Cardiovasc Intervent Radiol (2014) 37:1299–1305
DOI 10.1007/s00270-014-0934-x

CLINICAL INVESTIGATION INTERVENTIONAL ONCOLOGY

Microwave Ablation of Giant Hepatic Cavernous Hemangiomas

Timothy J. Ziemlewicz · Shane A. Wells · Meghan A. Lubner · Alexandru I. Musat · J. Louis Hinshaw · Alexandra R. Cohn · Fred T. Lee Jr.

Received: 29 January 2014 / Accepted: 21 April 2014 / Published online: 15 July 2014

Abstract

Purpose This study was designed to explore the safety and efficacy of percutaneous microwave (MW) ablation as an alternative treatment for symptomatic giant hepatic hemangiomas.

Methods Patients ($n = 7$; 6 females, 1 male; mean age = 44 years) with symptomatic, giant hemangiomas ($n = 8$) were treated with ultrasound-guided percutaneous MW ablation and followed for a mean of 18 months. Patient pain was recorded both before and after the procedure according to the 10-point visual analog scale. All patients were treated using one or three gas-cooled 17-gauge antennas powered by a 2.4-GHz generator (Neuwave Medical, Madison, WI). Mean ablation time was 11.6 min. Four patients received hydrodissection to protect the abdominal wall, colon, or gallbladder (5 % dextrose in water, mean volume 900 mL). Immediate postablation biphasic CT of the abdomen was performed, and four of seven patients have undergone delayed follow-up imaging.

Results All ablations were technically successful with no major or minor complications. Average pain score decreased from 4.6 to 0.9 ($p < 0.05$), and six of seven patients report resolution or improvement of symptoms at 18-month average follow-up (range 1–33 months). Immediately postablation, mean tumor diameter decreased 25 % (from 7.3 to 5.5 cm, $p < 0.05$) and volume decreased 62 % (from 301 to 113 cm^3, $p < 0.05$).

Discussion In this series, percutaneous MW ablation was safe, well-tolerated, and effective in markedly shrinking large hepatic hemangiomas and improving symptoms in most patients.

Keywords Hepatic hemangioma · Giant hemangioma · Cavernous hemangioma · Microwave ablation · Thermal ablation · Radiofrequency ablation

T. J. Ziemlewicz (✉) · S. A. Wells · M. A. Lubner · J. L. Hinshaw · A. R. Cohn · F. T. Lee Jr.
Department of Radiology, University of Wisconsin School of Medicine and Public Health, 600 Highland Avenue, E3/366, Madison, WI 53792-3252, USA
e-mail: tziemlewicz@uwhealth.org

S. A. Wells
e-mail: shaneawells@gmail.com

M. A. Lubner
e-mail: mlubner@uwhealth.org

J. L. Hinshaw
e-mail: jhinshaw@uwhealth.org

A. R. Cohn
e-mail: arcohn@wisc.edu

F. T. Lee Jr.
e-mail: flee@uwhealth.org

A. I. Musat
Department of Medicine, Division of Hepatology, University of Wisconsin School of Medicine and Public Health, 750 Highland Avenue, Madison, WI 53726, USA
e-mail: aim@medicine.wisc.edu

Introduction

Hepatic hemangiomas are the most common benign hepatic neoplasm, with a reported incidence of 3–20 % in the general population [1]. Hemangiomas are composed of dilated, endothelial-lined vascular spaces separated by various amounts of fibrous tissue that can progressively enlarge, probably the result of vascular ectasia rather than true neoplastic proliferation or neovascularization [2, 3]. Hemangiomas are referred to as "giant" if greater than 4 cm in diameter and small if less than 1 cm [4]. The vast majority are small, follow an indolent course, and require no specific treatment or imaging follow-up. Infrequently, large or enlarging hepatic hemangiomas are symptomatic due to mass effect with the primary cause of pain thought to be capsular distention [5, 6]. While the risk of rupture is exceedingly low with only case reports in the literature, tumor rupture is associated with a mortality rate of 60 % in these reports [7]. In a large series of untreated patients with hemangiomas, the overall rate of potentially life-threatening complications is ~2 %, including rupture, hemobilia, heart failure, and Kasabach-Merritt syndrome [8].

