Ann Surg Oncol (2010) 17:171–178
DOI 10.1245/s10434-009-0686-z

Annals of
SURGICAL ONCOLOGY
OFFICIAL JOURNAL OF THE SOCIETY OF SURGICAL ONCOLOGY

ORIGINAL ARTICLE – HEPATOBILIARY TUMORS

Safety and Efficacy of Microwave Ablation of Hepatic Tumors: A Prospective Review of a 5-Year Experience

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ABSTRACT

Background. This study was designed to evaluate the safety, efficiency, effectiveness, and overall long-term outcome in patients treated with microwave thermal ablation of hepatic tumors. Microwave ablation technology represents the next generation in ablative techniques for the treatment of hepatic malignancies. Currently there have been no large reports of its use in the United States with appropriate long-term follow-up.

Methods. An institutional review board-approved prospective phase II study of microwave ablation of hepatic malignancies from January 2004 to January 2009 was performed. All complications were recorded up to 90 days from operation and reported using an established five-point grading scale.

Results. One hundred patients underwent 270 ablations for hepatic malignancies. The most tumor types were as follows: metastatic colorectal cancer (50%), hepatocellular carcinoma (17%), metastatic carcinoid (11%), and other metastatic disease (22%). A majority of patents (53%) underwent combination hepatic resection and microwave ablation; 38% underwent ablation alone, 9% underwent ablation and additional organ resection, with 68% open procedures. Median tumor size was 3.0 (range, 0.6–6.0) cm, median number of tumors was 2 (range, 1–18), and median total ablation time was 13 (range, 5–45) min. Overall 90-day mortality was 0% and morbidity was 29%. One patient developed a hepatic abscess and no patients experienced bleeding complications. After a median follow-up of 36 months, 5 patients (5%) had incomplete ablation, 2 (2%) had local recurrence at the ablated site, and 37 (37%) developed intrahepatic recurrence at nonablated sites.

Conclusions. Microwave ablation of hepatic tumors is a safe and effective method for treating unresectable hepatic tumors, with a low rate of local recurrence.

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First Received: 25 June 2009;
Published Online: 26 August 2009

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Microwave ablation has been used clinically in Japan for several years.[1,2] Microwave ablation refers to the use of electromagnetic methods for inducing tumor destruction using devices with frequencies ≥900 MHz.[3–5] Although microwave ablation offers the same benefits as radiofrequency ablation (RFA), it has several theoretical advantages compared with RFA for the treatment of hepatic tumors. For example, microwave ablation heating is primarily active, whereas RFA heating is primarily passive. Microwave ablation has a much broader zone of active heating and does not rely on the conduction of electricity into the tissue, thus, the transmission of this energy is not limited by tissue desiccation and charring.[6] Therefore, intratumoral temperatures can consistently be greater than RFA, leading to a larger zone of ablation over a shorter treatment time, with more complete coagulative necrosis and tumor kill.[7] Another advantage of microwave ablation is overcoming the "heat sink" effect, which is related to the cooling effect of blood flow in major vessels in proximity to the tumor that can result in incomplete tumor ablation. Given the fact that microwave ablation has an active heating mechanism, it is less affected by this perfusion-mediated effect, thus potentially allowing for more uniform tumor necrosis within the target zone even in proximity to large blood vessels. Finally, the simultaneous treatment of multiple tumors is feasible with microwave ablation, which is not possible with RFA. This shortens the treatment time and leads to more efficient procedures when dealing with multiple tumors; it also allows multiple probes to be deployed in the efficient ablation of larger tumors.[8] Additionally, microwave ablation does not require the placement of grounding pads, which can result in skin burns.

The limitations of microwave technology in the past have been related to small ablation size, the lack of ablation efficacy, and paucity of data regarding safety and efficacy.

With the advent of novel microwave ablation technology, we began to perform microwave ablation in patients with unresectable liver malignancies. Subsequently, we reported our initial pilot evaluation of microwave ablation and demonstrated that microwave produces a reliable, efficient, and safe technique of hepatic tumor ablation.[9] However the limitation of that study was the short follow-up and small number of patients ($n = 20$).

