Int J CARS (2015) 10:459–464
DOI 10.1007/s11548-014-1095-8

ORIGINAL ARTICLE

Comparison of 3D ultrasound and magnetic resonance imaging for microwave ablation in the canine splenomegaly model

Lin Sheng · Jialiang Li · Jibing Chen · Ping Liang · Baowei Dong

Received: 9 March 2014 / Accepted: 11 June 2014 / Published online: 3 July 2014

Abstract
Purpose Microwave ablation is used for the treatment of hypersplenism. Image guidance and ablation volume assessment is important to ensure that the ablation is successful. The accuracy of 3D ultrasound (US) and magnetic resonance imaging (MRI) in determining the parameters for microwave ablation were compared in a canine splenomegaly model.
Methods Microwave ablation of the spleen was performed on 13 dogs with congestive splenomegaly. Several combinations of power output and ablation time were used: 60 W for 300 s, 50 W for 360 s and 40 W for 450 s. The ablation zone volume was measured by 3D US and 3D MRI immediately after microwave ablation, and at 1, 2 and 8 weeks thereafter.
Results Compared with 3D MRI, the ablation zone reconstruction rate was lower with 3D US (92 vs. 100 %). However, there was no significant difference was found in the ablation volume calculated soon after the treatment and 1 week and 2 months later.
Conclusion 3D US may be useful for quantifying the volume of microwave ablation zones in the spleens of experimental animals and appears promising as an alterative modality to MRI for clinical examinations.

Keywords 3D magnetic resonance imaging (3D MRI) · 3D ultrasound (3D US) · Microwave ablation (MWA)

This study was supported by the National Natural Science Foundation of People's Republic of China (No. 30371367), and the Ministry of Science and Technology of People's Republic of China (No. 2004BA714B10).

L. Sheng
Department of Interventional Ultrasound, Yuquan Hosiptal, Tsinghua University, No. 5 of Shijingshan Road, Shijingshan District, Beijing 100049, China
e-mail: jlslsyyx@163.com

J. Li · J. Chen
Fuda Cancer Hospital, Jinan University School of Medicine, No. 2 Tangdexi Road, Tianhe District, Guangzhou 510665, China
e-mail: galaxystarivy@gmail.com

J. Chen
e-mail: jibingchen398@163.com

P. Liang (✉) · B. Dong
Department of Interventional Ultrasound, Chinese PLA General Hospital, Beijing 100853, China
e-mail: fudaclab@gmail.com

B. Dong
e-mail: dongbw301@yahoo.com.cn

Introduction

Splenomegaly, which refers to the abnormal enlargement of the spleen, is associated with infections, liver disease and certain cancers. Surgical removal of an enlarged spleen is not the first line of treatment, and it is recommended only in certain situations. Alternatives to surgery for hypersplenism include partial splenic embolisation [1], radiofrequency ablation [2–4] and microwave ablation (MWA) [5].

Microwave ablation, as a minimally invasive technique, has been widely used in clinical treatment over the past decade [6–8]. MWA uses electromagnetic waves to create heat to destroy diseased cells and tissue and has been used for oncological treatment in recent years [9–12]. MWA is associated with a higher rate of temperature increase, high thermal efficiency, a stable and controllable thermal field, and good blood vessel coagulation leading to haemostasis [13]. Moreover, in the last 5 years, MWA has been found to be beneficial for the treatment of splenomegaly and hypersplenism [14–16], as the platelet count and total serum protein levels

increase in treated patients [14]. However, MWA treatment can induce bleeding or splenic rupture during ablation, and it is also difficult to predict the ablation zone with MWA. Other complications include fever, pain, and pleural effusion, which are related to the ablation volume: larger volumes are associated with more severe adverse effects. Therefore, monitoring the ablation volume is highly important to ensure the successful completion of MWA. Several imaging techniques can be used to determine the ablation volume.