Surgical resection has been considered the standard treatment for the few hemangiomas that need intervention. Unfortunately, resection is associated with up to 25 % morbidity, a long recovery period, missed time from work, and rare perioperative deaths [9, 10]. Minimally invasive strategies, such as transarterial embolization and radiation, have been reported with variable success and some morbidity [11–16]. The most extensively studied percutaneous ablation modality for treatment of hepatic hemangiomas is radiofrequency (RF) ablation. While generally effective for giant hepatic hemangiomas less than 7.5 cm, limited power and small ablation zones can result in long ablation times (29.4–126.5 min) and incomplete tumor devascularization requiring repeated ablation, presumably the result of perfusion-mediated tissue cooling (heat-sink) and limited power deposition [17–24].

Percutaneous microwave ablation is increasingly being used for the treatment of liver, lung, and renal malignancies [25–31]. In comparison to RF ablation, microwaves produce ablation zones that are hotter, larger, form faster, and are more reproducible [32, 33]. Microwaves rapidly oscillate polar molecules, such as water, and are therefore particularly effective for the treatment of tumors with high water content [34]. Because hemangiomas are composed primarily of vascular spaces and thus contain large amounts of intratumoral water, we hypothesized that microwave would be a highly effective percutaneous treatment modality. The purpose of this study was to evaluate the safety and technical as well as clinical effectiveness of microwave ablation of giant hepatic hemangiomas.

Materials and Methods

Patient Population

Institutional review board approval was obtained to de-identify a clinical database for research purposes, and a waiver of informed consent was granted. From December 2010 to September 2013, seven patients (6 females, 1 male; average age 44 years) with eight giant hepatic hemangiomas (mean diameter 7.3 cm, range 3.4–12.2 cm) were treated with image-guided percutaneous microwave (MW) ablation. The primary indication for treatment was abdominal pain. Before the procedure, the pain score, based on the visual analog scale, was recorded. Associated symptoms including nausea, vomiting, abdominal fullness, weight loss, and early satiety also were recorded. There were no asymptomatic patients in the cohort. Following thorough medical evaluation by a hepatologist or hepatic surgeon, no other clinical cause was found to explain symptoms. The diagnosis of hemangioma was made based on contrast-enhanced CT and/or MRI imaging demonstrating discontinuous peripheral nodular enhancement with centripetal fill-in in all patients.

Microwave Ablation Technique

Single-session, image-guided, percutaneous microwave ablation was performed in all patients. Following induction of general anesthesia and appropriate patient positioning and sterile preparation, real-time sonography (Logiq E9, GE Medical Systems, Waukesha, WI) was used to place 17-gauge microwave antennas using an intercostal or subcostal approach. Microwave energy (65–140 W) was deposited into each neoplasm with a 2.4 GHz generator and monitored using real-time sonography. For six tumors, three high-powered (0–140 W), gas-cooled, 17-gauge, liver-tuned antennas were powered simultaneously (Certus 140, LK antennas, Neuwave Medical, Madison, WI). For the other two tumors, a hemangioma abutting either the diaphragm or gallbladder was targeted using a modified triaxial antenna that produces a short ablation zone (Certus 140, PR antenna, NeuWave Medical, Madison, WI). Focused, unenhanced CT of the abdomen confirmed antenna position before ablation in six patients. Biphasic contrast-enhanced CT of the liver in a large-bore CT scanner (Lightspeed Ultra, GE Medical) using 150 mL of nonionic iodinated contrast material (Omnipaque 300, GE Healthcare) was performed immediately following antenna removal to evaluate the ablation zone, presence of residual perfused hemangioma, and to assess for immediate complications. Technical effectiveness was defined by treatment of 90–100 % of the volume of the hemangioma, as the goal was to debulk the tumor while minimizing the risk of complications. Complications were classified according to the Society of Interventional Radiology Classification system for Complications by Outcome [35]. In four patients, hydrodissection with 5 % dextrose in water (D5 W, mean volume 900 mL) was necessary before ablation to protect nontarget structures, specifically diaphragm, abdominal wall, colon, and gallbladder (Fig. 1).

