Ultrasound-guided percutaneous microwave ablation assisted by a three-dimensional visualization preoperative treatment planning system for larger adrenal metastasis (D ≥ 4 cm): Preliminary results

ABSTRACT

Objective: The objective of this study is to assess the clinical effect and safety of ultrasound-guided percutaneous microwave ablation (US-PMWA) assisted by three-dimensional (3D) visualization operative treatment planning system in larger adrenal metastasis (LAM) (D ≥ 4 cm).

Materials and Methods: From Dec 2011 to Dec 2017, 12 consecutive LAM patients with pathologically proven with a mean diameter of 5.2±1.3cm (range 4.1-7.6) were treated. Artificial ascites and thermal monitoring system as ancillary technique were used. The patients were followed up with imagings and complications were recorded.

Results: The median follow-up period was 31 months (ranged 6–52 m). All LAM achieved completely ablation according to the 3D planning preoperation. Complete ablation was achieved in 10 (10/12, 83.3%) patients by one session and 2 patients (2/12, 16.7%) by two sessions. Recurrence was detected at the treated site in 3 patients (3/12, 25.0%) at 5, 9, and 13 months after ablation and received another ablation. Progression of metastasis disease at extra-adrenal sites occurred in 9 patients (9/12, 75%). Seven (7/12, 58.3%) patients died during the follow-up period. Therefore, the 1-, 2-, and 3-year local tumor control rates were 91.7%, 75.0%, and 75.0%, respectively. No severe complications related to ablation occurred, except 3 (3/12, 25%) patients developed hypertension during ablation.

Conclusions: US-PMWA assisted by 3D visualization preoperative treatment planning system maybe a safe and efficient therapy for LAM, which could promote ablation precision, improve the clinical outcomes.

KEYWORDS: Artificial ascites, larger adrenal metastasis, microwave ablation, thermal monitoring system, three-dimensional visualization operative treatment planning system

INTRODUCTION

Adrenal metastasis (AM) is a common malignancy found in adrenal glands, particularly from lung cancer (LC), renal cell carcinoma (RCC), colorectal cancer (CRC), and hepatocellular carcinoma (HCC). Autopsy reviews showed that up to 27% of patients were happened to be detected with AM from unknown malignancy. AM is incidentally discovered increasingly for the decreasing mortality rates in cancer patients and the improved sensitivity of imaging techniques. Usually, AM is treated with chemotherapy or radiotherapy according to the primary tumor pathological diagnosis. Although several investigators have emphasized the utility of open surgical and laparoscopic adrenalectomy to improve the survival in selected patients with...
isolated metastasis, few patients are suitable for surgical resection for the reasons of the primary tumor, age, previous surgery, or metastasis extra adrenal.

Percutaneous image-guided thermal ablation therapy, such as microwave ablation (MWA), radiofrequency ablation (RFA), and laser ablation, has been shown to be an effective technique and yield promising local tumor control in small and selected adrenal tumors. In our team preliminary study, ultrason-guided percutaneous MWA (US-PMWA) was verified as an effective method in terms of good local control of adrenal tumors with a diameter of ≤ 5 cm, and with an capable of treating biochemically active tumors harboring clinical syndromes.

While larger AM (D ≥ 4 cm) (LAM) with boundary irregular were closely adjacent to surrounding important organs, such as intestinal tract, inferior vena cava, liver, and kidney. Multiple antennas, insertions, and ablation points were required, which is difficult to implement only depending on two-dimensional (2D) imaging. A precise ablation of LAM strongly depends on a well-planned treatment strategy preoperation. Conventionally, the preoperative planning for thermal ablation is usually performed based on US, computed tomography (CT), and MRI. The 3D spatial structure was reconstructed in radiologist own perception, which completely based on their subjectively spatial awareness and experience. The radiologist’s evaluation is not completely consistent with the actual situation and may result in incomplete ablation and/or major complications. 3D visualization preoperative planning could display tumor stereoscopically and the precise location of the tumor and relationship of tumor with surrounding tissues, predict time-temperature profile during ablation, improve the safety of ablation, reduce complications, and promote local tumor control.

