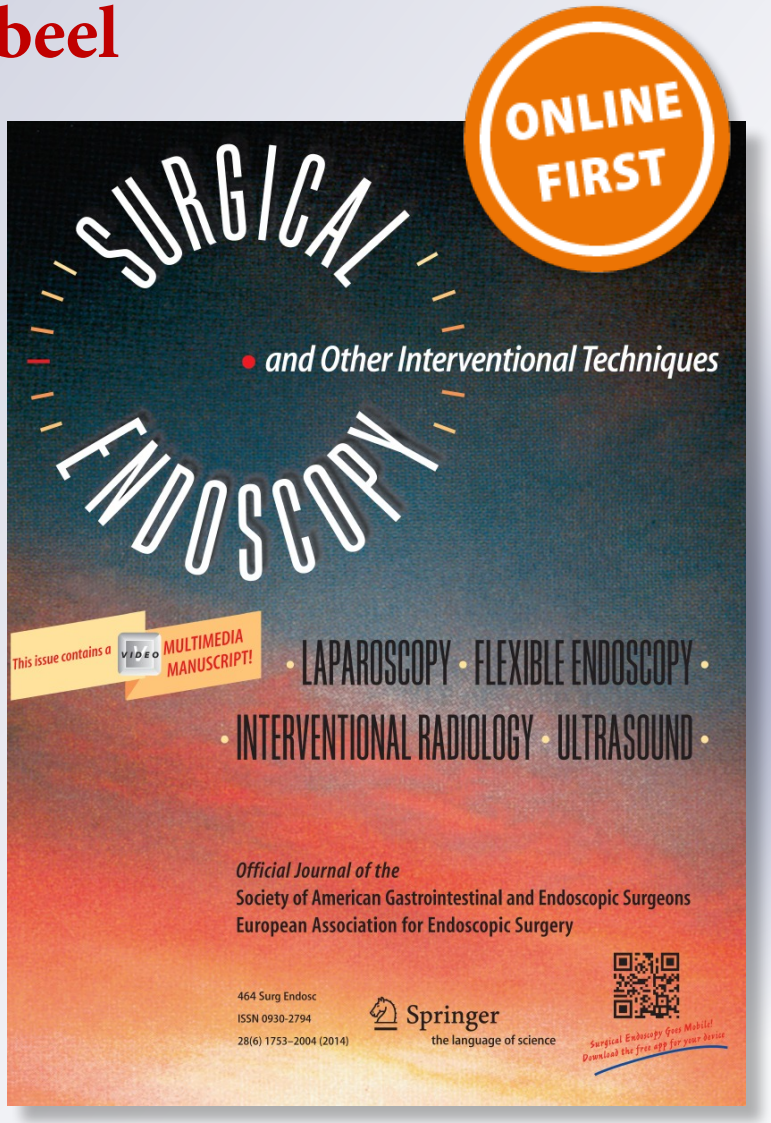
Efficacy and survival analysis of percutaneous radiofrequency versus microwave ablation for hepatocellular carcinoma: an egyptian multidisciplinary clinic experience

Ashraf Abdelaziz, Tamer Elbaz, Hend Ibrahim Shousha, Sherif Mahmoud, Mostafa Ibrahim, Ahmed Abdelmaksoud & Mohamed Nabeel

Surgical Endoscopy
And Other Interventional Techniques
Official Journal of the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and European Association for Endoscopic Surgery (EAES)

ISSN 0930-2794

Surg Endosc
DOI 10.1007/s00464-014-3617-4



Springer

Surg Endosc
DOI 10.1007/s00464-014-3617-4

Efficacy and survival analysis of percutaneous radiofrequency versus microwave ablation for hepatocellular carcinoma: an egyptian multidisciplinary clinic experience

Ashraf Abdelaziz · Tamer Elbaz · Hend Ibrahim Shousha · Sherif Mahmoud · Mostafa Ibrahim · Ahmed Abdelmaksoud · Mohamed Nabeel