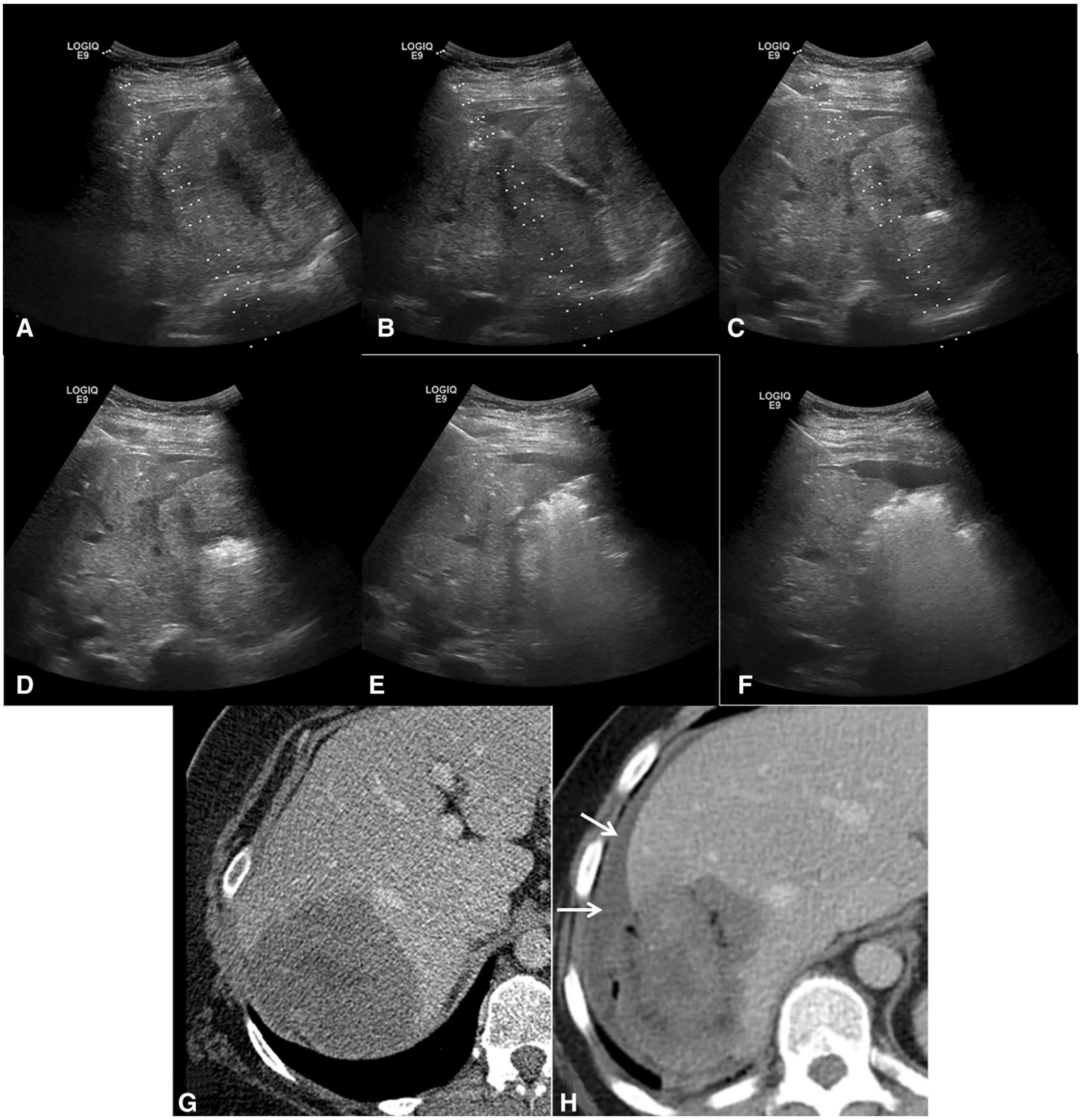

Fig. 1 Intraprocedural ultrasound images of 39-year-old female with a giant hemangioma. Pre-procedure diameter = 8.9 cm, volume = 382 mL. Postprocedure diameter = 5.4 cm, volume = 82 mL. **A** Pre-procedure ultrasound. **B** One of three antennas utilized in this case placed in the center of the hemangioma by US. **C** US image obtained within 10 s of beginning ablation, showing early gas bubble formation along the antenna. **D** US image obtained following 30 s of ablation with a single antenna. **E** US image obtained following 2 min of ablation with a single antenna. **F** US image at completion of procedure with entire hemangioma encompassed by gas. **G** Pre-procedure contrast-enhanced CT. **H** Post-procedure contrast-enhanced CT (*arrows outline* D5 W instilled to protect the diaphragm). Note capsular retraction due to the marked decrease in the size of the tumor

Follow-Up

All patients were admitted overnight for observation per our standard protocol. Patients were contacted via phone 1 week postprocedure and at varying intervals up to 12 months postprocedure to monitor for delayed complications, evaluate symptom relief, and to determine impact of the procedure on daily function. Clinical effectiveness was defined as improvement of symptoms notated during follow-up. Patients were encouraged to return to normal activity, including vigorous exercise 1 week following the procedure. Because patients were referred for treatment of symptoms, there was no standard postprocedure imaging algorithm. Four of seven patients underwent follow-up imaging at the discretion of the referring physician at an average of 6 (range 3–12) months postprocedure.