In our preliminary study, 3D-visualization operative treatment planning system was used in US-PMWA for larger hepatic hilar HCC and RCC, which promoted precise ablation, decreased complication rate, ensured the tumor-free safety margins, and improved the long-term survival outcomes. Hence, this novel technique may provide more information and valuable assistance for treatment for LAM.

Hence, we performed this preliminary study to retrospectively analyze the clinical outcomes of LAM treated by combination therapy of US-PMWA and 3D visualization preoperative treatment planning.

**MATERIALS AND METHODS**

**Patients and tumors**

From December 2011 to December 2017, 12 consecutive patients with pathologically proven with LAM with a mean diameter of 5.2 ± 1.3 cm (ranged, 4.1–7.6) were treated by US-PMWA assisted by 3D visualization preoperative treatment planning system in our department. The clinical indexes of patients and tumors are listed in Table 1. There were 2 female and 10 male patients with an average age 57.0 ± 10.7 years (ranged 34–70). All AM located in the right adrenal glands. Seven (7/12, 58.3%) tumors were adjacent to the intestinal tract, 6 (6/12, 50.0%) adjacent to the inferior vena cava and 4 (4/12, 33.3%) adjacent to both. The primary tumor were LC (4 cases), HCC (6 cases), RCC (1 case), and CRC (1 case). All LAM patients were closely followed up until December 2017. The retrospective study was approved by the Ethics Committee of the Chinese PLA General Hospital. Written informed consent for the procedures was obtained from each enrolled patient prior to performance.

**Preablation examination**

Patients with LAM met the following criteria were enrolled: (1) aged ranged from 18 to 85 years; (2) Eastern Cooperative Oncology Group performance status was, <2; (3) nonresectable tumors or patient refusal to undergo surgery; (4) preoperative blood pressure was controlled at the normal level (systolic pressure <140 mmHg, diastolic pressure <90 mmHg) with medicine; (5) without tumor thrombosis; (6) prothrombin time <25 s; prothrombin activity >40%; platelet count >60 cells × 10¹²/L; (7) diagnosed with by histopathology. The exclusion criteria for the study were as follows: (1) patients with severe cardiopulmonary diseases who could not tolerate

**Table 1: The characters and parameters of patients, tumors, and ablations**

| Number | Age/sex | Size (cm) | Primary tumor | Insertions number | Ablation time (s) | Sessions | Follow-up (months) | Local recurrence | Extra-metastasis | Died |
|--------|---------|-----------|---------------|------------------|------------------|---------|-------------------|-----------------|-----------------|------|
| 1      | 70/male | 7.4*5.7*5.5 | LC            | 6+2              | 2260+720         | 2       | 9                 | Yes             | Yes             | Yes  |
| 2      | 65/male | 6.5*5.2*4.3 | HCC           | 6                | 2160             | 1       | 29                | No              | Yes             | Yes  |
| 3      | 43/male | 4.8*4.7*2.7 | LC            | 6                | 2640             | 1       | 6                 | No              | No              | Yes  |
| 4      | 49/female | 7.6*6.3*5.2 | LC            | 6                | 3510             | 11      | Yes               | Yes             | Yes             | Yes  |
| 5      | 65/male | 6.8*5.4*6.1 | LC            | 6+2              | 2540 + 480       | 2       | 13                | Yes             | Yes             | Yes  |
| 6      | 44/male | 4.3*4.1*3.4 | HCC           | 4                | 1240             | 1       | 18                | No              | No              | No   |
| 7      | 61/male | 6.5*5.4*4.7 | RCC           | 6                | 2100             | 1       | 52                | No              | Yes             | No   |
| 8      | 34/male | 4.5*4.1*3.6 | HCC           | 4                | 1320             | 1       | 44                | No              | Yes             | No   |
| 9      | 58/male | 4.5*4.3*3.3 | HCC           | 4                | 1450             | 1       | 32                | No              | No              | Yes  |
| 10     | 60/male | 5.7*5.1*4.7 | HCC           | 6                | 1980             | 1       | 39                | Yes             | No              | Yes  |
| 11     | 56/male | 4.3*3.5*2.9 | HCC           | 4                | 1840             | 1       | 35                | No              | No              | No   |
| 12     | 51/female | 4.1*3.7*3.1 | CRC           | 4                | 1720             | 1       | 32                | No              | Yes             | Yes  |