Three-dimensional magnetic resonance imaging (3D-MRI) is one of the main imaging techniques used for MWA, and its accuracy depends on the thickness of and distance between layers [17]. Although this method has high levels of accuracy, it may be restricted by the breathing activity of animals. Moreover, this method is also time-consuming (30 min to calculate the ablation area) and costly, and these disadvantages limit the applicability of this technique. With rapid progress in related techniques over recent years, 3D ultrasonography (3D US) is becoming a popular method for rebuilding images and has been used to recreate foetuses [18–20], aspects of the cardiovascular system [21–23], and others. The current commercialised 3D US system takes <1 s to obtain one 3D US image and requires only 5–10 min to construct an 8–16-slice image and calculate the ablation volume [24]. However, 3D US may have certain shortcomings compared to 3D MRI, as the image resolution is inferior to MRI and it gives less accuracy to measurements of the ablation zone. However, there is no available data regarding a comparison of these techniques in terms of the accuracy of assessing the ablation zone area, and it remains unclear which technique is superior.

In the study, we investigated the efficacy of MWA in a canine splenomegaly model and compared 3D US and 3D MRI with regard to their accuracy in determining the ablation parameters.

Methods

Approval for the study was also obtained from the Research Animal Care and Use Committee of Tsinghua University, and all the experiments were conducted in accordance with the Guide for the Care and Use of Laboratory Animals.

Thirteen healthy adult male Chinese rural dog dogs were selected in this study. The average weight of these dogs was 17.6 ± 0.36 kg, and the average age was 2.0 ± 0.1 years. The dogs were maintained and fed in an environment with constant temperature and humidity levels.

After fasting overnight, the dogs were anesthetised with an intravenous injection of sodium pentobarbital (25 mg/kg). The spleen was accessed via a midline incision, and the splenic vein and its major branches were ligated to induce congestive splenomegaly.

Four weeks after splenic vein ligation, laparotomy was performed, followed by MWA of the congestive spleens using 14-G microwave antennas. A UMC-I microwave coagulator (PLA General Hospital, Beijing, China) with a maximum power output of 80 W was used at a microwave frequency of 2,450 MHz. A total energy of 18,000 J with different combinations of power output and ablation time was used. Three protocols were used for MWA: (1) power output of 40 W with an ablation time of 450 s; (2) power output of 50 W with an ablation time of 360 s; (3) and power output of 60 W with an ablation time of 300 s. All these three protocols were used in the given sequence in every canine spleen.

3D US and contrast-enhanced MRI were used to calculate the volume of the ablation zones immediately after ablation and at 1, 2 and 8 weeks thereafter. We used the Technos DU8 ultrasound machine (Esaote Genoa, Italy) equipped with a 3.5-MHz convex probe. The machine was used along with a 3D workstation (TOMTEC-ECHO-View 3D) for 3D reconstruction and volume measurement. The PCI-Bird magnetic tracker was used (Ascension, Burlington, VT, USA), which consisted of a base unit transmitter and a sensor: the sensor was mounted on the 3.5-MHz curved array probe, and the tracker measures the position and orientation of the sensor. The TOMTEC-ECHO-View graphic workstation was used to capture images and recording data from the location tracker for subsequent 3D reconstruction. Full-frame ultrasound images from the video output of the ultrasound scanner are digitised by a frame grabber board attached to the graphic workstation.

MRI was conducted using a GE Sigma 1.5T Horizon Twin-speed with TORSO coil. The slice thickness was 5 mm, without an inter-slice gap. Axial T1WI (Time Repeat/Time Echo, 150 ms/4.2 ms), T2WI (TR/TE, 4.4 ms/1.8 ms), and contrast-enhanced scans (Gd-DTPA, 0.2 mmol/kg) were taken for all 13 dogs. 3D volume measurement was performed using OSIRIS VERSION 2.5 (Hospital of Geneva University, Switzerland).

For the acquisition of 3D US images, the distance between the sender and receiver of the magnetic pulses was maintained within 50 cm. The depth of the probe was adjusted until the screen showed the entire image along the short axis of the spleen. Furthermore, the coordinates were adjusted so that they were consistent with those of the 3D machine. The probe was moved at a constant speed to scan canine spleens along their long axis and to start collecting images using the workstation. Image collection was discontinued after the scans were taken.

The collected 2D images were saved on a computer. After the images were linked, supplemented, smoothed and filtered, a database containing all the information was built. Then, data on the standard plane were retrieved from this database and post-processed on other planes in order to build a 3D image of the canine spleen. In addition, the 2D images

could be transposed and slanted along the *X*, *Y* and *Z* axes so as to reproduce the 3D US image from different aspects [25].