Fig. 2 Hemangioma abutting porta hepatis of 40-year-old female with giant hemangioma in the central liver adjacent to the porta hepatis. Pre-procedure diameter = 8.1 cm, volume = 289 mL. Post-procedure diameter = 6.5 cm, volume = 151 mL. Pre-procedure CT images demonstrating proximity to main *left* (**A**) and *right* (**B**) portal veins. **C** and **D** Postprocedure CT images demonstrating intentional under treatment (untreated tumor identified by *arrows*) near main portal veins and associated bile ducts. *Arrowhead* in image **C** outlines the left hepatic duct

Results

Technical effectiveness was 100 % (8/8) with a mean ablation time of 11.6 (range 5.0–24.5) min. Three tumors were treated with ~90 % tumor ablation due to the peripheral or central location of the neoplasm and associated increased risk of thermal injury to the gallbladder or central biliary tree (Fig. 2). Three additional tumors demonstrated a minimal amount of residual enhancement following treatment, whereas two tumors were treated with 100 % coverage. Immediately following the procedure, there was a significant decrease of mean tumor diameter (7.3–5.5 cm, $p < 0.05$) and volume (301–113 mL, $p < 0.05$), corresponding to a 25 % decrease in diameter and 62 % decrease in volume. There was minimal procedural blood loss, no significant procedural complications, and no delayed adverse events. Mean patient follow-up is 18 (range 1–33) months. In the four patients who underwent delayed imaging follow-up, there was a continued decrease from immediate postablation measurements in mean tumor diameter (6.0–5.2 cm) and volume (139–90 mL), corresponding to an overall 35 % decrease in tumor diameter and 76 % decrease in tumor volume in these four patients (Fig. 3). Patient, tumor, and procedure details are outlined in Table 1.

