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● *Original Contribution*

FEASIBILITY OF USING ULTRASONIC NAKAGAMI IMAGING FOR MONITORING MICROWAVE-INDUCED THERMAL LESION IN *EX VIVO* PORCINE LIVER

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Abstract—The feasibility of using ultrasonic Nakagami imaging to evaluate thermal lesions induced by microwave ablation (MWA) in *ex vivo* porcine liver was explored. Dynamic changes in echo amplitudes and Nakagami parameters in the region of the MWA-induced thermal lesion, as well as the contrast-to-noise ratio (CNR) between the MWA-induced thermal lesion and the surrounding normal tissue, were calculated simultaneously during the MWA procedure. After MWA exposure, a bright hyper-echoic region appeared in ultrasonic B-mode and Nakagami parameter images as an indicator of the thermal lesion. Mean values of the Nakagami parameter in the thermal lesion region increased to 0.58, 0.71 and 0.91 after 1, 3 and 5 min of MVA. There were no significant differences in envelope amplitudes in the thermal lesion region among ultrasonic B-mode images obtained after different durations of MWA. Unlike ultrasonic B-mode images, Nakagami images were less affected by the shadow effect in monitoring of MWA exposure, and a fairly complete hyper-echoic region was observed in the Nakagami image. The mean value of the Nakagami parameter increased from approximately 0.47 to 0.82 during MWA exposure. At the end of the postablation stage, the mean value of the Nakagami parameter decreased to 0.55 and was higher than that before MWA exposure. CNR values calculated for Nakagami parameter images increased from 0.13 to approximately 0.61 during MWA and then decreased to 0.26 at the end of the post-ablation stage. The corresponding CNR values calculated for ultrasonic B-mode images were 0.24, 0.42 and 0.17. This preliminary study on *ex vivo* porcine liver suggested that Nakagami imaging have potential use in evaluating the formation of MWA-induced thermal lesions. Further *in vivo* studies are needed to evaluate the potential application. (E-mail: mxwan@mail.xjtu.edu.cn) **© 2016 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Microwave ablation, Ultrasound imaging, Nakagami, Monitor.**

INTRODUCTION

Hepatocellular carcinoma (HCC) is the most common primary malignant tumor of the liver with an ample blood supply. Its worldwide incidence rate increases every year because of cirrhosis related to hepatitis B and C virus infections (Liu et al. 2014; Memeo et al. 2014; Thomas et al. 2009; Yaprak et al. 2012). Surgical resection and liver transplantation remain the optimal strategy for HCC treatment (Memeo et al. 2014; Yaprak et al. 2012). However, the majority of patients with HCC disease are not amenable to surgical resection because of an insufficient number of living donors and a high risk of complications (Memeo et al. 2014). The criteria for judging if a patient is a suitable candidate for surgical treatment of HCC depend on several factors, such as the size, location and stage of the tumor, especially when the patient has extrahepatic disease and/or liver dysfunction (Hasegawa and Kokudo 2009). Consequently, therapeutic alternatives have been developed for the treatment of HCC with unresectable hepatic tumors.

Image-guided percutaneous ablation technologies, such as radiofrequency, microwave, laser, cryotherapy, high-intensity focused ultrasound (HIFU), are available for the focal destruction of HCC tumors (Cheung et al. 2014; Chu and Dupuy 2014; Vogl et al. 2014; Wang