*LC=Lung cancer, RCC=Renal cell carcinoma, HCC=Hepatocellular carcinoma, CRC=Colorectal cancer
intravenous (IV) anesthesia; (2) serious and/or acute renal function failure with creatinine clearance rate <80 ml/min; (3) severe liver dysfunction with the index of transaminase twice more than normal levels; (4) active severe infection with the number of white blood cells more than the normal level or the percentage of neutrophils more than 80%.

All AM patients received two types of enhanced imaging, including CT and contrast-enhanced ultrasound (CEUS) for diagnosis and 3D visualization preoperative treatment planning [Figures 1-2]. US and CEUS were performed by Sequoia 512 unit (Siemens Ultrasound, Mountain View, CA, USA) equipped with contrast pulse sequencing software. Sulfur hexafluoride (SonoVue, Bracco, Milan, Italy) as ultrasound contrast agent was used. All CT examination were performed with multi-detector row CT (LightSpeed 16; GE Medical Systems, Milwaukee, WI, USA). The diagnosis was further confirmed through US-guided biopsy before the ablation procedure. Routine laboratory tests were evaluated as normal. If patients exhibited marked abnormal elevation in blood pressure, the ablation was performed in a surgical operating room with carefully anesthesia supervision throughout.

Three-dimensional visualization preoperative treatment planning
Contrast-enhanced CT scanning was performed with the arterial, venous, and later phases within 7 days prior to ablation. Our group original developed 3D visualization preoperative planning platform can reconstruct the anatomy structure of tumor and the relationship with the surrounding organs, plan ablation strategy, such as tumor segmentation, access path planning, simulation of ablation field.[17,21-23] The imaging data were imported into the EFILM software and were analyzed using the 3D visualization planning system. 3D visualization of patient-specific anatomical information, including tumors and surrounding vital structures, was reconstructed stereoscopically. As shown in Figure 3, radiologists can perform various operations on the 3D visualization platform, such as visualizing, hiding, moving, rotating, and measuring. Based on the results of 3D visualization analysis, multiple antennas inserted positions, ablation points, and puncture pathway were determined until the optimal preoperative plan was achieved [Figure 4].

The preoperative planning abided by the following principles: (1) simulation the ablation zone should cover the entire tumor; (2) minimizing the number of antennas,
insertions times, and ablation points; (3) avoiding through critical structures along the insertion pathways and damage to any vital structures.

Ultrasound-guided percutaneous microwave ablation
A microwave system (KY-2000, Kangyou Medical, Nanjing, China) comprising a microwave (MW) generator, a flexible coaxial cable, and a cooled-shaft antenna. The generator can drive two antennas simultaneously with the capability of producing 1–100 W of power at 2450 MHz. The 15G cooled-shaft antenna is coated with Teflon to prevent adhesion with dual channels inside the antenna shaft, through which distilled water circulated continuously by a peristaltic pump could cool the shaft to prevent overheating. The 21G thermocouple needles were equipped on the MWA system which is easily seen by US. The tip of thermosensor was made of the iron constant which is both accurate and sensitive to temperature, while not influenced by the electromagnetic field of MW.