The procedure provided clinical effectiveness in six of seven patients who had complete pain relief or improvement of pain following the procedure. Two of six patients described pain relief at 1 week follow-up phone call, whereas the other four reported relief at either a clinic visit or phone consultation ranging from 1 to 6 months postablation. Overall pain score on the visual analog scale decreased from an average of 4.6–0.9 ($p < 0.05$). All patients were able to return to their pre-procedure level of activity within a week of the procedure. The one patient whose pain was unchanged after MW ablation underwent laparoscopic cholecystectomy with chronic acalculous cholecystitis noted at pathology and subsequently had complete pain relief. There had been no gallbladder abnormality noted on imaging before MW ablation. There was resolution of nausea and intermittent vomiting in the three patients who demonstrated one of these symptoms

Fig. 3 Largest treated hemangioma: 42-year-old female with a giant hemangioma. **A** T1-weighted postcontrast MRI demonstrating large hemangioma occupying the majority of the right hepatic lobe (diameter = 12.2 cm, volume = 951 mL). **B** CT image with IV contrast obtained 3 months postprocedure. Note the marked decrease in tumor size (diameter = 7.9 cm, volume = 268 mL). The right kidney has migrated cephalad due to the tumor shrinkage

Table 1 Patient characteristics, procedure details, and radiologic outcomes

Patient	Gender	Age	Follow-up (mo)	Ablation time (min)	Mean power (W)	Preablation diameter (cm)	Postablation diameter (cm)	Percent diameter change	Preablation volume (cc)	Postablation volume (cc)	Percent volume change
1	F	39	33	15	88	8.9	5.4	−39	382	82	−79
2	F	57	24	8	65	7.3	6.1	−16	212	120	−43
3	F	42	24	24.5	65	12.2	7.9	−35	951	268	−72
4	F	40	16	9	65	8.1	6.5	−20	289	151	−48
5	F	57	14	5	65	4.1	4	−2	39	34	−13
				8.5	70	3.4	3	−12	21	14	−33
6	M	41	10	6	56	4.4	3.5	−20	40	18	−55
7	F	32	1	17	96	9.8	7.7	−21	471	214	−55
Mean		44	18	11.6	71.3	7.3	5.5	−25	301	113	−62

Table 2 Patient symptom reporting

Patient	Pain score before ablation (*x*/10)	Pain score post ablation (*x*/10)	Character of pain
1	4	0	Constant ache
2	5	3	Constant pain, limits activities
3	3	0	Constant pain and fullness
4	6	0	Intermittent pain
5	8	0	Constant ache
6	3	3	Intermittent pain
7	3	0	Constant pain
Mean	4.6	0.9	**N/A**

pre-procedure and resolution of early satiety in the patient who experienced this before the procedure. Symptom details are outlined in Table 2.

Discussion

Most hepatic hemangiomas are small, asymptomatic, and require no treatment. However, up to 40 % of patients with hemangiomas of at least 4 cm present with symptoms due to capsular stretching or impingement on adjacent structures [5, 6]. Unfortunately, there is no definitive test to determine whether a particular hemangioma is responsible for symptoms or is simply an incidental coexistent condition. With the uncertainties of treating individual patients in mind, the ideal treatment modality would be minimally invasive, safe with very low morbidity, highly effective in reducing symptoms, and allow a rapid return to normal function. It is important to keep in mind that many of the trade-offs encountered during the treatment of cancer are not applicable to hepatic hemangiomas due to their benign natural history. Thus, a highly effective but morbid treatment would be a poor choice for most patients.

Open surgical resection of hemangiomas is a definitive treatment method but is associated with a 14 % perioperative complication rate, 7 % of which are life-threatening, as well as rare mortality and a prolonged recovery period [9, 10]. Less invasive surgical techniques, such as laparoscopic or robotic liver resections, are becoming more common and hold promise to reduce morbidity and speed recovery in selected patients [36, 37]. However, to date, the largest clinical experience remains with conventional open surgery.

