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Comparative verification of theory and measurement of backscattering coefficient evaluation in media with multiple scatterers

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1. Introduction

Much of research has been progressing that tissue characteristics can be quantitatively evaluated using the backscatter coefficient (BSC) of the echo signal as an index. However, it is not fully understood what the estimated BSC reflects about the tissue structure. We have been studying BSC analysis using several kinds of measured phantoms with different scatterer structures and discussed the relationship between the transmitting/receiving sound fields and the tissue structure, but we have yet to compare and verify the relationship between the measured and theoretical results. Therefore, we are trying to theoretically ground the measured results by running simulations using a three-dimensional acoustic impedance map (3DZM) that reproduces the same phantom as in the actual measurements. 3DZM calculates the BSC only from the structure of the target, so it can estimate the BSC without the use of a mathematical model.

In this study, a 3DZM was created assuming a phantom with a mixture of two types of scatterers, and BSC was estimated from the created 3DZM.

2. Method

2.1 Construction of 3D impedance map (3DZM)

The 3DZM was constructed by randomly arranging two types of scatterers with diameters of 5 μm and 30 μm in a 3-dimensional space of 256 pixels × 256 pixels × 256 pixels (512 μm × 512 μm × 512 μm, 1 pixel = 2 μm), without overlap. Acoustic impedance contrast values were assigned to the scatterer regions, while the acoustic impedance contrast values in other regions were set to 0. The surrounding medium was assumed to be agar phantom, 5 μm diameter scatterer was assumed to be a spherical poly particle ORGASOL (Arkema), and 30 μm diameter scatterer was assumed to be a spherical acrylic particle MX (Soken Chemical). The acoustic impedance of each material is 1.5448, 2.2222, and 3.2487 [10^6kg/m^{2}s], respectively. Based on these values, the acoustic impedance ratios of each scatterer size are 0.4385 and 1.1030 for 5 μm and 30 μm scatterers. The volume fraction of each scatterer size was designed to be 0.05 %. The example of created 3DZM is shown in **Fig. 1**.

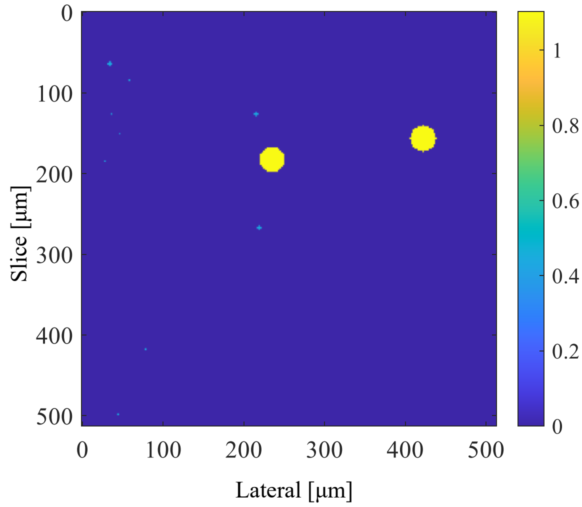

Fig. 1 Example of created 3DZM.

2.2 Calculate BSC from 3DZM

Assuming the plane wave propagation and the weak-scattering, the BSC in 3D space can be computed by averaging Fourier transforms of several 3DZMs as Eq. 1

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

where E denotes the expected values, k is the wave number, N_p is the resolution, L^3 is the volume of a 3D region-of-interest divided in N_p pixels to obtain the 3DZMs, and $FT(3DZM)$ represents the Fourier transform of the 3DZM [1].

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3. Results

Figures 2 and **3** show the calculated average BSC estimated from the 3DZM. The solid red line shows BSC estimated from 3DZM. The dashed red, orange, and light blue lines show the theoretical lines calculated by inserting the data of each scatterer into the Structure-Factor Model (SFM)[2] , which is a mathematical model of the backscattering coefficient when a single sphere is randomly placed. The purple dashed lines are the sum of the theoretical lines for each scatterer size. In the case of the single type of scatterer, the evaluation results at 5 µm were in close agreement with the theoretical line, and at 30 µm, the peaks and dips are shifted from the theoretical line. In the case of the two types of scatterers, the evaluation results agreed with the combined SFM theoretical line of BSC of each scatterer. The differences in the positions of the peaks and dips from the theoretical lines are considered to be a direct reflection of the differences between the 30 µm evaluation results and the theoretical lines when only single type of scatterer was used.

4. Conclusions

As a result of the BSC evaluation using the 3DZM assuming a phantom with two types of scatterers mixed together, the evaluation result was almost in agreement with the sum of the SFM theoretical lines for the BSC of each scatterer. It was also confirmed that the theoretical verification of BSC is possible using 3DZM even when two types of scatterers are included. The next step is to create an actual phantom that has the same characteristics as the 3DZM created in this study, and to compare the results of this study with the results of the measured BSC evaluation.

Acknowledgment

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References

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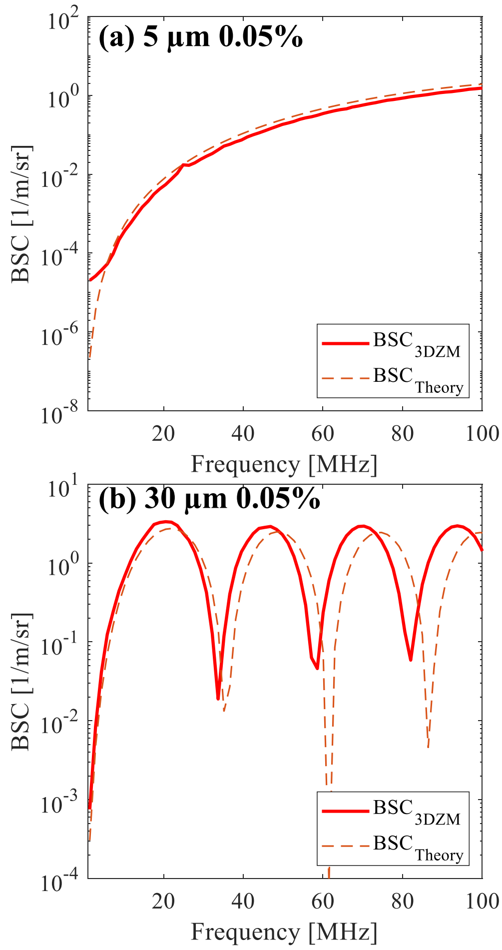

Fig. 2 Estimated BSC of two phantoms containing a single type of scatterer.

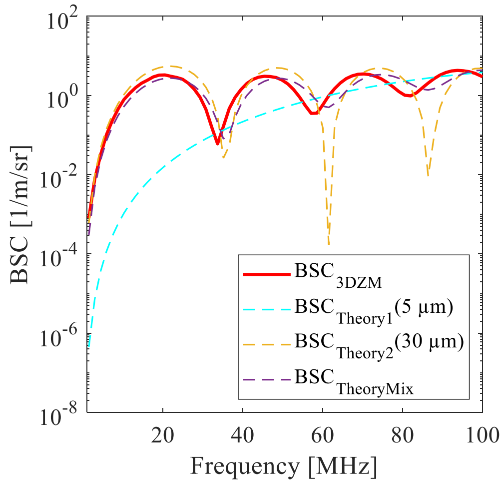

Fig. 3 Estimated BSC of phantom containing two types of scatterers.