US-guided biopsy (18G, Bard, Japan) was performed immediately before the ablation procedure. If the lesion was verified as benign, it was excluded from the analysis in the follow-up period. For right AM, according to the preoperative imaging and 3D visualization planning, a transhepatic approach was adopted to access the target tumor with the patient lying in the left decubitus position. After local anesthesia with 1% lidocaine, MW antennas were percutaneously inserted into the tumor according to the planning. Based on our previous experience, two antennas were applied with an inter-antenna distance <1.8 cm for LAM, which were activated simultaneously to obtain confluent ablation zone.24 After IV anesthesia administered by a combination of propofol and ketamine through peripheral vein, then MW were emitted at a power output of 20 W and lasted for 1 min firstly. Blood pressure was closely monitored during the ablation procedure. If the systolic pressure was not more than 170 mmHg during treatment, MW emission continued with output power increasing 5 W and interval of 1 min until reached the purpose power (50 W). If the systolic pressure exceeded 170 mmHg, MW emission should be suspended and anti-hypertensive drug (labetalol hydrochloride) be used. Then, MW emission could be resumed until the systolic pressure decreased to the baseline level. After ablation, the MW antenna needle path was routinely cauterized to avoid tumor seeding and bleeding.

Artificial ascites and thermal monitoring during the procedure
Following the local anesthesia, a 16G IV catheter (BD Angiocath; Sandy, UT, USA) was inserted into the peritoneal cavity between tumor and intestinal tract or the inferior vena cava, liver, and kidney under US guidance. We considered the induction of artificial ascites successful and drip infusion with 0.9% normal saline was continued during ablation to isolate the target lesion and the adjacent critical structures with a separation of 0.5 cm. The drip infusion was continued while performing PMWA. No special management was performed for artificial ascites after the operation due to the strong absorption ability of the greater omentum within the abdominal cavity. The 0.9% saline solution (1000-2000 ml) could be absorbed completely within 24 hours after the operation.

One or two thermocouple needles were percutaneously placed at the site of 5–10 mm away from the tumor margin to monitor the temperature continuously and not moved around. Complete ablation was considered when the entire tumor was enveloped by hyperechoic microbubbles and the temperature at the tumor periphery reached 54°C for at least 3 min, or else MW emission prolonged.

Imaging follow-up postablation
After PWMA treatment, patients were closely monitored for possible complications such as skin burn, bowel perforation, intraperitoneal bleeding, pleural effusion, pain, and fever. CEUS and CT examination was performed within 3 days after MWA to assess the treatment effect. If a residual tumor was detected, an additional ablation session was performed under CEUS guidance, or else patients entered the follow-up period. Technical success was defined as the tumor been treated according to planning, and the entire tumor was covered by ablation zone. The follow-up period was beginning from the ablation procedure. Contrast-enhanced CT and CEUS at 1 month and every 3 months intervals thereafter until December 2017. Complications were reported using the standardized Society of Interventional Radiology grading system.25

Statistical analysis
The data were analyzed using the SPSS 19.0 version for windows (SPSS Inc, Chicago, IL, USA). The data of patients and tumors are expressed as a mean ± standard deviation or median. Qualitative data are presented as a percentage. Technique effectiveness was defined as “complete ablation” on contrast-enhanced imaging at 1 month after ablation. Insertion number was defined as the total number of antenna placements for each tumor until the tumor was completely ablated. P < 0.05 was considered to indicate a difference with statistical significance.