Received: 21 December 2013 / Accepted: 14 May 2014

Abstract
Background Hepatocellular carcinoma (HCC) is a primary tumor of the liver with poor prognosis. For early stage HCC, treatment options include surgical resection, liver transplantation, and percutaneous ablation. Percutaneous ablative techniques (radiofrequency and microwave techniques) emerged as best therapeutic options for non-surgical patients.
Aims We aimed to determine the safety and efficacy of radiofrequency and microwave procedures for ablation of early stage HCC lesions and prospectively follow up our patients for survival analysis.
Patients and methods One Hundred and 11 patients with early HCC are managed in our multidisciplinary clinic using either radiofrequency or microwave ablation. Patients are assessed for efficacy and safety. Complete ablation rate, local recurrence, and overall survival analysis are compared between both procedures.
Results Radiofrequency ablation group ($n = 45$) and microwave ablation group ($n = 66$) were nearly comparable as regards the tumor and patients characteristics. Complete ablation was achieved in 94.2 and 96.1 % of patients managed by radiofrequency and microwave ablation techniques, respectively (p value 0.6) with a low rate of minor complications (11.1 and 3.2, respectively) including subcapsular hematoma, thigh burn, abdominal wall skin burn, and pleural effusion. Ablation rates did not differ between ablated lesions $\leq$3 and 3–5 cm. A lower incidence of local recurrence was observed in microwave group (3.9 vs. 13.5 % in radiofrequency group, p value 0.04). No difference between both groups as regards de novo lesions, portal vein thrombosis, and abdominal lymphadenopathy. The overall actuarial probability of survival was 91.6 % at 1 year and 86.1 % at 2 years with a higher survival rates noticed in microwave group but still without significant difference (p value 0.49).
Conclusion Radiofrequency and microwave ablations led to safe and equivalent ablation and survival rates (with superiority for microwave ablation as regards the incidence of local recurrence).

Keywords Hepatocellular carcinoma · Microwave · Radiofrequency · Survival

Hepatocellular carcinoma (HCC) was always labeled as a dismal primary tumor of the liver with high incidence, prevalence, and mortality rates. However, it is still a challenging potentially curable tumor with many treatment options that depend on tumor and patient-related factors [1]. Moreover, the recent focus on screening and surveillance for early detection and the improvement of the different therapeutic modalities led to a real change in the unpromising picture of HCC [2].

For early stage HCC, the tumor is potentially curable by different ablative techniques that include surgical resection, liver transplantation, and percutaneous ablation [3]. Although liver transplantation carries the greatest benefit of managing the tumor as well as the underlying precancerous liver cirrhosis, the lack of sufficient liver donation led to dropouts (as high as 25 %) from the waiting list due to either tumor growth

A. Abdelaziz · T. Elbaz · H. I. Shousha (✉) · S. Mahmoud · M. Ibrahim · M. Nabeel
Endemic Hepatogastroenterology Department, Faculty of Medicine, Kasr Al Ainy Hospital, Cairo University, Cairo 11562, Egypt
e-mail: hendshousha@yahoo.com

A. Abdelmaksoud
Diagnostic and Interventional Radiology Department, Cairo University, Cairo, Egypt

Published online: 17 June 2014

or development of contraindications to transplantation such as vascular invasion and extrahepatic spread [4]. Concerning surgical resection, survival rates can significantly drop if the patients are not properly selected with normal bilirubin and absent clinically significant portal hypertension [5]. Less than 5 % of cirrhotic patients with HCC fit these criteria [6].

Local ablation modalities emerged as the best therapeutic option for nonsurgical patients with early HCC. These percutaneous maneuvers carried many advantages such as the easy performance, safety and the possibility for repeated procedures [7]. Thermal ablation therapy gained a wide acceptance as a safe and effective curative therapy with long-term survival rates that are equivalent to surgical resection [8]. In a recent study, 5- and 10-year survival rates were 60.2 and 27.3 %, respectively, and the local tumor progression rates were both 3.2 % [9]. Radiofrequency ablation (RFA) technique, first described in 1993 [10], showed superior results in terms of prevention of recurrence and improvement of tumor necrosis in comparison to percutaneous ethanol injections [11]. A large recent systematic review for RFA concluded the possibility of use of this ablative technique for unresectable HCC cases as well as selected patients with resectable HCC [12]. Microwave ablation appeared as a more recent technique for tumor ablation with the capacity to perform larger and faster ablations and exceeding some limitations of RFA by guarding consistent higher intratumoral temperatures and ablating lesions that are nearby vessels [13].

