Validation of the accuracy of evaluation of the fat component of the DN Model in a multicomponent medium

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1. Introduction

Amplitude envelope analysis in ultrasound quantitative evaluation is expected to be one of the methods for noninvasive quantitative evaluation of biological tissue properties, and studies such as fatty liver evaluation using the Nakagami model [1] have been conducted in liver diseases.

To evaluate the characteristics of a medium with multiple mixed tissues, this research group has proposed a method for evaluating the amplitude envelope characteristics of echo signals using the Double-Nakagami (DN) model, which combines two Nakagami models [2]. In the previous studies, the frequency bands and array sensors were not sufficiently studied in accordance with the current clinical situation.

In this study, we evaluated the amplitude envelope characteristics of phantom echo signals containing two types of scatterers simulating fatty liver using the DN model and investigated the relationship between the scatterer structure and the evaluation parameters as an actual measurement study with reduced deviation from clinical practice.

2. Method

2.1 Amplitude envelope analysis Model

The Nakagami distribution is a probability density function that shows the amplitude enveloping property and is expressed by Equation (1) [3].

$$p(x) = \frac{2\mu^{\mu}x^{2\mu-1}}{\Gamma(\mu)\omega^{\mu}} \exp\left\{-\left(\frac{\mu}{\omega}\right)x^2\right\} \quad (1)$$

x is the amplitude envelope, Γ is the gamma function, and μ and ω are parameters of the scatterer number density and echo signal power, respectively. μ is Nakagami parameter and is classified as pre-Rayleigh when $\mu < 1$, Rayleigh when $\mu = 1$, and post-Rayleigh when $\mu > 1$.

The DN model used in this study is a combination of two Nakagami models and is expressed by the following equation.

$$p_{mix}(x) = (1-\alpha)p_L(x|\mu_L, \omega_L) + \alpha p_F(x|\mu_F, \omega_F) \quad (2)$$

p_L and p_F are defined as the probability density functions of the echo signals of normal liver tissue including luminal structures and fat droplets as the main scattering sources. μ_L and μ_F correspond to the number density of normal liver tissue and fat droplets, while $(1 - \alpha)\omega_L$ and $\alpha\omega_F$ are the parameters for the intensity of echo signals from normal liver tissue and fat droplets respectively.

2.2 Valuation target

We assumed that the fatty liver is composed of normal liver tissue structure and fat droplets and created a phantom that mimicked each of them. In the normal liver tissue mimicking phantom, scatterers with a particle size of 5 μm (Orgasol 2001 UD NAT1, Arkema) were mixed at a volume fraction of 0.1%. To mimicking the impedance ratio of liver tissue and fat droplets (1.29) in fatty liver, crushed seaweed was contained as scatterers to normal liver phantom. In order to confirm the respective effects of impedance ratio and scatterer size, the other phantom with an impedance ratio of 1.00 was created by containing spherical particles size of 40 μm (Orgasol 2002 ES4 NAT3, Arkema).

2.3 Data acquisition

For RF echo data acquisition, an ultrasound system (LOGIQ S8, GE Healthcare) and two types of linear probes with different center frequencies and bandwidths were used. The 9LD probe (GE Healthcare) has a center frequency of 6.5 MHz, and the ML6-15-D probe (GE Healthcare) has a center frequency of 10 MHz. The sampling frequency and quantization number were 50 MHz and 16 bits, respectively.

3. Results and Discussion

3.1 Amplitude envelope analysis

Figure 1 shows the evaluated results of the probability density characteristics of amplitude envelope on a fatty liver phantom with observed with the two probes. For both probes, the probability density function expressed by the DN model is better fitted to the amplitude enveloping

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characteristics of the actual observed signal than that by the Nakagami model. This is because the signal group consisting mainly of echoes from the weak scatterer with a base grain size of 5 μm is evaluated as p_L, while the signal group consisting mainly of echoes from the strong scatterer, which is a large scatterer and has an impedance ratio of 1.43, is evaluated as p_F.

Since p_L and p_F are both fit to the Nakagami distribution (or Rayleigh distribution), it can be understood that the amplitude distribution characteristics of the fatty liver phantom is composed of not only low echo group and high echo group but also each component and interference of both.