RESULTS
The characters of LAM patients and tumors and ablation data are listed in Table 1. In all LAM, 3D visualization preoperative treatment planning was achieved successfully. Complete ablation was defined as no enhancement of the treated region which covered the entire tumor on CEUS and CT images 3 days after treatment. Complete ablation was attained in every LAM after scheduled ablation session according to the 3D visualization planning (mean insertion number, 5.2 ± 1.0, ranged, 4–6). Among the 12 LAM, complete ablation was achieved in 10 (10/12, 83.3%) by one session and 2 (2/12, 16.7%) needed two sessions. One tumor
was with the maximum diameter 6.8 cm and adjacent to the intestinal tract and inferior caval vein, and one with the maximum diameter 7.4 cm adjacent to the intestinal tract. The mean number of sessions for the ablation of one tumor was 1.0±0.4 sessions. The mean time required for the ablation of one tumor in one session was 2040.0±638.4s (ranged from 1240 to 3510s). Artificial ascites was used in 10 (10/12, 83.3%) patients with tumor adjacent to the intestinal tract, and thermal monitoring system was used in all tumors (100%). Three (3/12, 25.0%) patients developed hypertension during the PMWA and controlled by medicine. No severe complications related to ablation occurred except for fever (5 patients, 41.7%), abdominal pain (7 patients, 58.3%), and hemoglobinuria (3 patients, 25.0%). All of the side effects were disappear with conservative treatment in 24–72 h. No severe complications related to ablation occurred, except in 3 patients who developed hypertension during ablation.

The median follow-up period was 31 months (ranged 6–52 m) There was recurrence at the treated site in three patients (3/12, 25.0%) at 5, 9, 13, and months after ablation, with two metastasis tumors from LC and one from HCC. The patients received another inpatient ablation and achieved complete ablation [Figures 5 and 6]. Therefore, the 1-, 2-, and 3-year local tumor control rates were 83.3%, 75.0%, and 75.0%, respectively. Nine (9/12, 75.0%) patients had tumor progression at extra-adrenal sites. The primary tumor was LC (4 patients), HCC (3 patients), RCC (1 patient), and CRC (1 patient). Seven (7/12, 58.3%) patients died during the follow-up period (3 patients with LC, 3 patients with HCC, and 1 patient with CRC). 1-, 2-, 3-, and 4-year overall survival rates were 91.7%, 75.0%, 50.0%, and 41.7%, respectively.

**DISCUSSION**

Percutaneous image-guided thermal ablation has been shown to be an effective technique and yield promising local tumor control in solid tumors, especially for RFA and MWA. For larger tumors, MWA uses electromagnetic energy to rotate adjacent polar water molecules rapidly, which shows several theoretical advantages over RFA in higher intratumoral temperature, larger ablation volume, faster ablation, less dependency on the electrical conductivities of tissue and less limited in energy delivery by the exponential rising electrical impedances of tumor tissue.[26-28] In our previous study, the results demonstrate that MWA is an effective and promising approach for the treatment of large-sized tumors (D >5 cm) for LAM. Hence, in the study, MWA treated LAM may show better tumor local control and prognosis.

For LAM, the actual situation of tumor and the relationship with surrounding organs could not be illustrated clearly on 2D imaging and need reconstructing in the operators’ perception, which is dependent on their spatial awareness and experience subjectively. Meanwhile, the thermal field of multi-antenna and multi-point ablation, which is difficult to predict on 2D imaging for larger tumors. Last but most important, the distance between tumor and surrounding organs (intestinal tract, inferior caval vein, kidney, and liver) is <5 mm, even adjacent closely, which increase the importance of thermal field calculation. Above reasons may lead to incomplete ablation and/or major complications, and further influence the therapy efficiency. Therefore, how to reconstruct the actual relationship between tumor and surrounding organs, calculate the thermal field of multi-antenna and multi-point ablation, minimize antenna insertions number, and plan puncture pathway objectively are key points for successful and safe ablation.

