Monitoring Radiofrequency Ablation with Ultrasound Nakagami Imaging

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ABSTRACT: Radiofrequency ablation (RFA) is a widely used alternative modality in the treatments of liver tumors. Ultrasound B-mode image is an important tool to guide the insertion of the RFA electrode into the tissue. However, it is difficult to visualize the ablation zone because RFA induces the shadow effect in the B-scan. Based on the randomness of ultrasonic backscattering, this study proposes ultrasound Nakagami imaging, which is a well-established method for backscattered statistics analysis, as an approach to complement the conventional B-scan for evaluating the ablation region. Porcine liver samples (n = 6) were ablated by using a RFA system and monitored by an ultrasound scanner equipped with a 7.5 MHz linear array transducer. During the stages of ablation (0-12 minutes) and postablation (12-24 minutes), the raw backscattered data were acquired at a sampling rate of 30 MHz for B-mode, Nakagami imaging. The results demonstrated that the Nakagami image has the ability to visualize the change in the backscattered statistics in the ablation zone including the shadow region during RFA. The average Nakagami parameter increased from 0.2 to 0.6 in the ablation stage, and then decreased to about 0.3 at the end of postablation stage. This study demonstrated that ultrasound Nakagami imaging based on the analysis of the backscattered statistics has the ability to visualize the RFA-induced ablation zone even if the shadow effect exists in the B-scan.

INTRODUCTION
Hepatocellular carcinoma (HCC) is a common cancer, and its incidence is increasing worldwide because of the dissemination of hepatitis B and C virus infection. Surgical resection and liver transplants offers the best chance of cure in HCC (Chen et al, 2010; Velazquez et al, 2003). However, not all patients are suitable surgical methods. Treatment must take into the many of condition factors, such as the number, location, size, and stage (El-Serag et al, 2008) of the tumor. These reasons have led to the development of alternative treatment procedures to destroy HCC tumors.

Radiofrequency ablation (RFA) is currently the most widely used technique for minimally invasive liver tumor treatment. During an RFA procedure, a small electrode is place within the tumor, enabling the delivery of strong radiofrequency energy directly to the tissue. Radiofrequency current generates ionic agitation, which is converted into frictional heat, and raises the temperature
to induce the coagulation necrosis of tissues surrounding the RF electrode (Lencioni and Crocetti, 2007).

Ultrasound is the ideal imaging modality for guiding RF needle electrode to the correct location of the tumor, because it provides real-time monitoring of the electrode location (Solbiati et al, 2004). RFA continued heating will cause the tissue temperature near the boiling point, thus making the ablation zone, the bubbles generated (Kotini et al, 2006; Winkler and Adam, 2011). The bubbles are as strong acoustic scatterers that interact with the incident ultrasound to contribute strong echo intensity in the B-mode image. Therefore, during RFA treatment, the surgeons can use grayscale images observed bubbles generated hyperechoic area as the ablation zone of evaluation. However, B-mode image which using the brightness to show the strength of the echo signal, it is not only affected by system setting but resulting acoustic posterior shadow effect due to tissue necrosis and bubble generation in the B-mode image, making it more difficult to observe the ablation region (Winkler and Adam, 2011).

Basically, the ultrasound RF data is which as the randomness of ultrasound backscattered signals. Therefore, how to find out the signal rules in a random process is a very important purpose of the information extraction. Probability density function (PDF) of analysis signals is a mathematical method can assist summed up the characteristics of random signals. Among various possibilities, the ultrasound Nakagami image based on the Nakagami parameter of the Nakagami statistical distribution has been verified to be an effective complementary method for the conventional B-scan in describing the backscattered statistics and the corresponding scatterer properties of the tissue (Tsui and Chang, 2007; Tsui et al, 2008). Nakagami images can detect the scattering concentration distribution and structure of the tissue and Nakagami image is formed by the shape of the local scattering enveloped not by signal backscattered strength (Shankar, 2000). The Nakagami image has been explored in several applications of tissue characterization, such as tumor classification (Tsui et al, 2010), monitoring ultrasound-induced thermal lesions (Li et al, 2010). Based on the literature review, this study proposes a hypothesis that the ultrasound Nakagami image may be able to visualize the ablation zone during RFA treatment.

This study explores the feasibility of using the ultrasound Nakagami image to visualize the ablation zone during RFA. The next section introduces the theoretical background of the Nakagami model and imaging. The subsequent sections present the experimental materials and methods, and lastly, show the results and discussion.