A belt was used to bind the chest and belly of the dogs after anaesthesia in order to control the movements caused by breathing. The breath-gated method was used at the edge of the canine ribs to monitor changes in the breath rate and scan the canine spleens within breath intervals. The images were processed using the software OSIRIS VERSION 2.5, and the edges of the ablative volume were delineated manually layer by layer to determine the total volume.

All analyses were performed using SPSS, version 10.0 (SPSS Inc., Chicago, Illinois). A value of $P < 0.05$ was considered to indicate a statistically significant difference, with $P < 0.01$ and $P < 0.001$ indicating highly significant differences.

Results

Splenomegaly model

Splenic volume was calculated using 3D US before splenic vein ligation and 1, 2 and 4 weeks after ligation. One week after splenic vein ligation, canine spleen volume increased significantly (65.87 ± 80.48 vs. 30.15 ± 35.79 ml; $P < 0.001$ one-way ANOVA; Fig. 1), but the volume decreased gradually over time (2 weeks, 65.48 ± 75.58 ml; 4 weeks, 63.51 ± 75.9 ml; both $P < 0.001$ compared with original volume). However, 1 month after splenic vein ligation, the splenic volume significantly increased compared to the normal spleens.

Microwave ablation zone volume measurement with 3D US

All 13 dogs survived the experiment. Sonography depicted the ablative zone as a nonhomogenous hypoechoic area with a central hyperechoic area corresponding to the carbonisation zone. A clear border was seen between normal and diseased spleen tissue. Most images could be rebuilt completely; however, due to disturbance caused by the presence of bowel gas, a small portion of the spleen could not be rebuilt. The reconstruction rate was 92 %. Thirty-six ablative zones were completely shown and rebuilt using manually controlled delineation, and the total volumes and ablation volumes were calculated (Fig. 2). The average ablation volume was 13.65 ± 7.83 ml, which accounts for 8–51 % of the whole volume of the spleens. Most of the ablative areas were spindle shaped, except for those close to vessels or capsules.

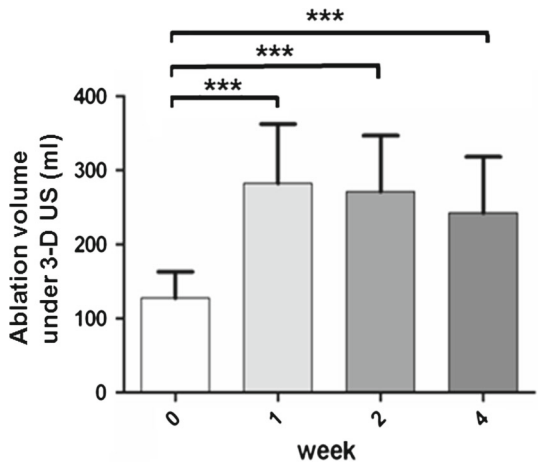

Fig. 1 Canine spleen volume before and after splenic vein ligation. Canine spleen volume was calculated using 3D US before splenic vein ligation and 1, 2 and 4 weeks after the ligation. $^{***}P < 0.001$

Microwave ablation zone volume measurements using 3D MRI

MRI examination of canine spleens was conducted using the inhale-door technique (Fig. 3a, b). Thirty-nine ablative zones were examined, and high-quality images were obtained in all cases. The ablative areas in the T1WI images showed a high signal intensity zone with a low signal intensity zone (along the needle) in the centre (Fig. 3c). The ablative areas in the T2WI images showed low sig-

