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Verification of effect of interference between multiple scatterers on the evaluation of backscattering coefficient

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1. Introduction

A quantitative ultrasound (QUS) method focusing on the backscattering coefficient (BSC) has been put into practical use, as an attempt to estimate and quantitatively evaluate the structure of scatterers from the echo signal. However, biological tissues contain a mixture of multiple scatterers, and the correlation between the physical structure of the medium and its acoustic properties has not been fully investigated. To accurately evaluate BSC, it is necessary to understand the relationship between the physical structure of the medium and the acoustic properties of the biological tissue that is the scattering source and the wave interference caused by them. In this study, the influence of the interference state of waves between different scatterers on the backscattering coefficient at very high frequency is investigated both mathematically and experimentally.

2. BSC evaluation of numerical phantoms

To verify the analytical results of the actual measurements, a three-dimensional numerical phantom (256 µm × 256 µm × 256 µm) was created on the computer. The numerical phantoms were set to the same placement conditions, volume fractions, and acoustic impedance as the scatterers in the substantive phantoms described below. In this case, plane wave propagation and weak scattering were assumed and the BSC was estimated using equation (2)3).

$$BSC_{3DZM} = \frac{k^4}{4\pi^2} E\left[|FT(3DZM)|^2\right] * \frac{1}{L^3}\left(\frac{l}{N_p}\right)^6 \qquad (2)$$

where $3DZM$ denotes the three-dimensional acoustic impedance map in the numerical phantom, $E[|FT(3DZM)|^2]$ is the expected value of the Fourier transform of 3DZM, and $\frac{1}{L^3}\left(\frac{l}{N_p}\right)^6$ is the correction term due to discretization. In addition, k, L, N_p denote the wavenumber, the length of the piece to be analyzed, and the resolution, respectively.

2. BSC evaluation of actual phantoms

2.1 Echo signal acquisition

Phantoms containing two types of scatterers with different particle size and acoustic impedance in 2% agar was made. The weak scatterers are 10 µm in diameter (ORGASOL, 2002 EXD NAT 1, Arkema) and the strong scatterers are 30 µm in diameter (MX-3000, Soken Chemical), with acoustic impedances of 1.493 and 1.665 Mrayl, respectively. Five types of phantoms shown in **Table 1** were made by varying the conditions of inclusion of these scatterers.

Table1 Phantom composition

	ORGASOL	MX-3000
Phantom1	0.5 wt%	-
Phantom2	-	0.5 wt%
Phantom3	0.5 wt%	0.1 wt%
Phantom4	0.5 wt%	0.3 wt%
Phantom5	0.5 wt%	0.5 wt%

A single concave transducer with a center frequency of 35 MHz was attached to a selfmade ultrasonic scanner and scanned to acquire three-dimensional RF echo signals of a phantom fixed in degassed water. The sampling frequency was 250 MHz and quantized at 12 bits.

2.2 Backscatter coefficient evaluation

In order to evaluate the BSC by excluding the characteristics of the transmitter/receiver system, the sound field, and the intrinsic attenuation from the acquired echo signals, the reference phantom method shown in Equation (1) was used, using a medium with known scattering conditions as a reference1).

$$BSC(f) = \frac{P(f)}{P_{ref}(f)} \frac{A(f)}{A_{ref}(f)} BSC_{ref}(f) \qquad (1)$$

where $P(f)$ and $P_{ref}(f)$ are the average power spectra of the echo signals of the analyzed and reference media at any depths, respectively, and f is the frequency. $A(f)$ and $A_{ref}(f)$ are terms that correct for the frequency dependence of the attenuation of the target and reference media. As a mathematical model for calculating $BSC_{ref}(f)$, we used the Structure-Factor model2), which takes into account the interference effects of the scattered signals.

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In the backscatter coefficient evaluation, the size of the three-dimensional region of interest was set to 10 times the wavelength in the depth direction, and 10 pairs of uncorrelated echo lines were cut out in the lateral direction and scanned to evaluate the BSC at each position. Phantom 1 was set as the reference phantom.

