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Improvement of stability of amplitude envelope statistics and discrimination evaluation of multi-components

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1. Introduction

Amplitude envelope statistics is one of the ultrasound-based tissue characterization methods that quantitatively evaluate the properties of biological tissues such as the liver. Evaluation of fatty liver using Nakagami model [1,2] and liver disease with fibrosis using Multi-Rayleigh (MRA) model, which consists of several Rayleigh models have been reported [3,4].

However, since amplitude envelope statistics is affected by the sound field characteristics of the measurement system, it is necessary to consider the effects of the amplitude gradient of the echo signal and spatial resolution as sound field characteristics in order to establish a generic and stable evaluation index.

In this study, we applied our amplitude envelope statistics to signals acquired from the same object under different sound field characteristics by changing the ultrasound system's transmission conditions and examined the analytical model's evaluation accuracy.

2. Materials and Methods

2.1 Data acquisition conditions

As a homogeneous medium for evaluation, a biomimetic phantom was prepared by encapsulating a scatterer (Orgasol 2002 EXD NAT 1; Arkema) with an average particle size of 10 µm at a volume fraction of 0.5% in a 2.0wt% agar gel (A1296; Sigma-Aldrich).

Diagnostic ultrasound systems, Scanner A (LOGIQ S8, GE Healthcare) and B (Vantage 256, Verasonics), and linear array probe (9L-D, GE Healthcare) were used to acquire echo signals. Both systems acquired signals under conditions where the sound field characteristics differed due to differences in the transmit aperture, transmit focus, and post-receive signal processing. **Table I** shows the transmission and reception conditions for both systems. The transmit frequency and sampling frequency were the same at both scanner, 6.5 MHz and 50 MHz, respectively. In Scanner B, plane wave signals are transmitted and received, and then analyzed after synthetic aperture processing.

Tab. I Measurement conditions in each system.

Scanner	LOGIQ S8 (A)	Vantage256 (B)
Number of Tx elements	81	192
Tx focus depth [mm]	40	-
Number of Rx elements	192	192

2.2 Amplitude envelope analysis

Nakagami and MRA models were applied as mathematical models to evaluate the amplitude enveloping characteristics of the acquired echo signals. Nakagami model can evaluate the number density of scatterers from the amplitude probability distribution, assuming that there is only one type of scatterer in the medium. When the scatterers are densely and homogeneously distributed, Nakagami-$\mu \approx 1$, Rayleigh distribution is obtained.

On the other hand, biological tissue is a medium in which multiple scatterer sources are mixed, and the acquired echo signal is expressed as the sum of the signals of each scatterer. Therefore, the Rayleigh distribution (Rayleigh$_M$), which is the main component of the signal to be evaluated, Rayleigh$_L$, which is the signal component from a group of scatterers with lower density or scattering intensity, and Rayleigh$_H$, which is the signal component from a group of scatterers with higher density or scattering intensity, are combined to evaluate the overall a three-component MRA model is proposed to evaluate the echo signal characteristics. The number of Rayleigh components and the resulting combination is determined from the Rayleigh distribution and the degree of deviation from the two-component MRA model using moments calculated from the amplitude envelope of the echo signal [4].

The parameters of both models were evaluated by scanning the region of interest (ROI) in two dimensions with a spatial resolution of five times the size and analyzing the amplitude envelope characteristics at each location.

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3. Results and Discussion

Figure 1 show B-mode images of phantom and the amplitude envelope averaged at each depth acquired with both systems and the data from the center 20 raster. Scanner A has a transmit focus depth of 40 mm, so the amplitude increases rapidly near the focal point and has a significant amplitude gradient in the depth direction. Before 40 mm, the amplitude gain is smaller due to the effect of processing of the diagnostic equipment. Scanner B with plane wave transmission/reception and synthetic aperture processing has high brightness over a wide area and a linear amplitude gradient in the depth direction. Therefore, the synthetic aperture method can be applied to eliminate the effect of locally complex variable gradients, which is one of the reasons for the low evaluation accuracy of amplitude envelope statistics. However, amplitude distribution in the lateral direction, there were regions of locally low values. We believe this is because the difference in sensitivity between the probe elements has not been fully calibrated.

Figure 2 shows the results of Nakagami model and determining the number of components for the MRA model at each ROI. Since the evaluation target is a homogeneous medium, the ideal for Nakagami-μ is approximately 1, and for MRA model component number is 1. Scanner A has a significant amplitude gradient near the focal point, resulting in a mixture of locally low values and regions evaluated as low. On the other hand, Scanner B has a slight amplitude gradient and maintains resolution, which was assumed to improve the evaluation accuracy. However, Nakagami-μ showed a lesser standard deviation, but low-value regions existed. MRA model component estimation showed an increase in regions judged to have two components; a result different from that assumed for both models.

The insufficient accuracy of the evaluation may be due to the influence of the lateral amplitude distribution. It was confirmed that the regions where the influence was small could be evaluated as a homogeneous medium.

4. Conclusion

We applied plane wave transmission and synthetic aperture methods to homogeneous phantoms to improve the evaluation accuracy of amplitude envelope statistics. As a result, we could suppress the amplitude gradient and beam divergence in the depth direction, suggesting the possibility of improving the evaluation accuracy. Currently, we are modifying the aperture synthesis method to compensate for transverse signals and promote the characterization of media with a mixture of various types of scatterers.

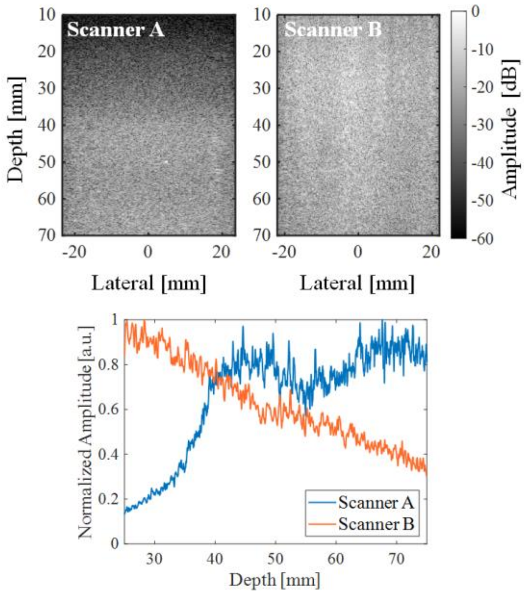

Fig. 1 B-mode images of the phantom and the normalized amplitude envelope averaged in center 20 raster acquired with Scanner A and B.

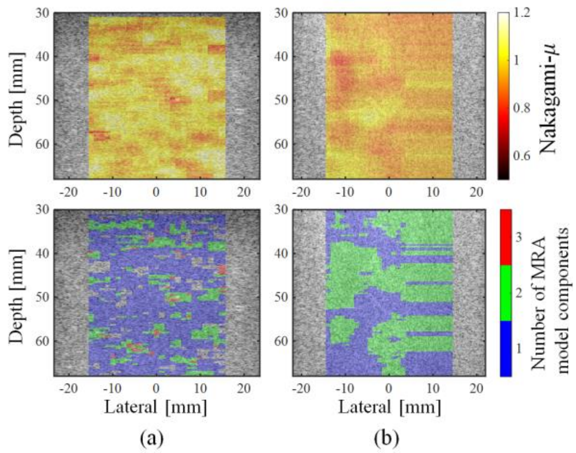

Fig. 2 Estimated component number by Nakagami model and MRA model. (a) Scanner A (b) Scanner B.

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