Because of the paucity of long-term data on microwave ablation and our initial microwave experience, we sought to report a more extensive experience with microwave, including safety, efficacy, and ablation efficiency. Thus, the hypothesis for this study was that microwave ablation is safe, with acceptably low complication rates, and effective, with low rates of local recurrence at the ablated sites.

MATERIALS AND METHODS

An institutional review board-approved, prospective, single-institutional study of microwave ablation of hepatic tumors was conducted from January 2004 to January 2009. Eligible patients were at least 18 years of age, with liver metastases or primary disease that was amenable to complete ablation or a combination of resection and ablation, leaving no residual disease in the liver. Patients with liver metastases amenable to resection alone were excluded. Standard preoperative evaluation of patients included a triple-phase computed tomography (CT) scan of the abdomen and pelvis, chest roentgenogram, and positron emission tomography (PET) for patients with metastatic colorectal cancer. Previous systemic therapy of any type and duration was allowed. Patients with any metastasis >5 cm were excluded from ablation; some patients with hepatocellular carcinoma >6 cm in size underwent ablation. Patients from our previous pilot study of microwave ablation were included in the present study.[9]

For patients who underwent hepatic resection in combination with microwave ablation, anatomic segmental liver resections or wedge resections were performed. Liver resections were classified as described by Couinaud.[10] For patients with disease that was believed to be unresectable because of the number, distribution, and/or location of the tumors, or because of patient comorbid factors, ablation was performed. Microwave ablation was performed using intraoperative ultrasound guidance to ensure that at least a 1-cm ablation margin was achieved around the tumors. Resectability was defined by the ability to resect and or ablate all visible tumor and leave enough viable normal liver for recovery.[11]

All patients underwent open or laparoscopic microwave ablation utilizing the Evident™ Microwave Ablation System (Covidien, Interventional Oncology, Boulder, CO). Two types of microwave probes were used for this study: the open surgical antenna, which is 17 cm in length, 14-gauge, with a 3.7-cm radiating active tip; and the laparoscopic antenna, which is 17 or 22 cm in length, 13-gauge, with a 3.7-cm active tip.

The laparoscopic approach was utilized, when possible, in patients with hepatocellular carcinoma who had a solitary tumor. A standard bracketed technique of placing multiple (maximum 3) probes around the periphery of the tumor was utilized in most cases; smaller tumors (<1.5 cm) often were treated with a single probe.[9] In all cases with multiple tumors, multiple ablations of hepatic lesions were performed simultaneously. The use of single or multiple probes was made at the surgeon's discretion, based on tumor size, tumor vascularity, nonliver tumor parenchyma, and intra-ablation ultrasound ablation assessment.

Complications and the length of hospital stay were prospectively evaluated and graded according to a standard five-point grading scale as described previously.[12,13] All in-hospital and 30-day postoperative complications were coded with the highest severity level recorded. Perioperative complications were defined as complications occurring within 30 days of the operation, with delayed complications defined as after 30 days. Contrast-enhanced, thin-cut, triple-phase CT scans were obtained during the immediate postoperative period (within 2 weeks) to define ablation success, and every 3–6 months thereafter. All patients were followed and none were lost to follow-up. Recurrence was evaluated using serological markers, PET scan (for metastatic colorectal cancer), and in some cases, octreotide scan (for metastatic carcinoid tumors) at the same intervals.

The *a priori* primary end points were: (1) rate of complete ablation of liver tumors (ablation success); (2) ablation recurrence defined as recurrent disease within 1 cm from ablated site(s); (3) hepatic recurrence at non-ablated sites; and (4) morbidity and mortality associated with the surgical procedure. We used CT confirmed complete ablation as our primary end point for sample size determination.

Our statistical assumptions when designing the trial were as follows: alpha risk of 0.05, beta risk of 0.9, recurrence of tumor at ablated site(s) of 17%;[14] the number of patients needed to treat to reduce ablation recurrence to <5% was estimated to be 90. Assuming a post-planned treatment dropout of 10%, the sample size required for this study was estimated to be 100 patients.