3D visualization preoperative treatment planning system has been used in surgery for many years, but seldom in percutaneous image-guided thermal ablation.[20] Image-guided thermal ablation therapy requires the quantitative calculation of the tumor volume and the distance between the tumor and surrounding vital structures, accurate simulation of spacial thermal field, and planning of puncture pathways. In 2012, an original 3D-visualization operative treatment planning system used for US-PMWA was applied in HCC, which promoted the rate of complete ablation by one session and long term efficacy significantly.[19] In 2016 and 2017, our team also study the clinical efficiency of combination therapy of 3D visualization operative treatment planning system and US-PMWA in the management of larger hepatic hilar HCC and RCC, which achieved promising prognosis.[22-23] The results further very

**Figure 5:** Postoperation computed tomography imaging transverse section and coronal view in artery phrase showed no-enhancement of the ablation zone without damage of the surrounding organs (arrow) (a and b)

**Figure 6:** Postoperation contrast-enhanced ultrasound imaging showed constantly no-enhancement of the ablation zone without residual tumor (arrow)
the valuable of 3D visualization operative treatment planning system.

In this pilot study, 3D visualization preoperative treatment planning was achieved and US-PMWA was performed according to the scheduled panning for all tumors successfully. Among 12 tumors, one-time ablation rate was 83.3%, which could be comparable with that of the image-guided ablation for small AM (80% vs. 84.6%).[11-12] For two tumors with maximum diameter were 6.8 cm and 7.4 cm, which treated by two sessions. The second ablation was performed by CEUS-guidance and achieved complete ablation. Hence, the size of tumor is still the major influence factor for adrenal lesion ablation. Artificial ascites was used in 10 (10/12, 83.3%) patients with tumor adjacent to the intestinal tract and real-time thermal monitoring system was used in all tumors (100%), which were safe and effective auxiliary methods for ablation and can achieve good local control.[31,32] No severe complications related to ablation occurred due to the precisely 3D visualization planning and effective auxiliary techniques.

Hypertensive crisis was occurred in 3 (25.0%) patients during PMWA, which was life-threatening. Whereas the hypertensive crisis may also occur in treating liver cancers adjacent to the adrenal gland and AM lesions.[32‑34] Maybe the thermal transmission affected the normal adrenal tissue and stimulated the releasing of catecholamine. To prevent excessive catecholamine release, MW emission could increase from low power (20 W) to high power (50 W) intermittently accordingly to our past experience.[111] Moreover, MW emission was suspended when the systolic pressure exceeded 170 mmHg, and anti-hypertensive drugs were applied. No hypertensive crisis was occurred in this study by taking preventive measures.

During the follow-up period, the results showed that patients with LC were inclined to recurrence, metastasis and poorer prognosis. As there were 2 LC patient recurrence (50.0%), 3 extra-metastasis (75.0%), and 3 died (75.0%). For the long-term prognosis of the patients with LAM, the pathological type of primary tumor maybe an important influence factor.

There are some limitations of the study. First, the sample is smaller, and the follow-up period is short, more patients needed to enlarge the sample, and long-term follow-up is mandatory. Second, the operation of US-PMWA, artificial ascites, and real-time thermal monitoring system could be difficult in practice. Solid knowledge of anatomy and rich experience were needed for green hands. Third, the pathological type is an important influence factor for long-time outcomes; the prognosis should be analyzed according to the types of primary tumors. Finally, all of the LAM was located in the right side adrenal gland, and transhepatic approach through the liver was chosen, which was relatively safe. More experience of US-PMWA in the left AM lesion was needed in future.

CONCLUSIONS

In summary, the 3D visualization preoperative treatment planning system could show the spatial stereoscopical constructure of tumor and surrounding organs, promote ablation precision, decrease ablation points, and shorten ablation time. From these preliminary results, ancillary technique such as intraoperative artificial ascites and real-time temperature measuring system further improve the safety of ablation. Combination therapy is a safe and efficient alternative for the patients with LAM, which expand the indications of US-PMWA, and improved the local tumor control rate and long-term outcomes in AM.

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CONFLICTS OF INTEREST

There are no conflicts of interest.