Taking in consideration all these previous points of concern, we aimed in our study to determine the safety and efficacy of both techniques (radiofrequency and microwave procedures) for ablation of early stage HCC lesions and prospectively follow up our patients to clarify any survival advantage that can be provided by such techniques.

Patients and methods

Patients

In February 2009, a specialized multidisciplinary hepatocellular (HCC) carcinoma clinic was established in Kasr El Eini Hospital, Cairo University, Egypt. This multidisciplinary clinic includes hepatologists, diagnostic and interventional radiologists, hepatology surgeons, and clinical oncologists. All patients presented to our clinic are diagnosed and managed according to the EASL guidelines [14], AASLD updated practice guidelines for management of HCC [15], and BCLC guidelines [16] with a case-by-case discussion and in compliance with the ethics principles of the declaration of Helsinki with GCP guidelines.

Inclusion criteria: In respect to BCLC guidelines, we selected our patients for percutaneous ablative techniques as follows: Patients with early stage disease and preserved liver function (Child–Pugh A and B), performance status 0 and with 3 or less focal lesions (the largest not exceeding 5 cm in size) and a proper coagulation profile (prothrombin concentration >60 % and platelet count >50.000/mm^3). Patients who were eligible for resection or liver transplantation but not feasible (due to financial issues, unavailability of donors as we adopt Living donor liver transplantation in Egypt, or refusal of the patient for such modality of treatment) are also included.

A written informed consent is obtained from all managed patients. They are randomly divided by simple randomization (flipping coin) [17] into two groups: First group (radiofrequency group): it includes 45 patients managed by radiofrequency for their hepatic focal lesions. Second group (microwave group): it includes 66 patients who were subjected to microwave ablation.

Exclusion criteria: Child Pugh C patients, Portal vein thrombosis, distant metastases, Unacceptable coagulation profile, Tumors beyond selective criteria as regards their size and number or are technically difficult and nonfeasible (lesions settled near the portal vein or IVC).

Methods

The ablative procedures were ultrasonography guided using a Hitashi EUB-5500 machine with a 3.5–5 MHz probe. Microwave ablation was performed using an HS AMICA® microwave machine (HS Hospital service S.P.A. Roma, Italy), the so-called AMICA GEM machine. It operates at frequency of 2,450 MHz. 14 gage (150 and 200 mm) cooled shift electrodes named AMICA-probes were used to deliver the microwave energy into liver tissue. Concerning RFA, they were performed using 18 gage (200 mm) internally Cool tip electrodes (Radionics®) connected to a 500-KHz radiofrequency generator (Series CC-1; Radionics®).

All patients were early assessed after the ablative procedures for complications. Ultrasonography and laboratory assessments are performed to all cases 1 week later to the procedure. Thereafter, contrast-enhanced (triphasic) computed tomography (CT) imaging is performed 4 weeks post ablation and every 3 months during the follow-up period. Ablation was rated as complete when CT scans showed no contrast enhancement inside the lesion in the arterial phase. The ablation was rated as partial when CT scans show areas of enhancement within the boundaries of the original lesion in the arterial phase. Moreover, the diameter of the lesions is measured and primary recurrence or de novo

lesions are recorded. Finally, we will assess the therapeutic efficacy, safety, and overall survival in relation to radiofrequency and microwave ablation techniques.

Statistical analysis

Numerical data are reported as mean ± standard deviation (SD). Categorical data are represented as counts and percentages. The student *t* test and the Chi square test are used when appropriate. Statistical significance is considered if the probability of occurrence by chance is 5 % or less ($p < 0.05$). Survival analysis using the Kaplan–Meier method is performed from the date of primary diagnosis to the date of last follow up or death.