The definition of complete ablation was the radiologic evaluation at both the initial CT scan (within 2 weeks of ablation) in which all radiologic viable tumor was ablated with a lack of vascular perfusion on triple phase CT of the liver. An ablation recurrence defined as the appearance of viable tumor by both CT criteria, which was confirmed by PET scan. This represents a continuation of our phase II

study that was published previously to evaluate a larger cohort of patients and allow for longer follow-up.[9]

A planned matched comparison of microwave and radiofrequency ablation in regards to ablation time, operative time, and hospital charges was performed. Matched cases in the same hospital system were compared in terms of the number of tumors, histology, ablation time, ablation success, ablation recurrence, and hospital charges were compared to evaluate differences in success and efficiency.

Fisher's exact test, Student's *t*-test, and Mann–Whitney *U* test for nominal, continuous, and ordinal variables were used to evaluate the association of independent variables to surgical complications. Proportional hazards analysis was performed on all variables found significant by bivariate analysis. Relative risk (RR) with 95% confidence intervals was calculated as a measure of association. Differences of $P < 0.05$ where considered significant. Statistical analysis was performed using JMP software (JMP; SAS Institute Inc., Cary, NC).

RESULTS

Microwave ablation was utilized to treat 270 hepatic tumors in 100 patients. There were 55 men and 45 women (median age, 60 (range, 27–84) years). The majority (93%) was white; 6% were African American, and one patient was of Asian descent. Cancer types treated included metastatic colorectal cancer (50%), hepatocellular cancer (HCC; 17%), and metastatic carcinoid tumor (11%); miscellaneous tumor types (22%) included cholangiocarcinoma, metastatic breast cancer, metastatic renal cell carcinoma, metastatic bladder, metastatic carcinoid, metastatic melanoma, and metastatic sarcoma.

Microwave ablation was utilized to treat a median of two (range, 1–18) tumors per patient. The median size of the largest lesion was 3 (range, 0.6–6.0) cm in maximum diameter. The location of these tumors was fairly evenly distributed between the right lobe (55%) and the left lobe (45%). Patients with metastatic tumors commonly underwent microwave ablation of multiple lesions, whereas the median number of tumors for patients with HCC ablated was one (Table 1). An open operative approach was used in 68% of patients and a laparoscopic approach was used in the remaining 32% of patients. Concomitant hepatectomy was performed in 53% of these patients and a concomitant extrahepatic organ resection was performed in 23%.

The median total ablation time was 13 (range, 5–45) minutes, which was facilitated by the ability to perform

TABLE 1 Clinical and operative demographics of 100 patients who underwent microwave ablation

	Metastatic colorectal cancer ($n = 50$)	Hepatocellular cancer ($n = 17$)	Metastatic carcinoid ($n = 11$)	Other metastatic disease ($n = 22$)	*P*
Male/female ratio	32/18	10/7	4/7	9/12	0.2
Decent					
White	44	16	11	21	0.3
African American	5	1	0	0	
Other	1	0	0	0	
Age (yr)	59 (38–84)	68 (41–83)	61 (50–80)	58 (34–76)	0.07
No. tumors Median (range)	2 (1–12)	1 (1–5)	4 (1–13)	1 (1–14)	0.003
Largest size (cm)					
Median (range)	3 (0.8–6)	4 (2–5.9)	2.5 (1–4.5)	2 (0.6–4.5)	<0.001
Mean (SE)	2.4 (0.3)	4.1 (0.3)	2.9 (0.2)	2.4 (0.2)	
Ablation time (min)					
Median (range)	10 (5–45)	15 (2–25)	20.5 (10–35)	10 (5-25)	0.14
Mean (SE)	14.5 (1.4)	14.8 (2.2)	20.4 (2.9)	12.5 (1.3)	
No. microwave antennas utilized for largest lesion Median (range)	2 (1–3)	3 (1–3)	1 (1–1)	2(1–3)	0.14
Operative time					
Median (range)	140 (47–240)	100 (60–170)	146 (60–249)	125 (60–240)	0.09
Mean (SE)	138.3 (6.6)	108.6 (10.8)	148.1 (14.2)	131 (11.1)	
Incision					
Laparoscopic	11	9	3	8	0.12
Open	39	8	8	13	
Estimated blood loss	200 (50–2000)	100 (20–300)	225 (90–500)	150 (20–600)	0.17