4. Results and Discussion

Figure 1 shows the results of the backscattering coefficient estimated from the 3DZM. The theoretical values for the two-scatterer mixed phantom are the sum of the set proportions of each scatterer. The backscattering properties of all phantoms were found to be consistent with the theoretical values. Although the backscattering characteristics of a medium containing multiple scatterers exhibit complex behavior, they were shown to be consistent with the sum of the theoretical values for each scatterer. This suggests that the backscattering coefficients estimated from 3DZM may be affected by the interference of multiple types of scatterers.

The backscatter coefficient evaluation results for the actual phantoms are shown in **Fig. 2**. Phantom 1 was evaluated with high accuracy, but the other phantoms showed large deviations from the theoretical values. The similarity of the evaluation results for Phantom 2, 4, and 5 suggests that the signal from the strong scatterer with a diameter of 30 µm is dominant in the reflected signal in the actual measurements, and that the interference of the signal from the weak scatterer has little effect on the backscattering characteristics.

5. Conclusions

In this study, in order to understand the relationship between the physical structure of the medium and the interference of echoes generated by various types of scatterers, we evaluated a phantom mixture of two types of scatterers from the viewpoints of both mathematical verification and measurement. Although the numerical phantom confirmed the influence of mutual interference between the echoes of the weak and strong scatterers, the signal from the strong scatterer was dominant in the actual measurement, making it difficult to evaluate the concentration and distribution of the two types of scatterers. In actual measurement, it is assumed that the frequency bandwidth and S/N of the transducer used for measurement have a large influence. In future works, we will investigate using a high-frequency linear array probe that enables observation at higher intensities, evaluate phantoms that are close to the scattering intensity of biological tissue, and investigate using real living tissues as targets.

Acknowledgment

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References

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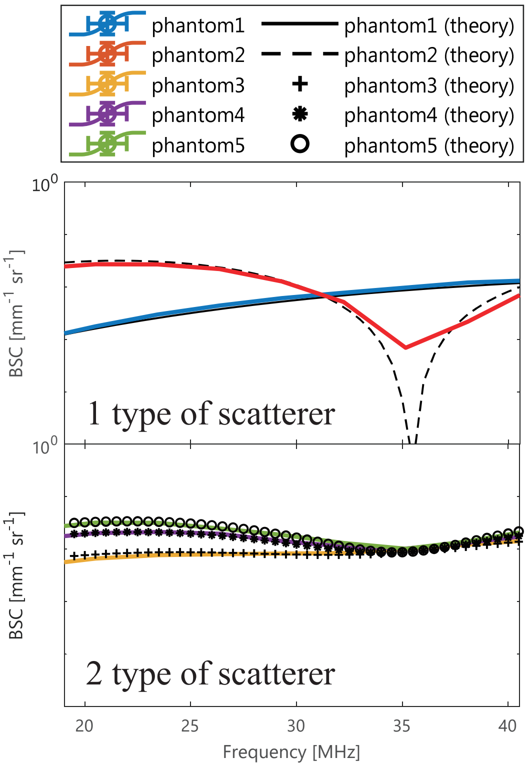

Fig. 1 BSC estimated from 3DZM

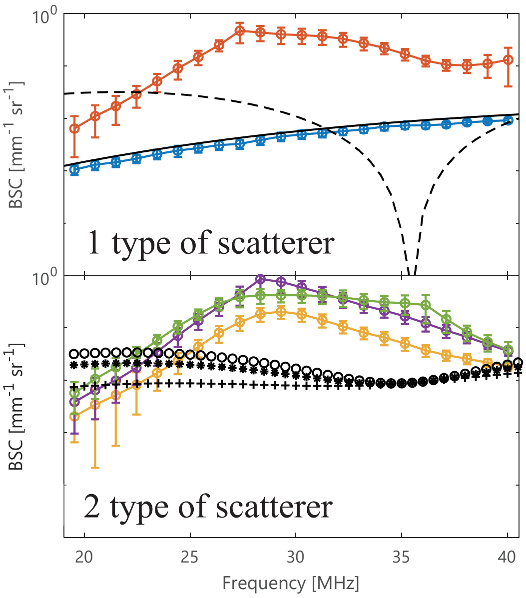

Fig. 2 BSC estimation results for scatter phantom