3.2 Evaluation parameters

The RF echo signals measured by the ML6-15-D probe on the fatty liver phantom with 40 μm scatterer were analyzed by the DN model, and the results of mapping the evaluation parameters at each ROI are shown in **Fig. 2**.

At a depth of 60-80 mm near the electron focus, both μ_L, the number density of low amplitude signal components, and $(1\text{-}\alpha)\omega_L$, the power considering the existence probability, are close to 1.0, indicating that a single homogeneous scatterer is dominantly distributed. And μ_F is smaller than 1.0 suggests that the scatterers are classified into two types: the base 5 μm scatterers and the sparsely distributed 40 μm scatterers with strong scattering intensity.

In contrast, μ_F is generally lower and $\alpha\omega_F$ is higher at shallower than 60 mm, indicating that the signal strength of the strong scatterer is dominant. Since the resolution in this region is lower than that near the focus, it is assumed that the signals from the 5 μm and 40 μm scatterers interfere with each other, and the weak scattering component was masked by the strong scattering component, resulting in a signal composed of higher power.

4. Summary

At high resolution (both spatial and intensity), it is possible to discriminate between the two types of scattering sources by analyze the echo envelope characteristics by DN model, and it is confirmed that one of the two types of scatterers dominates at low resolution. These results suggest that the DN model can be used to evaluate the mixture of fat droplets in the liver if sufficient degradability can be ensured.

Currently, analysis of echo signals obtained by transmitting and receiving plane waves, which are less device-dependent, is being promoted.

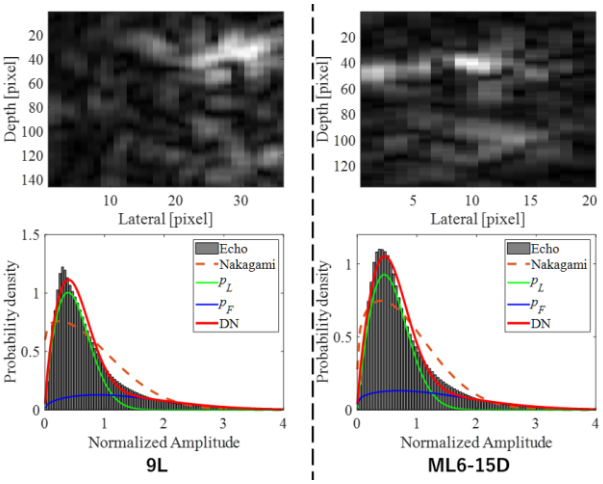

Fig. 1 B-mode images and probability densities of phantom

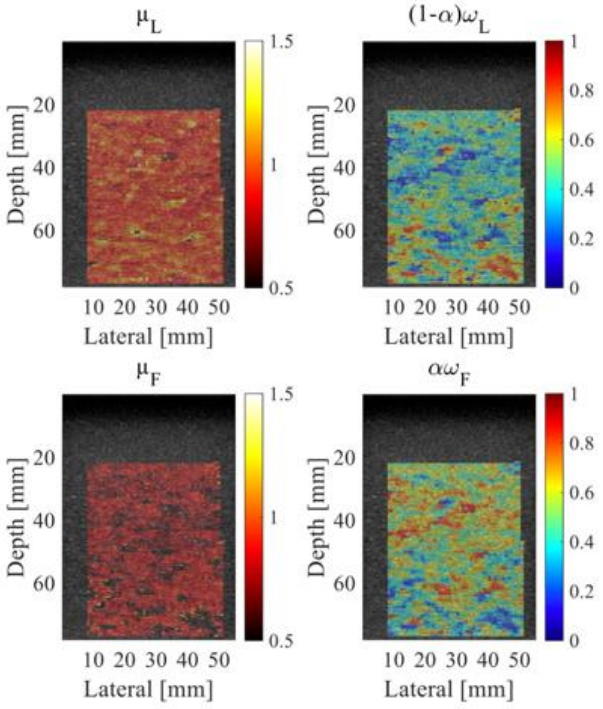

Fig. 2 Estimated Double-Nakagami parameters of 40 μm fatty phantom measured by ML6-15-D

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