multiple ablations simultaneously. The median OR time was 131 (range, 47–249) minutes with a median estimated blood loss of 200 mL (range, minimal to 2000 ml). Median length of stay for all patients was 5 (range, 1–25) days. Overall, 35 patients sustained 37 complications, with a median complication grade of 2 (range, 1–3). Hepatic insufficiency occurred in two patients, both of which resolved: one at 18 days, the other at 48 days. There were no perioperative deaths. Two patients (2%) who had ablation specific complications of hepatic abscess that required percutaneous drainage. The overall ablation success was 98%, with only two incomplete ablations. One patient had to have hepatic arterial therapy with LC Bead, and the other underwent percutaneous ablation to the residual area. The median tumor volume of the largest lesion ablated was 50.2 (range, 11.2–1256) cm^3.

Fifty percent of all patients treated had metastatic colorectal cancer (Table 1). In this subgroup, the median number of tumors was two. The median largest lesion that was ablated was 3 (range, 0.8–6.0) cm. Median ablation time was 10 min with a median operating room time of 140 min. The most common access was through an open laparotomy, predominantly because 30 of these patients had a concomitant hepatectomy and 15 had a concomitant colorectal cancer resection. Median estimated blood loss was 200 ml. Fifteen patients sustained 20 complications, with the highest grade of complication being a grade 3 (range, 1–3) and a median length of stay of 6 days (Table 2).

The next most common histology treated was HCC (Table 1). The distribution of the Child-Pugh scores for the HCC cohort was as follows: eight were noncirrhotic HCC and nine were Child-Pugh B, not amenable to transplant because of age, transplant refusal, or were outside of transplant criteria. The median number of tumors ablated was 1, with the median largest lesion treated 4.0 (range, 2.0–5.9) cm. Median ablation time was 15 min, and the median operating room time was 100 min. There was an even distribution of access through a laparoscopic incision or an open incision; only five patients underwent concomitant hepatectomy at the same time as microwave ablation. Four patients sustained six complications. The median highest complication grade was 2, and the length of stay in these patients was 3 (range, 1–10) days (Table 2).

The third most common histology was metastatic carcinoid tumor (Table 1). The median number of tumors treated was four (range, 1–13); the median largest lesion was 2.5 cm in size (range, 1.0–4.5 cm). Median ablation time was 20 min, and the median operating room time was 146 min. Most of these patients had an open operation because the majority underwent concomitant hepatectomy and/or extrahepatic organ resection, most commonly to resect the primary carcinoid tumor. Three patients sustained five complications; the median highest grade was 1 (range, 1–2) and median length of stay was 6 (range, 1–25) days (Table 2). The remaining patients who were treated with microwave ablation with metastases from other types of primary tumors had a similar overall clinical and ablation demographics as the metastatic carcinoid patients. Metastatic carcinoid had the lowest overall ablation success (90%), based on the multiplicity of the lesions attempting to be treated. The ablation failures were found

TABLE 2 Microwave ablation success, complications, and severity of complications

	Metastatic colorectal cancer ($n = 50$)	Hepatocellular cancer ($n = 17$)	Metastatic carcinoid ($n = 11$)	Other metastatic disease ($n = 22$)	*P*
Ablation success	98%	100%	90%	100%	0.3
Ablation volume of largest lesion (cm^3) (range)	56.9 (23.8–1256)	125.8 (21.2–243.6)	29 (17.7–95.3)	33.9 (11.95–502.4)	0.7
Concomitant hepatectomy					
Yes	30	5	7	11	0.16
No	20	12	4	10	
Concomitant extrahepatic tumor resection					
Yes	15	0	6	2	0.0004
No	35	17	5	19	
Complications					
Yes	15	4	3	7	0.8
No	30	13	8	14	
Highest Complication grade median (range)	3 (1–3)	2 (2–3)	1 (1–4)	2 (1–3)	0.7
LOS median (range)	6 (1–14)	3 (1–10)	6 (1–25)	4 (1–10)	0.008

LOS length of stay

on the postoperative CT in which all lesions that had planned to be treated preoperatively were not found intraoperatively based on lesion size and ultrasound image accuracy compared with CT with thin cuts and intravenous contrast.