REFERENCES

1. Lam KY, Lo CY. Metastatic tumours of the adrenal glands: A 30-year experience in a teaching hospital.Clin Endocrinol 2002; 56:95-101.
2. Abrams HL, Spiro R, Goldstein N. Metastases in carcinoma; analysis of 1000 autopsied cases. Cancer 1950;3:74-85.
3. Mitchell IC, Nwariaku FE. Adrenal masses in the cancer patient: surveillance or excision. The Oncologist 2007;12:168-74.
4. Sancho JJ, Triponез F, Montet X, Sitges-Serra A. Surgical management of adrenal metastases. Langenbecks Arch Surg 2012;397:179-94.
5. Wagnerova H, Lazurova I, Felsoci M. Adrenal metastases. Bratislavské Lekarske Listy 2013;114:237-40.
6. Gunjur A, Duong C, Ball D, Siva S. Surgical and ablative therapies for the management of adrenal ‘oligometastases’- A systematic review. Cancer Treat Rev 2014;40:838-46.
7. Shah MM, Isrow D, Fareed MM, Wen N, Ryu S, Ajlouni M, et al. Single institution experience treating adrenal metastases with stereotactic body radiation therapy. J Cancer Res Ther 2019;15(Supplement):S27-S32.
8. Muth A, Persson F, Jansson S, Johanson V, Ahlman H, Wangberg B. Prognostic factors for survival after surgery for adrenal metastasis. Eur J Surg Oncol 2010;36:699-704.
9. Yamakado K. Image-guided ablation of adrenal lesions. Semin Intervent Radiol 2014;31:149-56.
10. Uppot RN, Gervais DA. Imaging-guided adrenal tumor ablation. AJR Am J Roentgenol 2013;200:1226-33.
11. Wang Y, Liang P, Yu X, Cheng Z, Yu J, Dong J. Ultrasound-guided percutaneous microwave ablation of adrenal metastasis: Preliminary results. Int J Hyperthermia 2009;25:455-61.
12. Mayo-Smith WW, Dupuy DE. Adrenal neoplasms: CT-guided radiofrequency ablation—preliminary results. Radiology 2004;231:225-30.

13. Mendiratta-Lala M, Brennan DD, Brook OR, Faintuch S, Mowschenson PM, Sheiman RG, et al. Efficacy of radiofrequency ablation in the treatment of small functional adrenal neoplasms. Radiology 2011;258:308-16.

14. Pacella CM, Stasi R, Bizzarri G, Pacella S, Graziano FM, Guglielmi R, et al. Percutaneous laser ablation of unresectable primary and metastatic adrenocortical carcinoma. Eur J Radiol Open 2008;66:68-94.

15. Hasegawa T, Yamakado K, Nakatsuka A, Uraki J, Yamanaka T, Fujimori M, et al. Unresectable Adrenal Metastases: Clinical Outcomes of Radiofrequency Ablation. Radiology 2015;277:584-93.

16. Ren C, Liang P, Yu XL, Cheng ZG, Han ZY, Yu J. Percutaneous microwave ablation of adrenal tumours under ultrasound guidance in 33 patients with 35 tumours: A single-centre experience. Int J Hyperthermia 2016;32:517-23.

17. Liu F, Liang P, Yu X, Lu T, Cheng Z, Lei C, et al. A three-dimensional visualisation preoperative treatment planning system in microwave ablation for liver cancer: A preliminary clinical application. Int J Hyperthermia 2013;29:671-7.

18. Sindram D, Swan RZ, Lau KN, McIlwraith IH, Iannitti DA, Martinie JB. Real-time three-dimensional guided ultrasound targeting system for microwave ablation of liver tumours: A human pilot study. HPB (Oxford) 2011;13:185-91.

19. Harms J, Bartels M, Bourquain H, Peitgen HO, Schulz T, Kahn T, et al. Computerized CT-based 3D visualization technique in living related liver transplantation. Transplant Proc 2005;37:1059-62.