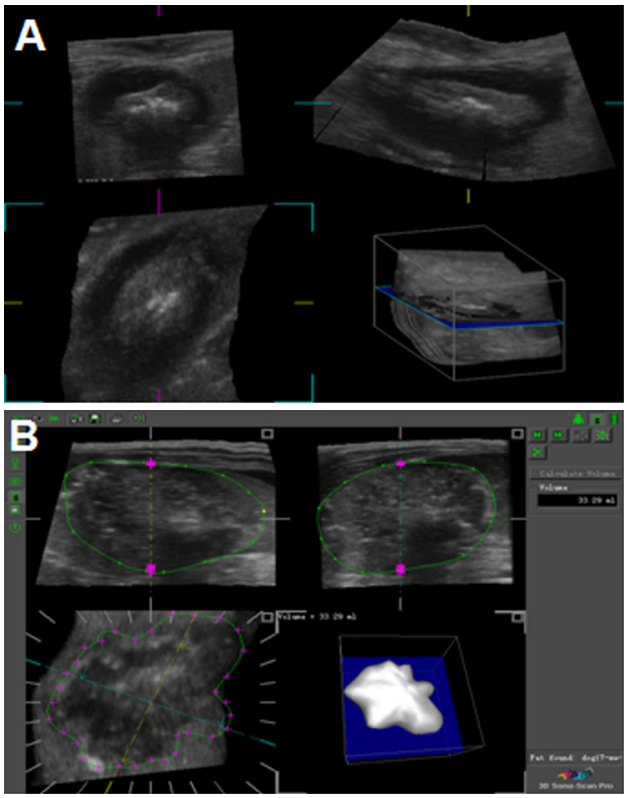

Fig. 2 Calculation of the coagulation necrosis zone with 3D US. **a** Images of the coagulation necrosis zone; **b** calculation of the coagulation necrosis zone