**NAKAGAMI MODE**

Probability density function of ultrasonic backscattered envelope \( R \) under Nakagami statistical model is given by formation (1) (Shankar, 2000), where \( \Gamma(\cdot) \) and \( U(\cdot) \) are the gamma function and the unit step function, respectively.

\[
f(r) = \frac{2m^m r^{2m-1}}{\Gamma(m)\Omega^m} \exp\left(-\frac{m}{\Omega}r^2\right) U(r), \tag{1}
\]

If \( E(\cdot) \) denotes the statistical mean, then the scaling parameter \( \Omega \) and the Nakagami parameter \( m \) associated with the Nakagami distribution can be respectively obtained from formation (2) and (3).

\[
\Omega = E(R^2) \tag{2}
\]

\[
m = \frac{[E(R^2)]^2}{E[R^2 - E(R^2)]}. \tag{3}
\]
The Nakagami parameter \( m \) is a shape parameter to determine the statistical distribution of the ultrasonic backscattered envelope. When the variance of parameter changing from 0 to 1, the statistics distribution of the envelope changes from pre-Rayleigh to the Rayleigh and the parameter is lager then 1, the statistics distribution is post-Rayleigh. Because different scatterer concentrations result in different envelope statistics, the parameter \( m \) is a good parameter for quantifying concentrations of scatterers in the tissues.

The Nakagami image is constructed using the Nakagami parametric map. The window size determines the resolution and the stable parameter estimation of the Nakagami image. To simultaneously satisfy the stable estimations of \( m \) and an acceptable imaging resolution, a previous study performed simulations to generalize a criterion: a square with a side length equal to 3 times the pulse length of the incident ultrasound is an appropriate size for the sliding window of a Nakagami image construction.

MATERIALS AND METHODS

Tissue measurements were conducted to validate the feasibility of using the Nakagami image to monitor the ablation region during RFA. The experimental setup is shown in Figure 1.

![Figure 1. The experimental setup. The raw image data were acquired from the Terason ultrasound system for B-mode and Nakagami imaging.](image)

Before the experiment, the liver was cut into the appropriate size, and placed in a box filled with saline solution of 0.9% NaCl. At the bottom of the case, a gel phantom was created to hold the liver samples. To enable the operation of the RFA system (Model VIVA RF generator, Starmed Co. Ltd., Goyang, Gyeonggi, South Korea) which include a cool tip RF electrode with a length of 1.5cm (Model 17-20V15-40, Starmed Co.), an RF generator, a peristaltic pump, cables and other devices, a metal board was attached to the wall of the case as a grounding pad.

In the experiments, the RF needle electrode was inserted into the liver sample obtained from local markets through a small hole created in the case wall. To avoid leakage of the saline solution from the hole, clay materials were used to it. The ultrasound transducer was immersed in the saline solution and placed above the liver sample. The RF system was turn on and set to Auto mode which starts at 50 and Increments of 10 watts, until the first highest resistance appears; then it generates a sequence of RF pulses as a function of time. See Figure 2., time period of Auto mode is 12 minutes. Collection of ultrasound image data continued for 24 minutes which include the
Ablation time was 12 minutes and cooled to 12 minutes. Independent experiments on six liver samples were conducted (n=6).

**Figure 2.** Raw image data acquisition was performed every 5 sec in both the ablation and post-ablation stages. The total acquisition time is 24 minutes.

**RESULTS AND DISCUSSIONS**

Figure 3. shows the B-mode and Nakagami images of porcine liver obtained from before ablation to post ablation stages at 0, 3, 6, 9, 12, 15, 18, 21, 24 minute. The white arrow in the top left diagram shows the position of the RF needle in the beginning. At the ablation zone, the imaging intensity is increased in the ablation. However, in the post-ablation, the images intensity is gradually decreased. Therefore, due to necrosis zone harden, making the tissue in the ablation zone more closely, so that acoustic energy is absorbed and penetrate difficultly and artifact caused. We can predict ablation position from the brighter part of the image, but it cannot be clearly defined contour of ablation zone. Then, see the Nakagami images. At the 0 minute, the image display dark blue, that it indicated in the liver the intrinsic backscatter statistics of the ultrasound envelope signal shows a pre-Rayleigh. During ablation process, the images color from dark blue to light blue and the red interspersed in the ablation zone. This shows that the backscatter of the ultrasound envelope signal display a Rayleigh distribution. In the post ablation, the color from an interlaced red-blue to dark blue, indicating that the backscatter statistics figures returns to the pre-Rayleigh distribution.

**Figure 3.** The B-mode images and Nakagami images of porcine liver obtained from before ablation stage to post ablation stages at 0, 3, 6, 9, 12, 15, 18, 21, 24 minute.

Comparison two mode images B-mode and Nakagami images, the results show some information. In the ablation, due to the backscattering change within the tissue, Nakagami images can clearly present the ablation zone. In particular, during ablation, due to tissue coagulation, makes the shaded portion cannot be observed by B-mode image. However, because of the change of the backscattering in ablation zone, that can still detected by Nakagami image.
CONCLUSION
This study explores the feasibility of using the ultrasound Nakagami image to visualize the ablation zone during RFA. According to the current results, we suggest that the Nakagami image can be combined with the conventional B-mode images for the assessment of the ablation zone by RFA.

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