Results

In our multidisciplinary HCC clinic, 111 HCC patients were randomly managed either by radiofrequency ($n = 45$) or microwave ($n = 66$) ablation therapy and were prospectively followed up for HCC recurrence and survival assessment.

Concerning the demographic characteristics of the two studied groups, RFA patients were older in age compared to the microwave ablation patients with statistical significance. As it was not intended to select patients with age difference, we verified this difference by univariate analysis and found no impact on HCC recurrence or survival. Otherwise, no statistical significance was detected between both groups as regards their gender, Child Pugh classification, performance status, and alpha fetoprotein levels (Table 1). Similarly, ultrasonographic features of the focal lesions showed no statistical significance between both groups for the number and site of focal lesions as well as their size (even when sub classified to lesions with diameters either ≤3 or 3–5 cm). Right lobar single small lesions (≤3 cm) were the most predominant in both groups (Table 2).

We assessed the success rates of both procedures. Complete ablation was achieved in 94.2 and 96.1 % of patients managed by radiofrequency and microwave ablation techniques, respectively, without statistical significance. In addition, complete ablation rates did not differ statistically between both groups when we sub classified lesions again to ≤3 and 3–5 cm (Table 3). As we looked for procedure-related complications (Table 4), 11.1 % of RFA group suffered from complications as compared to 3.2 % only of the second group (microwave ablation group). Complications included subcapsular hematoma, thigh burn, abdominal wall skin burn, and pleural effusion. However, no statistical significance was detected between both groups.

Table 1 General characteristics of the studied groups

	Radiofrequency Ablation group	Microwave Ablation group	*p* value
Number of patients	45	66	
Age (years)	56.8 ± 7.3	53.6 ± 5	0.01
Gender			0.6
Male	31 (68.9 %)	48 (72.7 %)	
Female	14 (31.1 %)	18 (27.3 %)	
Child pugh			0.1
Child A	24 (53.3 %)	25 (37.9 %)	
Child B	21 (46.7 %)	41 (62.1 %)	
Performance status			0.4
0	21 (46.7 %)	28 (42.4 %)	
1	19 (42.2 %)	34 (51.5)	
2	5 (11.1 %)	3 (4.5 %)	
3	0 (0 %)	1 (1.5 %)	
Alpha fetoprotein (ng/ml)			0.5
Median	51	20	
Range	5–12,900	5–3,800	

Table 2 Ultrasonographic features of the focal lesions

	Radiofrequency ablation group	Microwave ablation group	*p* value
Number of patients	45	66	
Number of tumors			0.92
Single	39 (86.7 %)	57 (86.4 %)	
Two	5 (11.1 %)	8 (12.1 %)	
Three	1 (2.2 %)	1 (1.5 %)	
Site of tumors			0.08
Right lobe	37 (82.2 %)	62 (93.9 %)	
Left lobe	6 (13.3 %)	4 (6.1 %)	
Both lobes	2 (4.4 %)	0 (0 %)	
Size of the tumors			
Mean (cm)	2.95 ± 1.03	2.9 ± 0.97	0.78
Subclassified to:			0.21
≤3 cm	32/52 (61.5 %)	55/76 (72.4 %)	
3–5 cm	20/52 (38.5 %)	21/76 (27.6 %)	

Importantly, follow up of both groups showed a statistically significant lower incidence of local recurrence in the ablated HCC lesions in the microwave group (3.9 %) compared to the radiofrequency group (13.5 %) (p value 0.04). No difference between both groups was detected as regards the development of de novo lesions (13.6 and 22.2 %, respectively, p value 0.2), portal vein thrombosis, and abdominal lymphadenopathy (Table 5).