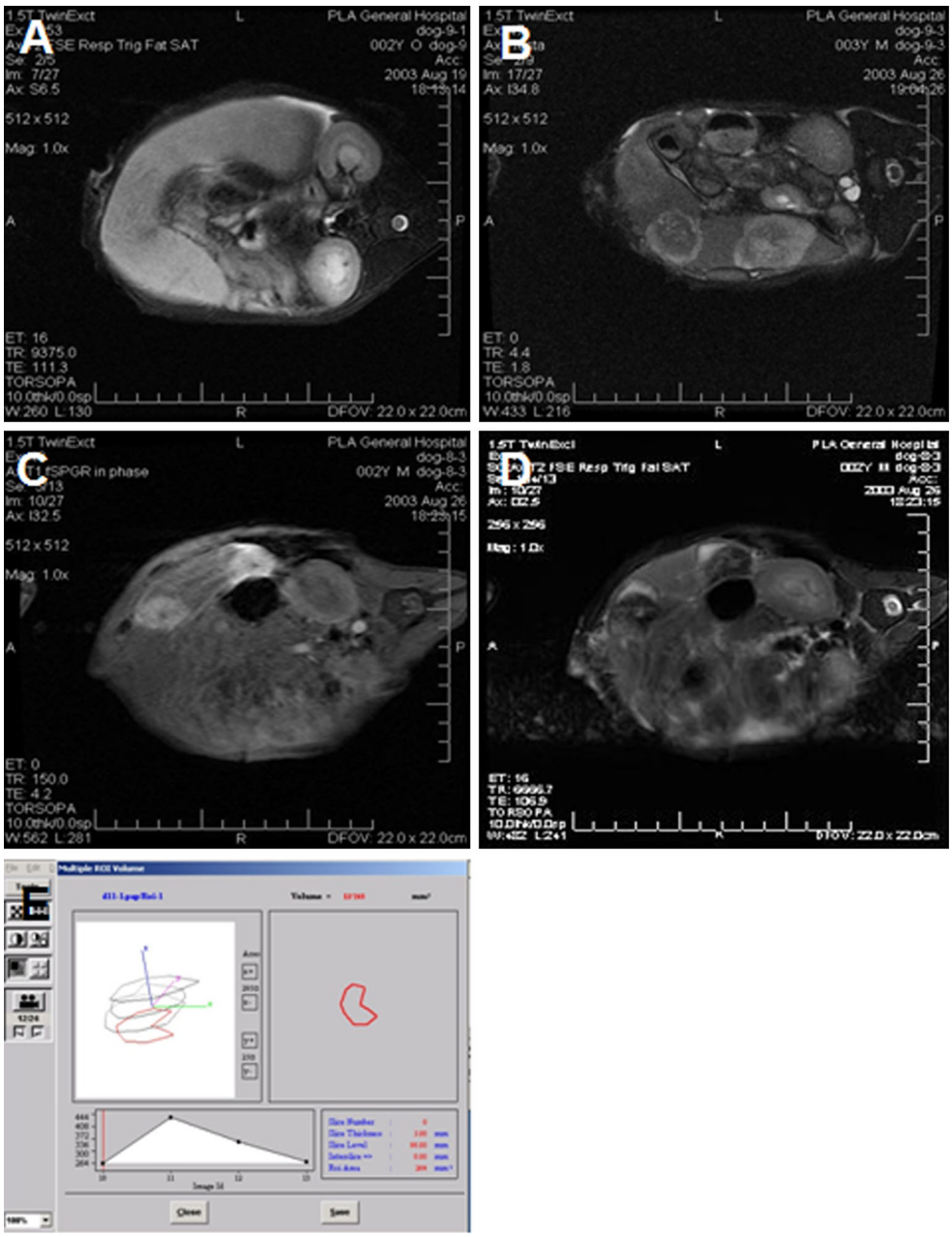

Fig. 3 Calculation of the coagulation necrosis zone with MRI. **a** MRI image of the canine spleen before MW ablation; **b** MRI image of the canine spleen after MW ablation; **c** the ablative areas in T1WI images; **d** the ablative areas in T2WI images; **e** coagulation necrosis zone volume calculation using OSIRIS VERSION 2.5

nal intensity (Fig. 3d). Moreover, by using OSIRIS VERSION 2.5 in the T2WI images, we were able to delineate the edges of the ablative areas and calculate their volume (Fig. 3e).

Comparison between 3D MRI and 3D US

In this study, there was no significant difference in the ablation volume calculated using 3D US and 3D MRI soon after the ablation as well as one week and two months after the ablation (Fig. 4). Although the total output energy was the same, the ablation volume was different between the three protocols. In the instant group (Fig. 4a), the ablation volume with the 60 W power output for 300 s (15.4 ± 9.09 ml for 3D US and 15.08 ± 9.75 for 3D MRI; $n = 19$) was higher than that with the 40 W power output for 450 s (10.18 ± 6.24 ml for 3D US, and 10.58 ± 5.63 for 3D MRI; $n = 13$; $P = 0.0378$, two-way ANOVA). For the group 2 months later (Fig. 4c), the ablation volume with the 60 W power output for 300 s (10.93 ± 3.94 ml for 3D US, and 10.56 ± 3.38 for 3D MRI;

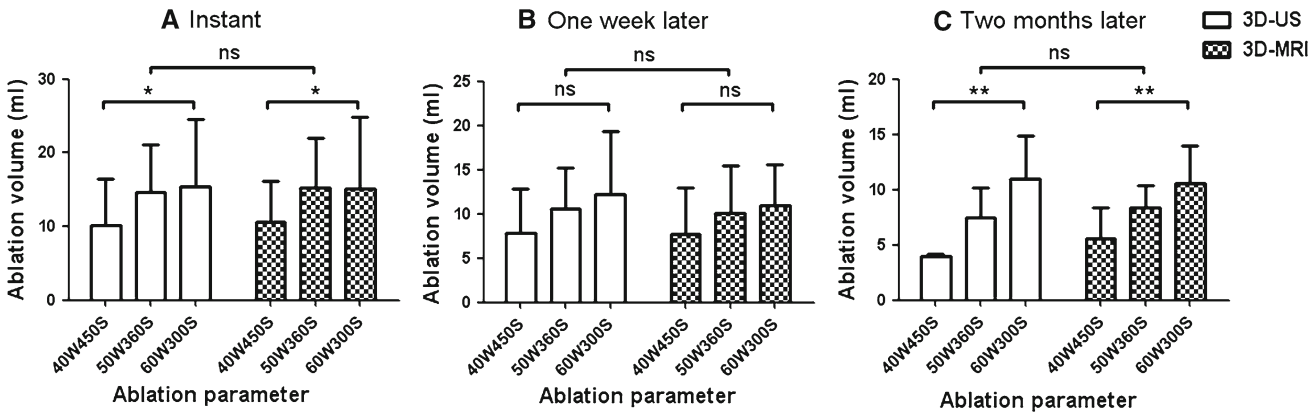

Fig. 4 Comparison of the ablation volume calculated with 3D US and 3D MRI. Ablation volumes were calculated immediately after MWA (**a**), 1 week later (**b**), and 2 months later (**c**). $^{*}P < 0.05$, $^{**}P < 0.01$, *ns* indicates no statistical difference

$n = 4$) was much higher than that with the 40 W power output for 450 s (3.99 ± 0.14 ml for 3D US, and 5.52 ± 2.83 for 3D MRI; $n = 3$; $P = 0.0025$, two-way ANOVA).