20. Hansen C, Wieferich J, Ritter F, Rieder C, Peitgen HO. Illustrative visualization of 3D planning models for augmented reality in liver surgery. Int J Comput Assist Radiol Surg 2010;5:133-41.

21. Wu W, Xue J, Liang P, Cheng Z, Zhang M, Mu M, et al. The assistant function of three-dimensional information for I125 particle implantation. IEEE J Biomed Health Inform 2014;18:77-82.

22. Li X, Yu J, Liang P, Yu X, Cheng Z, Han Z, et al. Combination therapy of three-dimensional (3D) visualisation operative treatment planning system and US-guided percutaneous microwave ablation in larger renal cell carcinomas (D > 4 cm): Preliminary results. Int J Hyperthermia 2016;1:7.

23. Li X, Yu J, Liang P, Yu X, Cheng Z, Han Z, et al. Ultrasound-guided percutaneous microwave ablation assisted by three-dimensional visualization operative treatment planning system and percutaneous transhepatic cholangial drainage with intraductal chilled saline perfusion for larger hepatic hilum hepatocellular (D ≥ 3 cm): preliminary results. Oncotarget 2017;8:79742-9.

24. Liang P, Yu J, Lu MD, Dong BW, Yu XL, Zhou XD, et al. Practice guidelines for ultrasound-guided percutaneous microwave ablation for hepatic malignancy. World J Gastroenterol 2013;19:5430-8.

25. Cardella JF, Kundu S, Miller DL, Millward SF, Sacks D. Society of Interventional Radiology clinical practice guidelines. J Vasc Interv Radiol 2009;20 (7 Suppl):S189-91.

26. Wright AS, Sampson LA, Warner TF, Mahvi DM, Lee FT, Jr. Radiofrequency versus microwave ablation in a hepatic porcine model. Radiol 2005;236:132-9.

27. Liang P, Dong B, Yu X, Yu D, Wang Y, Feng L, et al. Prognostic factors for survival in patients with hepatocellular carcinoma after percutaneous microwave ablation. Radiol 2005;235:299-307.

28. Yu J, Liang P, Yu X, Liu F, Chen L, Wang Y. A comparison of microwave ablation and bipolar radiofrequency ablation both with an internally cooled probe: Results in ex vivo and in vivo porcine livers. Eur J Radiol 2011;79:124-30.

29. Liu C, Liang P, Liu F, Wang Y, Li X, Han Z, et al. MWA combined with TACE as a combined therapy for unresectable large-sized hepatocellular carcinoma. Int J Hyperthermia 2011;27:654-62.

30. Yin XY, Xie XY, Lu MD, Xu HX, Xu ZF, Kuang M, et al. Percutaneous thermal ablation of medium and large hepatocellular carcinoma: long-term outcome and prognostic factors. Cancer 2009;115:1914-23.

31. Zhang M, Liang P, Cheng ZG, Yu XL, Han ZY, Yu J. Efficacy and safety of artificial ascites in assisting percutaneous microwave ablation of hepatic tumours adjacent to the gastrointestinal tract. Int J Hyperthermia 2014;30:134-41.

32. Zheng L, Zhou F, Yu X, Liang P, Cheng Z, Han Z, et al. Hypertensive Crisis during MW Ablation of Adrenal Neoplasms: A Retrospective Analysis of Predictive Factors. J Vasc Interv Radiol 2019 May 30. doi: 10.1016/j.jvir.2019.01.016. [Epub ahead of print].

33. Onik G, Onik C, Medary I, Berridge DM, Chicks DS, Proctor LT, et al. Life-threatening hypertensive crises in two patients undergoing hepatic radiofrequency ablation. AJR Am J Roentgenol 2003;181:495-7.

34. Chini EN, Brown MJ, Farrell MA, Charboneau JW. Hypertensive crisis in a patient undergoing percutaneous radiofrequency ablation of an adrenal mass under general anesthesia. Anesth Analg 2004;99:1867-9.