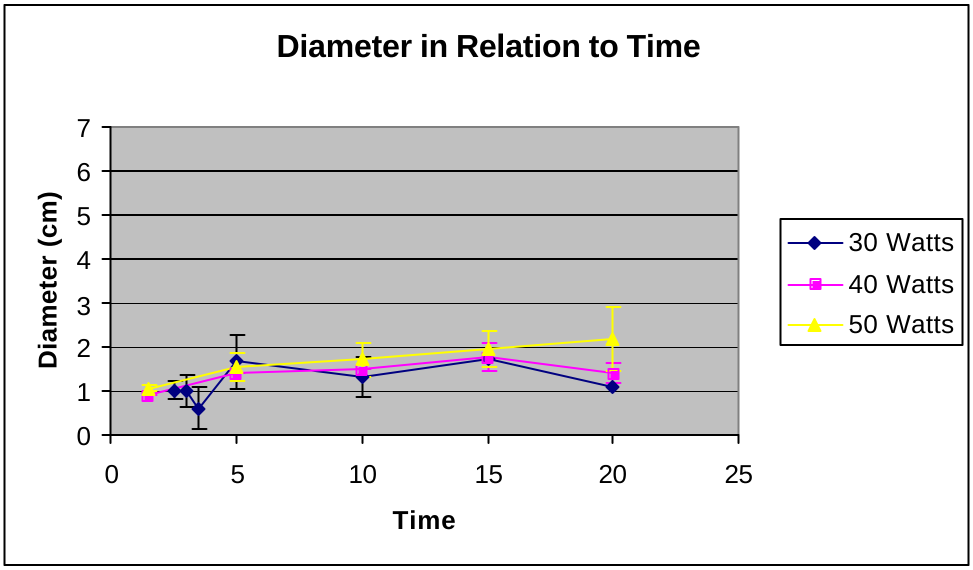

Figure 5: Microwave ablation diameter with respect to duration of application and power applied.

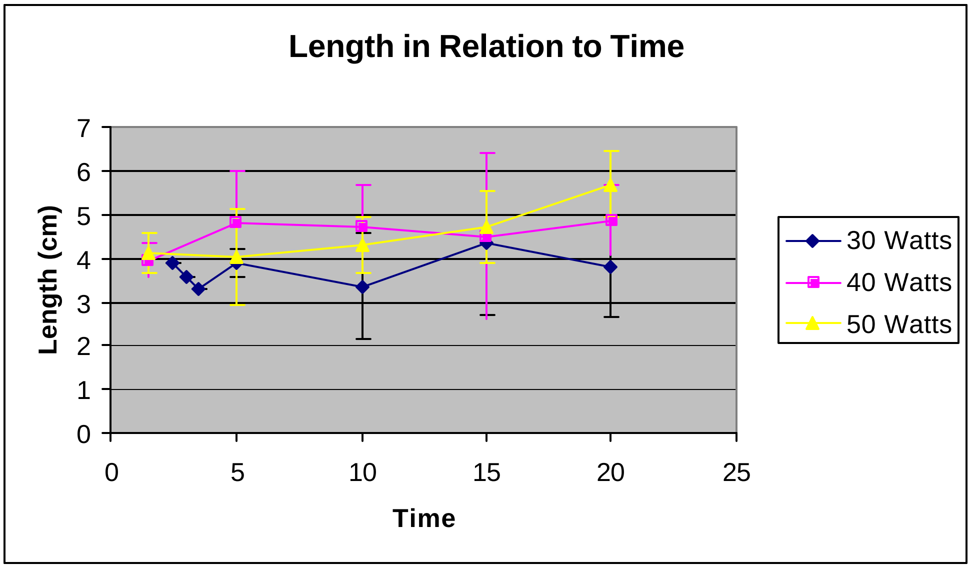

Figure 6: Microwave ablation length with respect to duration of application and power applied.

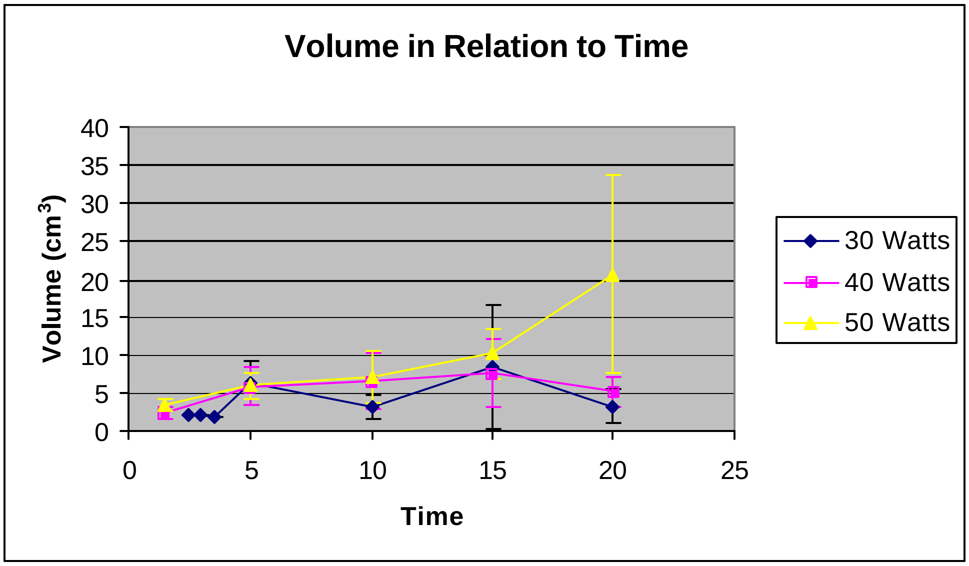

Figure 7: Microwave ablation volume with respect to duration of application and power applied.

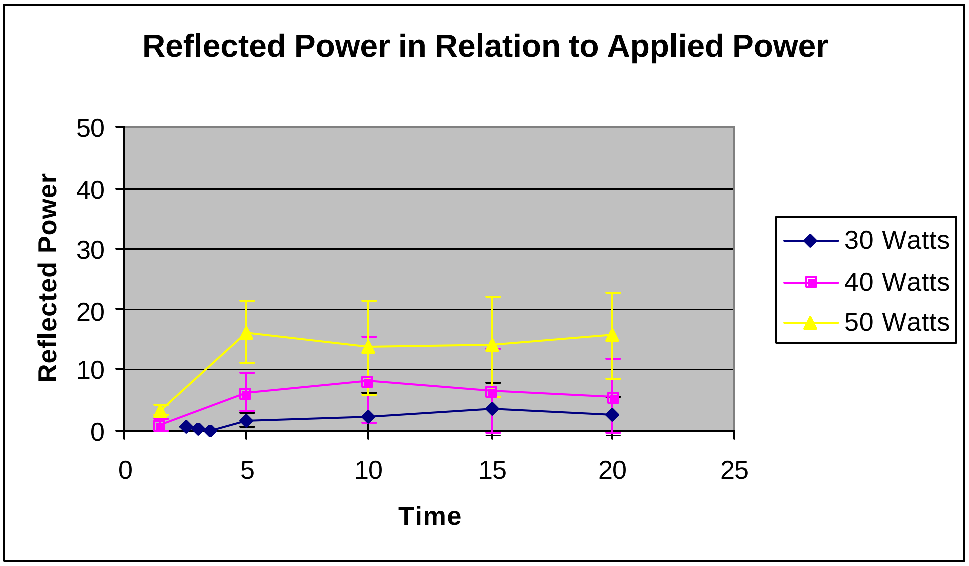

Figure 8: Reflected power with respect to applied power and duration of application.