Various percutaneous treatment methods have been proposed for hepatic hemangiomas, and the largest experience to date is with RF ablation. While the results of small case series have been excellent, particularly for smaller hemangiomas [17, 18, 21, 22, 24], RF (as a technology) has the potential to be replaced by MW for the treatment of benign and malignant tumors in the liver, kidney, and lung [26–30, 38]. MW devices create a uniform electromagnetic field surrounding antennas, causing rapid volume tissue heating by oscillation of polar water molecules. Because MW does not rely on the conduction of electrical current and is not limited by charring, tissue can be driven to very high temperatures. This translates to larger, faster, and more consistent ablation zones in tissue when compared to RF [32, 33]. For example, in one study of RF for hemangiomas, the mean treatment time was 39 min for tumors that ranged between 2.5 and 9.5 cm in diameter (no mean size was reported). The 9.5 cm tumor in that study required seven separate RF electrode insertions and 125 min of RF ablation [17]. In another report, a 7.5 cm hemangioma treated by RF required 40 min of ablation with three electrodes [21]. By way of comparison, the mean treatment time in the current MW study was 11.6 min. The largest hemangioma in this series (12.2 cm mean diameter, 951 mL volume) was successfully treated by MW in only 24.5 min of ablation time. This more rapid treatment time and decreased number of punctures has the potential to decrease anesthesia and bleeding complications. The inherently high water content of hepatic hemangiomas appears to be a near ideal substrate for heating by microwaves, and the very slow circulation time in the tumor may limit vascular mediated cooling—a common reason for failure with all heat-based ablation methods but less of a limitation with MW [39].

The results of this study demonstrate that microwave ablation may be a highly effective and safe treatment modality that rapidly devascularizes even very large hepatic hemangiomas. In addition, complete coverage of the hemangioma with ablation is not necessitated for symptom relief; rather the goal should be to treat 90 % or more of the tumor volume. Secondary benefits of the treatment appear to be extensive tumor shrinkage (62 % by volume immediately following the procedure and 76 % by volume at follow-up in this series) and rapid resolution of abdominal pain, apparently attributed to capsular distention in most patients. MW is known to cause increased tissue shrinkage compared with RF ablation [34], and this may be an advantage when treating symptoms caused by bulky tumors. The patients in our series recovered quickly, with all but one reporting either resolution or substantial improvement of symptoms post treatment, and were able to rapidly resume activity, including strenuous exercise.

This study has several limitations. First, the number of patients and tumors is small. This is a reflection of the limited pool of patients that meet the criteria for treatment, including: (1) patients with large hemangiomas, (2) abdominal pain or other symptoms likely to be from the tumor, and (3) those that wish to undergo any form of invasive treatment for a benign condition. Another limitation is that this study is retrospective and therefore not a randomized comparison with either surgery or other treatment modalities. Again, the limited pool of patients makes such a comparison impractical outside of a multicenter trial. Despite these limitations, the procedure is noted to provide statistically significant pain relief without complication.

In summary, microwave ablation of hepatic hemangiomas with a high-powered microwave device appears to be safe and effective in providing tumor devascularization, shrinkage, and pain relief. While not a direct comparison with RF ablation, comparison with historical data demonstrates that MW can treat similar sized tumors far more rapidly with fewer applicator insertions.

Conflict of interest Timothy J. Ziemlewicz, Shane A. Wells, Meghan A. Lubner, Alexandru I. Musat, and Alexandra R. Cohn declare that they have no conflict of interest. J. Louis Hinshaw, Shareholder, Neuwave Medical. Fred T. Lee Jr., Shareholder, patent holder, and board of directors, Neuwave Medical.