In an evaluation of the overall ablation volume that was created in relation to the largest lesion ablated, there was a statistically significant difference in overall ablation volume as assessed by postoperative CT scan, even though there was a nonstatistically significant difference in the size of the largest tumor ablated. The largest ablation volumes were seen in patients with HCC (Table 2), consistent with these being the largest tumors ablated in this study.

Only five patients in the study experienced recurrence at the ablated site; most had metastatic colorectal cancer (Table 3). Hepatic recurrence at nonablated sites was relatively common in all groups. Extrahepatic recurrence also was evident in all but the HCC group (Table 3). After a median follow up of 36 (range, 2–60) months, differences in the median disease-free and overall survival rates among the various tumor subgroups are likely related to tumor biology and are consistent with other reports in the literature ($P = 0.01$; Fig. 1).[14–16]

Last, a matched pair evaluation of patients who underwent radiofrequency ablation with a similar cohort of patients who underwent microwave ablation was performed (Table 4). Patients were matched for sex, age, histology, number of tumors, size of tumors, operative exposure, and the lack of the need to perform additional concomitant hepatectomy or extrahepatic organ resection. These two groups were then evaluated for ablation success, ablation recurrence, and ablation time, all of which were significantly improved in the microwave ablation group. Ablation and operating times were significantly shorter in the microwave ablation group, primarily related to the ability to do simultaneous ablations with multiple probes.

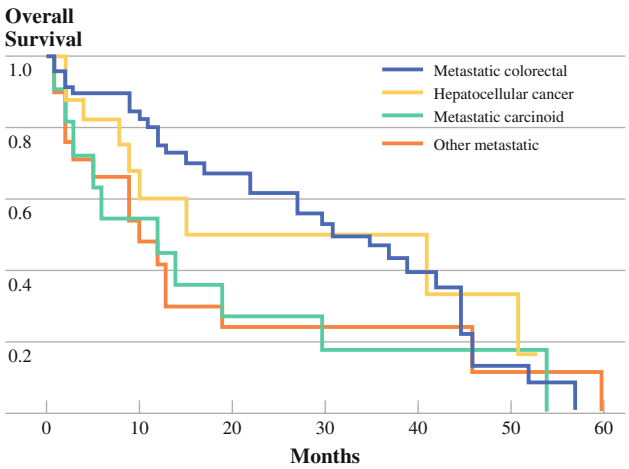


FIG. 1 Overall survival curve of patients treated with microwave ablation

The reduced ablation and operating room times led to a statistically significant improvement in operative room time, which subsequently translated to improvements in operating room charges, operating room variable direct charges, and operating room fixed direct charges ($P = 0.02$).

DISCUSSION

Microwave energy is an effective local thermal ablation technique for the treating of hepatocellular carcinoma, which exhibits many of the advantages over alternative ablation and resection techniques.[2,3,5,15] In the recent years, microwave ablation technology has undergone tremendous improvement due to the better understanding of energy delivery and technological advances that are currently now commercially available. This report represents the single largest evaluation of microwave ablation in unresectable

TABLE 3 Ablation recurrence, hepatic nonablation recurrence, disease-free survival, and overall survival in microwave-ablated patients

	Metastatic colorectal cancer ($n = 50$)	Hepatocellular cancer ($n = 17$)	Metastatic carcinoid ($n = 11$)	Other metastatic disease ($n = 22$)	*P*
Ablation recurrence	6% ($n = 3$)	6% ($n = 1$)	0	9% ($n = 2$)	0.6
Hepatic nonablation recurrence	19 (38%)	6 (35%)	3 (27%)	9 (40%)	0.4
Extrahepatic recurrence	6 (12%)	0 (0%)	2 (18%)	9 (40%)	0.14
Location of extrahepatic recurrence	Lung (5) Peritoneum (1) Lymph nodes (1)	NA	Bladder (1) Bone (1)	Brain (2) Bone (2) Lung (4) Peritoneum (1)	
Median disease-free survival (months)	12	18	8	6	0.04
Median overall survival (months)	36	41	18	12	0.01