Table 3 Success rate of both procedures

	Radiofrequency ablation group	Microwave ablation group	*p* value
Total			0.6
Complete ablation	49/52 (94.2 %)	73/76 (96.1 %)	
Partial ablation	3/52 (5.8 %)	3/76 (3.9 %)	
Tumors ≤ 3 cm			0.2
Complete ablation	30/32 (93.8 %)	54/55 (98.2 %)	
Partial ablation	2/32 (6.2 %)	1/55 (1.8 %)	
Tumors 3–5 cm			0.5
Complete ablation	19/20 (95 %)	19/21 (90.5 %)	
Partial ablation	1/20 (5 %)	2 (9.5 %)	

Table 4 Procedure-related complications

	Radiofrequency ablation group	Microwave ablation group	*p* value
Complications	5 (11.1 %)	2 (3.2 %)	0.09
Subcapsular hematoma	2 (4.4 %)	1 (1.5 %)	
Thigh burn	1 (2.2 %)	0 (0 %)	
Abdominal wall skin burn	0 (0 %)	1 (1.5 %)	
Pleural effusion	2 (4.4 %)	0 (0 %)	

Table 5 Follow-up data of the studied groups

	Radiofrequency ablation group	Microwave ablation group	*p* value
Recurrence	7/52 (13.5 %)	3/76 (3.9 %)	0.04
De Novo lesions	10 (22.2 %)	9 (13.6 %)	0.2
Portal vein thrombosis	0 (0 %)	2 (3 %)	0.2
Abdominal lymph nodes	2 (4.4 %)	1 (1.5 %)	0.3

We finally performed survival analysis (Table 6; Fig. 1). By the end of the follow-up period, 58 patients (52.2 %) had dropped out, while 53 patients had completed the follow-up period (25 patients in the radiofrequency group and 28 patients in the microwave group). Fourteen patients (out of total 53 patients, 26.4 %) had died; 9 patients in the radiofrequency group and 5 patients in the microwave group. The causes of death were hepatic failure in 6 patients, gastrointestinal hemorrhage in 2 patients, spontaneous bacterial peritonitis in 2 patients, pulmonary embolism in one patient, and the cause of death was unknown for the rest of the patients. The overall median survival was 27 months from the date of diagnosis. The overall actuarial probability of survival was 91.6 % at 1 year and 86.1 % at 2 years, the actuarial probability of survival at 1 and 2 years for patients treated with microwave and radiofrequency was 96.4, 62, and 67.6 and 47.4 % without statistical significant difference (*p* value 0.49).

Table 6 Overall survival of studied patients

	Radiofrequency ablation group (n 25)	Microwave ablation group (n 28)	*p* value
Overall survival of total patients (n 53) 27 months			
1 year		91.6 %	
2 years		86.1 %	
Overall survival			0.49
1 year	67.6 %	96.4 %	
2 years	47.4 %	62 %	

n number

Discussion

One hundred and eleven patients with early HCC were managed in our multidisciplinary clinic using either radiofrequency or microwave techniques to ablate their lesions. Apart from age, both groups were comparable as regards their patients and tumor characteristics. Most of our HCC lesions were found in the right lobe that could be explained by the issue that the right lobe is six times larger than the left lobe [18]. In compliance with BCLC guidelines, percutaneous techniques were performed to compensated cirrhotic patients (Child Pugh A/B and good performance status) and with three or less focal lesions (the largest not exceeding 5 cm in size). We divided the tumors according to their sizes to ≤3 or 3–5 cm.

Both radiofrequency and microwave techniques have a similar mechanism based on the generation of friction heat between the tissue and the electric current or the microwave. That heat leads to coagulation followed by cellular death when the intratumoral temperature exceeds 60 °C [7]. In our experience, we achieved good success rates with both techniques (94.2 and 96.1 % for radiofrequency and microwave techniques, respectively). The success rate was not statistically significantly different between both procedures. However, we highlight a lower incidence of HCC recurrence in the microwave group when compared to the radiofrequency group (3.9 vs. 13.5 %, *p* value 0.04). Some studies showed superiority for radiofrequency [19] but the