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et al. 2015), as they may provide some potential advantages over surgical resection. A number of recent studies and reviews compared different ablation technologies for colorectal liver metastases and found that ablation technologies remain a useful adjunct in the multidisciplinary treatment of patients with colorectal liver metastases not amenable to hepatic resection (Chu and Dupuy 2014; Pathak et al. 2011; Vogl et al. 2014; Wang et al. 2015). Radiofrequency ablation (RFA) and microwave ablation (MWA) are the two dominant modalities currently used to treat HCC. RFA is widely used as a minimally invasive therapeutic alternative modality for the treatment of tumors, such as HCC and liver metastases (Lee et al. 2016; Vogl et al. 2014). During RFA treatment, a needle-like radiofrequency electrode is inserted into a tumor to deliver a strong high-frequency alternating electrical current. This current agitates ions and increases the temperature to generate areas of coagulative necrosis and tissue desiccation surrounding the RF electrode (Lee et al. 2016; Vogl et al. 2014). As an alternative to standard surgical resection, RFA is interesting with promising oncologic results and a relative degree of safety for the treatment of liver tumors (Lee et al. 2016; Vogl et al. 2014). MWA is currently being developed as a minimally invasive therapeutic alternative modality capable of selective and localized destruction of tissue volumes within the body, while sparing surrounding tissue from harmful exposure (Chu and Dupuy 2014; Korkusuz et al. 2015; Liang et al. 2008; Yue et al. 2013). In clinical applications of MWA, an applicator is inserted into the tumor under the guidance of ultrasound imaging and acts as a microwave antenna. Single or multiple antennas (arrays) are used to launch microwave energy at a frequency of 915 or 2450 MHz into the tumor tissue, inducing the rotation of dipoles found in water molecules in the electromagnetic field. Microwaves heat the tissue until it reaches a local high temperature via rapid frictional heating from dipole rotation, resulting in coagulation necrosis with irreversible cell death within minutes. At present, MWA is extensively used in the treatment of liver, kidney, lung, breast, adrenal gland, bone, adenomyosis, and uterine fibroids (Fornage and Hwang 2014; Gomez et al. 2014; Stattner et al. 2015; Yang et al. 2015).

Clinical use of MWA for the treatment of tumors located in various tissues is now being investigated by taking advantage of the recent development of medical imaging techniques, such as ultrasound (US) imaging (Daoud et al. 2013; Korkusuz et al. 2015; Liang et al. 2008; Tsui et al. 2012b; Yue et al. 2013), computed tomography (CT) (Wei et al. 2015), and magnetic resonance imaging (MRI) (Birkl et al. 2014; Dong et al. 2015), for targeting and monitoring MWA. CT is capable of predicting thermal ablation with a precision of 2–3 mm (Wei et al. 2015). However, CT is less applicable in real time, and there are concerns regarding the radiation dose to both the patient and the physician. The temperature sensitivity of proton resonance frequency (PRF) or relaxation time T_1 is used to monitor temperature distribution (Birkl et al. 2014). A range of applications of magnetic resonance-guided MWA have been used in the clinical field, because of its quantitative spatial-temporal temperature information with high accuracy and spatial resolution (Birkl et al. 2014). US imaging has a number of advantages such as portability, wide clinical availability, real-time imaging capability, low cost and non-invasiveness. Conventional ultrasonic B-mode imaging is clinically used to guide insertion of the MWA needle electrode at the correct location of the tumor during MWA treatment (Liang et al. 2008; Yue et al. 2013). A number of ultrasound imaging methods for monitoring MVA have been investigated in recent years. Several ultrasound elastography modalities have potential in the monitoring of percutaneous microwave ablation (Korkusuz et al. 2015). Non-invasive temperature estimation via ultrasound echo strain caused by changes in sound speed and thermal expansion has been proposed as a reasonable approximation over a limited range of temperature change (Varghese and Daniels 2004). A variety of techniques using time and frequency domain features of raw ultrasound backscattered signals from the ablated region have been used to estimate temperature during thermal ablation therapy. These acoustic features include time shift (Daoud et al. 2013), frequency shift (Amini et al. 2005), attenuation coefficient (Techavipoo et al. 2004), changes in backscattered energy (Tsui et al. 2012a), probability distribution (Tsui et al. 2012b), B-mode US image texture (Yang et al. 2010) and speckle tracking (Lai et al. 2010). Changes In acoustic properties, such as attenuation (Bevan and Sherar 2001), backscattering (Tsui et al. 2012a) and mean scatterer spacing (Zhou et al. 2013), have been proposed for monitoring MWA treatment. Conventional ultrasonic B-mode images reveal variations in echogenicity, and a hyper-echoic region is clinically used for guiding and monitoring MWA (Liang et al. 2008; Yue et al. 2013). The use of ultrasound imaging for the guidance and monitoring of MWA most often relies on the appearance of a hyper-echoic region in the ultrasound image (Liang et al. 2008; Yue et al. 2013). This hyper-echoic region is often caused by the thermal lesions associated with protein coagulation necrosis and/or the appearance of bubble activity (Liang et al. 2008; Yue et al. 2013; Zhang et al. 2009). During thermal ablation treatment, bubble activity may be the result of cavitation and/or boiling (Khokhlova et al. 2006; McLaughlan et al. 2010). Cavitation is one of the primary mechanisms