TABLE 4 Matched ablation efficiency, success, recurrence, and operative changes in microwave- and radiofrequency-ablated patients

	Microwave ($n = 40$)	Radiofrequency ablation ($n = 40$)
No. tumors	1–2	1–2
Ablation success	98%	92%
Ablation recurrence	2%	17%
Ablation time (min)	13	40 (20–65)
OR time	56.9 (23.8–1256)	125.8 (21.2–243.6)
OR charges		
Median (range)	$13,389 ($8059–18,136)	$25,687 ($19,410–40,235)
OR variable direct charges	$909 ($562–1420)	$2903 ($2052–4503)
OR fixed direct charges	$514 ($337–628)	$787 ($565–1305)

OR operating room

hepatic tumors, demonstrating acceptable safety, superior efficacy, and long-term ablation success.

Microwave ablation refers to the electromagnetic method of inducing tumor destruction by using devices with frequency $\geq$900 MHz.[17] The rotation of the dipole molecules accounts for the efficient amount of heat generated during microwave ablation.[18] One or more molecules are dipoles with unequal electrical charge distribution, and they attempt to reorient continuously at the same rate in the microwave's oscillating electric field. As a result of the microwave transmission, the water molecules flip back and forth at a billion times a second leading to this vigorous movement to produce friction and heat, which leads to cellular death via coagulation necrosis. An additional mechanism responsible for heat generation in microwave ablation is ionic polarization, which occurs when ions move in response to the applied electric field of the microwave. The displaced ions cause collisions with other ions converting this kinetic energy into heat. However, this is the lesser of the two mechanisms that generate the efficient heat from microwave ablation.

The current frequencies of the commercially available microwave ablation devices are at 915 or 2450 MHz. The benefit of the 915-MHz microwave is that it can penetrate deeper than the 2450-MHz microwave, which may theoretically yield larger ablation zones. However, the energy deposition is influenced by the dielectric properties of the antenna design; thus, there are specific antenna design limitations that do not necessarily translate into the 915-MHz generator leading to larger ablations. We utilized the 915 system that is currently commercially available in the United States. These results further confirm our small pilot evaluation, as well as our collaborative evaluation in the initial use of this ablation device.[9,19]

Microwave ablation offers the same benefits of RFA, with a number of advantages. The zone of active tissue heating in RFA is limited to a few millimeters surrounding the active electrode with the remainder of the ablation occurring through thermal conduction.[20] Microwave ablation has a much broader field of power density up to 2 cm surrounding a single probe, with a correspondingly significantly larger zone of active heating.[6] This active zone has led to a much more uniform tumor ablation and subsequent tumor kill both within the targeted zone and next to blood vessels.[8] This method of heating overcomes the limitation of RFA, which is limited by an increase in impedance secondary to the outgassing of tissue and subsequent charring.[21] Similarly, the effectiveness of heating allows for greater energy deposition, more efficient and rapid temperature rise, and thus greater resistance to the "heat sink" effect of more vascular tumors or tumors that lie near major hepatic veins.

Microwave ablation has been reported to be effectively delivered through open laparotomy, laparoscopically, percutaneously, and even thorascopically in the appropriate patients.[4,9,15,22,23] Each approach offers advantages and disadvantages. The percutaneous approach is less invasive and does not require an operating room to perform the ablation. The potential disadvantages of percutaneous ablation are the inability to evaluate the surface of the liver and the inability to evaluate the abdomen for potentially more extensive disease. As demonstrated in metastatic colorectal, percutaneous ablation has the limitation of under-staging patients when relying on cross-sectional imaging. The potential advantages of the laparoscopic approach are the ability to truly evaluate the hepatic parenchyma on the surface of the liver and the peritoneal cavity for more precise staging; the limitation is that these require general anesthesia and an intra-abdominal access, which has the potential to be a greater risk for patients with marginal hepatic function.