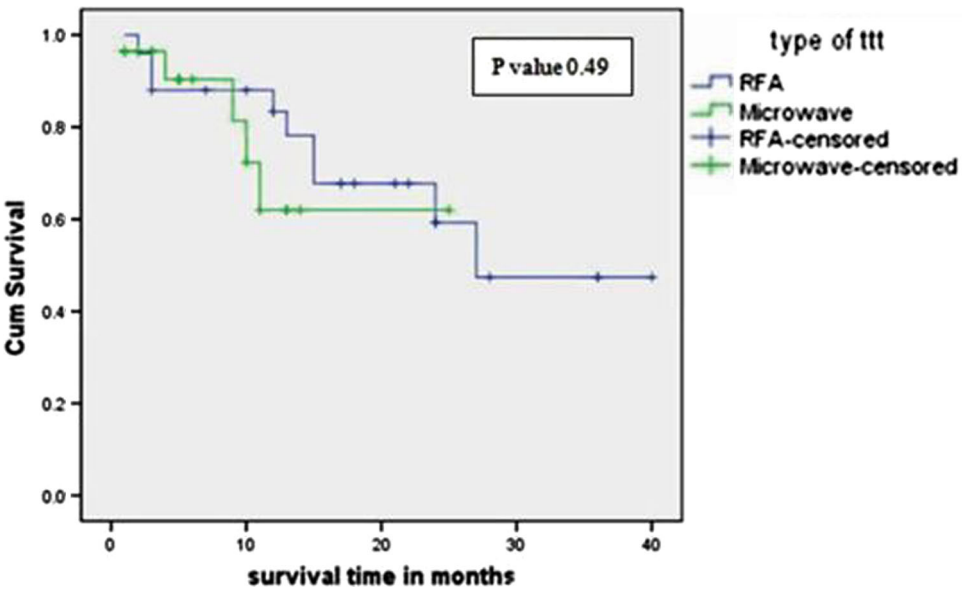


Fig. 1 Kaplan–Meier survival analysis of the studied groups

vast majority of studies showed either an equivalent role for both techniques [20–22] or even an upper hand for microwave technique [23, 24]. Although the resulting coagulation necrosis is similar in histopathological examination in both ablative procedures [25, 26], many factors can lead to different endpoints. Site of tumors plays an important role. Lesions in proximity to vessels are best ablated by microwave than radiofrequency [27, 28] with a consequent lower rate of local recurrence. Multiple applicators for microwave ablation can be performed simultaneously in the same session [24]. The type of microwave generator (either 915 or 2,450 MHz) and the delivered power (either 40 or 60 W) may also affect the results.

In addition, we report that larger lesions (3–5 cm) showed similar complete ablation rates to smaller ones ($\leq$3 cm) with both techniques. Similar results were recently published by Lu et al. [21] when they compared both ablative techniques for lesions 3 cm or less and other lesions more than 3 m. Moreover, Yin et al. [29] ablated lesions between 3 and 7 cm and still an acceptable tumor control and long-term outcomes were found with large lesions. One of the main benefits of percutaneous ablative techniques is their safety.

We recorded a small rate of minor complications (11.1 % of RFA patients and 3.2 % only of the microwave group). No major complications or death occurred with both techniques. A large multicentric Italian study that included 14 centers that performed microwave ablations for 736 patients with 1,037 lesions finally confirmed the safety of microwave procedures with low rate of major complications [30]. Another systematic review for both ablative techniques (radiofrequency and microwave) declared the same conclusion of safety of both techniques with a low rate of acceptable complications (4.1 and 4.6 % for radiofrequency and microwave techniques, respectively) [20].

During the follow-up period, 52.2 % of patients dropped out. This large rate of dropouts can be explained by the absence of a national computerized registry system. Without any cost or payment, our unit provides service management of HCC for all Egyptian governments. We depended on phone calls to push and remind patients for follow up and the success to contact some people was not possible.

Our overall median survival was 27 months from the date of diagnosis. The overall actuarial probability of survival was 91.6 % at 1 year and 86.1 % at 2 years. Higher actuarial probability of survival at 1 and 2 years was evident for patients treated with microwave patients (96.4 and 62 %, respectively) when compared to radiofrequency patients (67.6 and 47.4 %, respectively) without statistical significant difference. These survival rates are acceptable and compared to else studies that showed similar results [21] and are even equivalent to survival rates from surgical resections.