References

1. Ishak KG, Rabin L (1975) Benign tumors of the liver. Med Clin N Am 59:995–1013
2. Trastek VF, van Heerden JA, Sheedy PF 2nd, Adson MA (1983) Cavernous hemangiomas of the liver: resect or observe? Am J Surg 145:49–53
3. Hugh TJ, Poston GJ (2001) Benign liver tumors and masses. In: Blumgart L, Fong Y (eds) Surgery of the liver and biliary tract. Churchill Livingstone, Edinburgh, pp 1397–1422
4. Schnelldorfer T, Ware AL, Smoot R, Schleck CD, Harmsen WS, Nagorney DM (2010) Management of giant hemangioma of the liver: resection versus observation. J Am Coll Surg 211:724–730
5. Lerner SM, Hiatt JR, Salamandra J (2004) Giant cavernous liver hemangiomas: effect of operative approach on outcome. Arch Surg (Chicago, Ill: 1960) 139:818–821 discussion 821–813
6. Adam YG, Huvos AG, Fortner JG (1970) Giant hemangiomas of the liver. Ann Surg 172:239–245

7. Cappellani A, Zanghi A, Di Vita M, Zanghi G, Tomarchio G, Petrillo G (2000) Spontaneous rupture of a giant hemangioma of the liver. Ann Ital Chir 71:379–383
8. Watzke HH, Linkesch W, Hay U (1989) Giant hemangioma of the liver (Kasabach-Merritt syndrome): successful suppression of intravascular coagulation permitting surgical removal. J Clin Gastroenterol 11:347–350
9. Yoon SS, Charny CK, Fong Y et al (2003) Diagnosis, management, and outcomes of 115 patients with hepatic hemangioma. J Am Coll Surg 197:392–402
10. Ozden I, Emre A, Alper A (2000) Long-term results of surgery for liver hemangiomas. Arch Surg (Chicago, Ill: 1960) 135:978–981
11. Althaus S, Ashdown B, Coldwell D, Helton WS, Freeny PC (1996) Transcatheter arterial embolization of two symptomatic giant cavernous hemangiomas of the liver. Cardiovasc Interv Radiol 19:364–367
12. Deutsch GS, Yeh KA, Bates WB 3rd, Tannehill WB (2001) Embolization for management of hepatic hemangiomas. Am Surg 67:159–164
13. Panis Y, Fagniez PL, Cherqui D, Roche A, Schaal JC, Jaeck D (1993) Successful arterial embolisation of giant liver haemangioma. Report of a case with five-year computed tomography follow-up. HPB Surg 7:141–146
14. Srivastava DN, Gandhi D, Seith A, Pande GK, Sahni P (2001) Transcatheter arterial embolization in the treatment of symptomatic cavernous hemangiomas of the liver: a prospective study. Abdom Imaging 26:510–514
15. Giavroglou C, Economou H, Ioannidis I (2003) Arterial embolization of giant hepatic hemangiomas. Cardiovasc Interv Radiol 26:92–96
16. McKay MJ, Carr PJ, Langlands AO (1989) Treatment of hepatic cavernous haemangioma with radiation therapy: case report and literature review. Austral N Z J Surg 59:965–968
17. Cui Y, Zhou LY, Dong MK et al (2003) Ultrasonography guided percutaneous radiofrequency ablation for hepatic cavernous hemangioma. World J Gastroenterol 9:2132–2134
18. Zagoria RJ, Roth TJ, Levine EA, Kavanagh PV (2004) Radiofrequency ablation of a symptomatic hepatic cavernous hemangioma. AJR Am J Roentgenol 182:210–212
19. Tak WY, Park SY, Jeon SW et al (2006) Ultrasonography-guided percutaneous radiofrequency ablation for treatment of a huge symptomatic hepatic cavernous hemangioma. J Clin Gastroenterol 40:167–170
20. Fan RF, Chai FL, He GX et al (2006) Laparoscopic radiofrequency ablation of hepatic cavernous hemangioma. A preliminary experience with 27 patients. Surg Endosc 20:281–285