Microwave ablation also can supplement hepatic resection. Combined resection and ablation has been found to be effective and safe in the management of patients with multifocal hepatocellular carcinoma.[24] The technique for microwave ablation requires the treating physician to have extensive knowledge of not only hepatic anatomy, but tumor biology and imaging. Ultrasound is currently the

most commonly used imaging technique for guidance of ablation because of its convenience and ability to continually allow for real-time evaluation of the ablation. However, ultrasound of the liver is a learned technique that must be optimized to appropriately and effectively treat patients utilizing microwave energy. Even with the advantages of microwave energy compared with radiofrequency ablation, microwave energy will not make a treating physician a better ablator of hepatocellular carcinoma if that treating physician does not have extensive knowledge in imaging guidance and image acquisition during the ablation process.

Accurate preablation imaging with ultrasound using B-mode or combination B-mode and harmonic contrast-enhanced ultrasound leads to precise lesion size estimation as well as defining potential moderate-to-large heat sink vessels from inflow or outflow structures. This allows for a more precise antenna placement strategy leading to a greater incidence of overall ablation success and significantly reduced ablation recurrence. This also allows for intra-ablation assessment to better define the need for single or multiple antennas, which might be needed based on tumor size, tumor vascularity, and nonliver tumor parenchyma. Given the rapidity of the heat generated using microwave ablation, the size of the ablation zone can be more precisely judged by the expanding hyperechoic area during the ablation especially during the first 3–5 min. Thermocoupling evaluation also has been reported to be utilized. Placed at 0.5 cm outside of the tumor margin and once target temperature of 60°C is reached or 54°C for at least 3 min is reached, then successful ablation has occurred.[24] Postablation contrast-enhanced ultrasound has been found to further enhance the accuracy of ablation using microwave, and if there is any residual tumor, then focal ablations can be performed in those certain areas.

Assessing the efficacy of microwave ablation is of utmost importance and needs to be further standardized to avoid the wide-ranging results that have plagued radiofrequency ablation. It has been recommended that an immediate follow-up CT (defined as within 1 month of ablation) be performed to accurately determine ablation success.[24] Repeat imaging at 3-month intervals for the first year and then at 6-month intervals thereafter is needed to accurately define ablation recurrence (recurrent disease within 1.0 cm of the ablation defect) as well as nonablation hepatic recurrence and, lastly, extrahepatic recurrence. Defining ablation success utilizing these four criteria is of utmost importance to accurately define the ablation technique as well as technology.

Our results are similar to others in the use of microwave ablation to treat hepatic malignancies. The largest reported use of microwave ablation system for HCC in a single institution evaluated 288 patients with 477 tumors.[25] This study yielded 1-, 2-, 3-, 4-, and 5-year cumulative survival results of 93, 82, 72, 63, and 51%, respectively, with local tumor recurrence or ablation recurrence in 8% of patients.[24] Similar results have been reported in smaller series in which Yamanaka et al. evaluated the therapeutic effects of microwave ablation in 27 patients compared with 23 patients who underwent hepatectomy.[26] They demonstrated that microwave ablation achieved long-term survivals equivalent to that obtained with hepatectomy with significantly lower complications rates. Abe et al. also reported 43 patients with hepatocellular carcinoma who were treated with microwave ablation and demonstrated a complete ablation rate of 93% for tumors measuring $\leq$4.0 cm, but only 38.5% ablation success for tumors $>$4.0 cm.[22] Through careful patient and tumor selection, ablation success can be achieved and should be at least 98% of better.

The limitation of this study is its single-institutional review, which brings a surgical bias to the use of ablation as a primary therapy. It has always been our bias to use ablation as an adjunct to resection and not to replace resection as the optimal technique. This limitation will need to be verified with multi-institutional reviews and possible clinical studies.

CONCLUSIONS

Microwave ablation represents a safe, reliable, fast, and efficacious way to perform hepatic ablation in patients with primary and secondary hepatic malignancies. The ability to perform bracketed ablations for tumors may result in a more complete initial ablation and possibly fewer local recurrences. The ability to perform multiple ablations simultaneously allows for a more efficient surgical procedure, especially in patients with multiple lesions and thus could translate into improved recovery and overall improvement in quality of life.

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