In summary, we concluded that radiofrequency and microwave ablations led to safe and equivalent ablation and survival rates (with superiority for microwave ablation as regards the incidence of local recurrence). Both ablative techniques are a good replacement to surgical interference for patients who are not fit for surgical resection.

Disclosure Drs. Ashraf Omar Abdelaziz, Tamer Mahmoud Elbaz, Sherif Hamdy Mahmoud, Hend Ibrahim Shousha, Mostafa Mohamed Ibrahim, Ahmed Hosni Abdelmaksoud, and Mohamed Mahmoud Nabeel) have any conflicts of interest to disclose. No financial or any other support was supplied by any other party.

References

1. Elbaz T, Kassas M, Esmat G (2013) Management of hepatocellular carcinoma: updated review. J Cancer Ther 4(2):536–545
2. Esmat G, Elbaz T, Kassas M (2013) Hepatocellular carcinoma in Egypt: an updated status. Liver cancer: act today, save your life tomorrow. World Gastroenterology Organisation (WGO). WDHD 2013 Final Publication. www.wgofoundation.org/WDHD-2013-Final-Publication.pdf
3. Bruix J, Sherman M (2005) Management of hepatocellular carcinoma. Hepatology 42:1208–1236
4. Yao FY, Bass NM, Nikolai B, Davern TJ, Kerlan R, Wu V, Ascher NL, Roberts JP (2002) Liver transplantation for hepatocellular carcinoma: analysis of survival according to the intention-to-treat principle and dropout from the waiting list. Liver Transplant 8:873–883
5. Llovet JM, Fuster J, Bruix J (1999) Intention-to-treat analysis of surgical treatment for early hepatocellular carcinoma: resection versus transplantation. Hepatology 30:1434–1440
6. Crocetti L, Lencioni R (2008) Thermal ablation of hepatocellular carcinoma. Cancer Imaging 8(1):19–26
7. Lin S-M, Lin D-Y (2003) Percutaneous local ablation therapy in small hepatocellular carcinoma. Chang Gung Med J 26:308–314
8. Kuang M, Xie XY, Huang C, Wang Y, Lin MX, Xu ZF, Liu GJ, Lu MD (2011) Long-term outcome of percutaneous ablation in very early-stage hepatocellular carcinoma. J Gastrointest Surg 15(12):2165–2171
9. Shiina S, Tateishi R, Arano T, Uchino K, Enooku K, Nakagawa H, Asaoka Y, Sato T, Masuzaki R, Kondo Y, Goto T, Yoshida H, Omata M, Koike K (2012) Radiofrequency ablation for hepatocellular carcinoma: 10-year outcome and prognostic factors. Am J Gastroenterol 107(4):569–577
10. Rossi S, Fornari F, Buscarini L (1993) Percutaneous ultrasound-guided radio-frequency electrocautery for the treatment of small hepatocellular carcinoma. J Interv Radiol 8:97–103
11. Salhab M, Canelo R (2011) An overview of evidence-based management of hepatocellular carcinoma: a meta-analysis. J Cancer Res Ther 7(4):463–475
12. Tiong L, Maddern GJ (2011) Systematic review and meta-analysis of survival and disease recurrence after radiofrequency ablation for hepatocellular carcinoma. Br J Surg 98(9):1210–1224
13. Poggi G, Montagna B, DI Cesare P, Riva G, Bernardo G, Mazzucco M, Riccardi A (2013) Microwave ablation of hepatocellular carcinoma using a new percutaneous device: preliminary results. Anticancer Res 33(3):1221–1227
14. Bruix J, Sherman M, Llovet JM (2001) EASL Panel of Experts on HCC. Clinical management of hepatocellular carcinoma. Conclusions of the Barcelona-2000 EASL conference. European Association for the Study of the Liver. J Hepatol 35(3):421–430
15. Bruix J, Sherman M (2011) American Association for the Study of Liver Diseases. Management of hepatocellular carcinoma: an update. Hepatology 53(3):1020–1022