Discussion

In this study, both 3D US and 3D MRI were used to assess the efficiency of MWA in a canine splenomegaly model; moreover, the accuracy of these two techniques was compared with regard to the determination of ablation parameters. We found that the ablation area in the spleen was spindle shaped and that some ablation areas were much smaller than predicted. If the ablation area is adjacent to major vessels or the surface of the spleen, the shape may vary remarkably and appear irregular, so it possible that the ablation areas in this study were adjacent to major vessels or the spleen surface. These results are consistent with previous studies which reported that blood perfusion influenced thermal distribution significantly [26]. We also detected other necrotic areas in the canine spleen besides the ablation area. Another paper on the treatment of splenomegaly with radiofrequency ablation defined this phenomenon as the bystander effect [4]. With 3D US, we found that the additional necrosis areas corresponded to the vascular distribution and almost extended to the edge of the spleen. This indicates that vascular perfusion significantly influenced thermal distribution. Finally, the ablation volume determined was not significantly different between 3D US and 3D MRI, soon after the ablation as well as 1 week and 2 months later. Thus, 3D US may be a useful technique to quantify the volume of MWA zones in the spleens of experimental animals.

As the canine spleen is at the anterior of the abdomen, it is easier to identify the edge of the ablation zone using 3D US, which therefore makes measurements of the volume of the ablation zone simpler. However, the presence of air and the ribcage may interfere with the quality of the image. This is why some of the images obtained were not satisfactory. Finally, 36 of the 39 ablative zones examined were completely shown and rebuilt with 3D US, using manually controlled delineation, and the volumes and ablative volumes were calculated. However, with 3D MRI, all 39 ablative zones could be examined. Thus, it appears that the accuracy of 3D US detection needs to be improved to quantify the volume of MWA zones in the spleens of experimental animals.

With regard to the efficiency of the MWA technique, we used three different combinations of power and ablation time, and we found that different combinations can produce different ablation volumes, which decreased with time.

Conclusion

In this study, the possibility of using 3D US to measure microwave ablation volumes was investigated and compared with 3D MRI in a canine model of splenomegaly. Our findings determined that 3D MRI was superior to 3D US with regard to the number of ablative zones that could be reconstructed (100 vs. 92 %). However, there was no significant difference in the ablation volume calculated using 3D US or 3D MRI. Thus, 3D US can be used to quantify the volume of MWA zones in the spleens of experimental animals. Moreover, considering that 3D US is a faster, inexpensive technique, it is also possible for use in clinical examinations.

Conflict of interest None to declare.

References

1. Runyan BL, Smith RS, Osland JS (2008) Progressive splenomegaly following splenic artery embolization. Am Surg 74(5):437–439
2. Liu Q, Ma K, He Z, Dong J, Hua X, Huang X, Qiao L (2005) Radiofrequency ablation for hypersplenism in patients with liver cirrhosis: a pilot study. J Gastrointest Surg 9(5):648–657