21. Hinshaw JL, Laeseke PJ, Weber SM, Lee FT Jr (2007) Multiple-electrode radiofrequency ablation of symptomatic hepatic cavernous hemangioma. AJR Am J Roentgenol 189:W146–W149
22. Park SY, Tak WY, Jung MK et al (2011) Symptomatic-enlarging hepatic hemangiomas are effectively treated by percutaneous ultrasonography-guided radiofrequency ablation. J Hepatol 54: 559–565
23. Gao J, Ke S, Ding XM, Zhou YM, Qian XJ, Sun WB (2012) Radiofrequency ablation for large hepatic hemangiomas. Initial experience and lessons. Surgery 153(1):78–85
24. Sharpe EE 3rd, Dodd GD 3rd (2012) Percutaneous radiofrequency ablation of symptomatic giant hepatic cavernous hemangiomas: report of two cases and review of literature. J Vasc Interv Radiol 23:971–975
25. Lloyd DM, Lau KN, Welsh F et al (2011) International multicentre prospective study on microwave ablation of liver tumours: preliminary results. HPB (Oxf) 13:579–585
26. Martin RC, Scoggins CR, McMasters KM (2010) Safety and efficacy of microwave ablation of hepatic tumors: a prospective review of a 5-year experience. Ann Surg Oncol 17:171–178
27. Liang P, Wang Y, Yu X, Dong B (2009) Malignant liver tumors: treatment with percutaneous microwave ablation–complications among cohort of 1,136 patients. Radiology 251:933–940
28. Yu J, Liang P, Yu XL et al (2012) US-guided percutaneous microwave ablation of renal cell carcinoma: intermediate-term results. Radiology 263:900–908
29. Guan W, Bai J, Liu J et al (2012) Microwave ablation versus partial nephrectomy for small renal tumors: intermediate-term results. J Surg Oncol 106(3):316–321
30. Lu Q, Cao W, Huang L et al (2012) CT-guided percutaneous microwave ablation of pulmonary malignancies: results in 69 cases. World J Surg Oncol 10:80
31. Shiomi H, Naka S, Sato K et al (2008) Thoracoscopy-assisted magnetic resonance guided microwave coagulation therapy for hepatic tumors. Am J Surg 195:854–860
32. Andreano A, Huang Y, Meloni MF, Lee FT Jr, Brace C (2010) Microwaves create larger ablations than radiofrequency when controlled for power in ex vivo tissue. Med Phys 37:2967–2973
33. Lubner MG, Hinshaw JL, Andreano A, Sampson L, Lee FT Jr, Brace CL (2012) High-powered microwave ablation with a small-gauge, gas-cooled antenna: initial ex vivo and in vivo results. J Vasc Interv Radiol 23:405–411
34. Brace CL, Diaz TA, Hinshaw JL, Lee FT Jr (2010) Tissue contraction caused by radiofrequency and microwave ablation: a laboratory study in liver and lung. J Vasc Interv Radiol 21:1280–1286
35. Sacks D, McClenny TE, Cardella JF, Lewis CA (2003) Society of interventional radiology clinical practice guidelines. J Vasc Interv Radiol 14:S199–S202
36. Ha JF, Sudhakar R, Chandraratna H (2008) Combination laparoscopic radiofrequency ablation and partial excision of hepatic hemangioma. Ochsner J 8:205–207
37. Kalil AN, Mastalir ET (2002) Laparoscopic hepatectomy for benign liver tumors. Hepatogastroenterology 49:803–805
38. Vogl TJ, Naguib NN, Gruber-Rouh T, Koitka K, Lehnert T, Nour-Eldin NE (2011) Microwave ablation therapy: clinical utility in treatment of pulmonary metastases. Radiology 261:643–651
39. Wright AS, Sampson LA, Warner TF, Mahvi DM, Lee FT Jr (2005) Radiofrequency versus microwave ablation in a hepatic porcine model. Radiology 236:132–139