16. Llovet JM, Bustamante J, Castells A, Vilana R, Ayuso Mdel C, Sala M, Brú C, Rodés J, Bruix J (1999) Natural history of untreated nonsurgical hepatocellular carcinoma: rationale for the design and evaluation of therapeutic trials. Hepatology 29(1):62–67
17. Suresh K (2011) An overview of randomization techniques: an unbiased assessment of outcome in clinical research. J Hum Reprod Sci 4(1):8–11
18. Portmann BC (2000) Anatomy of the normal liver: Comprehensive clinical hepatology. O'Grady J, Lake J, Howdle P, 1st edn: London, Edinburgh, New York, Philadelphia, Sydney and Toronto. Chap.1. P1.1
19. Ohmoto K, Yoshioka N, Tomiyama Y, Shibata N, Kawase T, Yoshida K, Kuboki M, Yamamoto S (2009) Comparison of therapeutic effects between radiofrequency ablation and percutaneous microwave coagulation therapy for small hepatocellular carcinomas. J Gastroenterol Hepatol 24(2):223–227
20. Bertot LC, Sato M, Tateishi R, Yoshida H, Koike K (2011) Mortality and complication rates of percutaneous ablative techniques for the treatment of liver tumors: a systematic review. Eur Radiol 21(12):2584–2596
21. Lu MD, Xu HX, Xie XY, Yin XY, Chen JW, Kuang M, Xu ZF, Liu GJ, Zheng YL (2005) Percutaneous microwave and radiofrequency ablation for hepatocellular carcinoma: a retrospective comparative study. J Gastroenterol 40(11):1054–1060
22. Signoriello S, Annunziata A, Lama N, Signoriello G, Chiodini P, De Sio I, Daniele B, Di Costanzo GG, Calise F, Olivieri G, Castaldo V, Lanzetta R, Piai G, Marone G, Visconti M, Fusco M, Di Maio M, Perrone F, Gallo C, Gaeta GB (2012) Survival after locoregional treatments for hepatocellular carcinoma: a cohort study in real-world patients. Sci World J 2012:564706
23. Qian GJ, Wang N, Shen Q, Sheng YH, Zhao JQ, Kuang M, Liu GJ, Wu MC (2012) Efficacy of microwave versus radiofrequency ablation for treatment of small hepatocellular carcinoma: experimental and clinical studies. Eur Radiol 22(9):1983–1990
24. Lencioni R, Crocetti L (2012) Local-Regional Treatment of Hepatocellular Carcinoma. Radiology 262:43–58
25. Boss A, Dupuy D, Pereira PL (2008) Microwave. In: Vogl TJ, Helmberger TK, Mack MG, Reiser MF (eds) Percutaneous tumor ablation in medical radiology, 1st edn. Springer, Berlin, pp 21–28
26. Simon CJ, Dupuy DE, Mayo-Smith WW (2005) Microwave ablation: principles and applications. Radiographics 25(1):S69–S83
27. Lu DS, Yu NC, Raman SS, Limanond P, Lassman C, Murray K, Tong MJ, Amado RG, Busuttil RW (2005) Radiofrequency ablation of hepatocellular carcinoma: treatment success as defined by histologic examination of the explanted liver. Radiology 234(3):954–960
28. Yu NC, Raman SS, Kim YJ, Lassman C, Chang X, Lu DS (2008) Microwave liver ablation: influence of hepatic vein size on heat-sink effect in a porcine model. J Vasc Interv Radiol 19(7):1087–1092
29. Yin XY, Xie XY, Lu MD, Xu HX, Xu ZF, Kuang M, Liu GJ, Liang JY, Lau WY (2009) Percutaneous thermal ablation of medium and large hepatocellular carcinoma: long-term outcome and prognostic factors. Cancer 115(9):1914–1923
30. Livraghi T, Meloni F, Solbiati L, Zanus G (2012) Collaborative Italian Group using AMICA system. Complications of microwave ablation for liver tumors: results of a multicenter study. Cardiovasc Intervent Radiol 35(4):868–874