3. Hashemieh M, Akhlaghpoor S, Azarkeivan A, Azizahari A, Shirkavand A, Sheibani K (2012) Partial radiofrequency ablation of the spleen in thalassemia. Diagn Interv Radiol 18(4):397–402
4. Liu QD, Ma KS, He ZP, Ding J, Huang XQ, Dong JH (2003) Experimental study on the feasibility and safety of radiofrequency ablation for secondary splenomagely and hypersplenism. World J Gastroenterol 9(4):813–817
5. Liang P, Gao Y, Zhang H, Yu X, Wang Y, Duan Y, Shi W (2011) Microwave ablation in the spleen for treatment of secondary hypersplenism: a preliminary study. AJR Am J Roentgenol 196(3):692–696
6. Xu HX, Lu MD, Xie XY, Yin XY, Kuang M, Chen JW, Xu ZF, Liu GJ (2005) Prognostic factors for long-term outcome after percutaneous thermal ablation for hepatocellular carcinoma: a survival analysis of 137 consecutive patients. Clin Radiol 60(9):1018–1025
7. Liang P, Dong B, Yu X, Yang Y, Yu D, Su L, Xiao Q, Sheng L (2003) Prognostic factors for percutaneous microwave coagulation therapy of hepatic metastases. AJR Am J Roentgenol 181(5):1319–1325
8. Ward RC, Healey TT, Dupuy DE (2013) Microwave ablation devices for interventional oncology. Exp Rev Med Devices 10(2):225–238
9. Lubner MG, Brace CL, Hinshaw JL, Lee FT Jr (2010) Microwave tumor ablation: mechanism of action, clinical results, and devices. J Vasc Interv Radiol 21(8 Suppl):S192–203
10. Groeschl RT, Pilgrim CH, Hanna EM, Simo KA, Swan RZ, Sindram D, Martinie JB, Iannitti DA, Bloomston M, Schmidt C, Khabiri H, Shirley LA, Martin RC, Tsai S, Turaga KK, Christians KK, Rilling WS, Gamblin TC (2014) Microwave ablation for hepatic malignancies: a multiinstitutional analysis. Ann Surg 259(6):1195–1200
11. Chiang J, Wang P, Brace CL (2013) Computational modelling of microwave tumour ablations. Int J Hyperth 29(4):308–317
12. Lubner MG, Brace CL, Ziemlewicz TJ, Hinshaw JL, Lee FT Jr (2013) Microwave ablation of hepatic malignancy. Semin Intervent Radiol 30(1):56–66
13. Brace CL (2009) Radiofrequency and microwave ablation of the liver, lung, kidney, and bone: what are the differences? Curr Probl Diagn Radiol 38(3):135–143
14. Liang P, Yu J, Lu MD, Dong BW, Yu XL, Zhou XD, Hu B, Xie MX, Cheng W, He W, Jia JW, Lu GR (2013) Practice guidelines for ultrasound-guided percutaneous microwave ablation for hepatic malignancy. World J Gastroenterol 19(33):5430–5438
15. Gao Y, Wang Y, Duan Y, Li C, Sun Y, Zhang D, Lu T, Liang P (2010) 915MHz microwave ablation with high output power in in vivo porcine spleens. Eur J Radiol 75(1):87–90
16. Duan YQ, Gao YY, Ni XX, Wang Y, Feng L, Liang P (2007) Changes in peripheral lymphocyte subsets in patients after partial microwave ablation of the spleen for secondary splenomegaly and hypersplenism: a preliminary study. Int J Hyperth 23(5):467–472
17. McKeown MJ, Makeig S, Brown GG, Jung TP, Kindermann SS, Bell AJ, Sejnowski TJ (1998) Analysis of fMRI data by blind separation into independent spatial components. Hum Brain Mapp 6(3):160–188
18. Chang CH, Yu CH, Ko HC, Chen CL, Chang FM (2005) Fetal upper arm volume in predicting intrauterine growth restriction: a three-dimensional ultrasound study. Ultrasound Med Biol 31(11):1435–1439
19. Leung KY, Ngai CS, Chan BC, Leung WC, Lee CP, Tang MH (2005) Three-dimensional extended imaging: a new display modality for three-dimensional ultrasound examination. Ultrasound Obstet Gynecol 26(3):244–251
20. Babinszki A, Nyari T, Jordan S, Nasseri A, Mukherjee T, Copperman AB (2001) Three-dimensional measurement of gestational and yolk sac volumes as predictors of pregnancy outcome in the first trimester. Am J Perinatol 18(4):203–211
21. Landry A, Spence JD, Fenster A (2005) Quantification of carotid plaque volume measurements using 3D ultrasound imaging. Ultrasound Med Biol 31(6):751–762
22. Bu L, Munns S, Zhang H, Disterhoft M, Dixon M, Stolpen A, Sonka M, Scholz TD, Mahoney LT, Ge S (2005) Rapid full volume data acquisition by real-time 3-dimensional echocardiography for assessment of left ventricular indexes in children: a validation study compared with magnetic resonance imaging. J Am Soc Echocardiogr 18(4):299–305
23. Ohto M, Kato H, Tsujii H, Maruyama H, Matsutani S, Yamagata H (2005) Vascular flow patterns of hepatic tumors in contrast-enhanced 3-dimensional fusion ultrasonography using plane shift and opacity control modes. J Ultrasound Med 24(1):49–57
24. Neshat H, Cool DW, Barker K, Gardi L, Kakani N, Fenster A (2013) A 3D ultrasound scanning system for image guided liver interventions. Med Phys 40(11):112903
25. Zotz RJ, Trabold T, Bock A, Kollmann C (2001) In vitro measurement accuracy of three-dimensional ultrasound. Echocardiography 18(2):149–156
26. Liang P, Dong B, Yu X, Yu D, Cheng Z, Su L, Peng J, Nan Q, Wang H (2001) Computer-aided dynamic simulation of microwave-induced thermal distribution in coagulation of liver cancer. IEEE Trans Biomed Eng 48(7):821–829