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Stability verification of backscattering coefficient evaluation in medium composed of scatterers of multiple sizes

複数の散乱体が混在した媒質における後方散乱係数評価の安定性の検証

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1. Introduction

The quantitative ultrasound (QUS) techniques are used to provide insight into tissue structures such as scatterer diameter and volume fraction and based on the frequency-based analysis of the ultrasound signal from biological tissues. For tissue characterization, the ultrasonic backscattering techniques use the backscatter coefficient(BSC), which is defined by particle size and volume fraction of scatters in tissues and it is possible to estimate the parameters (particle size, volume fraction) in the tissue by fitting calculated BSC with theoretical models.

In this study, some self-made phantoms which had a particle size of a single scatter and two particle sizes of multiple scatters were used for establish the applied technique of the reference phantom method. The phantoms were measured in three dimensions using three single element focused transducers with different center frequency. Then, the BSC tendency when calculating with a reference phantom which has different scatter distributions was confirmed.

2. Materials and Methods

2.1 Phantoms and RF data acquisition

In the general reference phantom method, a phantom with one scatterer is used as a reference, however, phantoms with two scatterers are mutually referenced in this study in order to understand the effect of the properties of the reference phantom on BSC analysis.

The analysis target were three agar-gel phantoms, which include nylon particle scatters (Orgasol 2001 UD, EXD) that have different radius (2.5 μm and 5 μm). Phantom(a) were mixture of distilled water, 2% (w/w) agar powder, and 0.25 wt% particles with radius 2.5 μm, and 0.25 wt% particles with radius 5 μm. It means 2.5 μm and 5 μm particles were contained as same mass. The phantom(b) contained 0.05 wt% of 2.5 μm and 0.45 wt% of 5.0 μm, respectively, so that the number of two kind of particles would be the same. Phantom(c) was a phantom created so that the particle size is biased to 5.0 μm in number density. **Figure 1** shows the existence rate of two types of scatterers in the mediums used to make three phantoms. In addition, two normal phantoms were also created that contained either only 2.5 μm particles or only 5.0 μm particles for use to regular refarance phantom method.

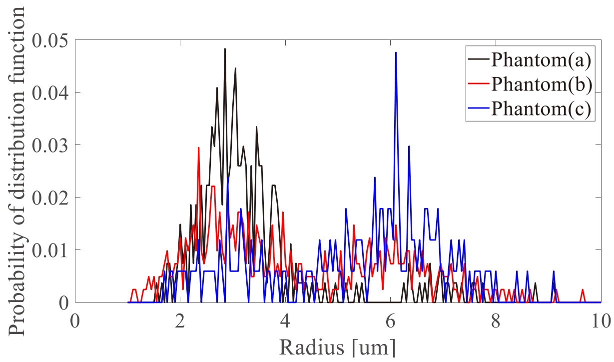


Fig. 1 Existence rate of two types of scatterers in mediums used to make three phantoms.

RF echo signals were acquired in three-demension (3D) using laboratory-made scanner and three single-element focusedtransducers with different center frequency(10, 15, 25 MHz), and were digitized to 12-bits with the sampling frequency of 100 MHz. The focal depth was at approximately 2 mm from the surface of each phantom. During the measurement, each phantom was fixed in a water tank filled with degassed water.

2.2 Backscatter coefficient analysis

The measured BSC_{meas} was calcurated using the reference phantom method from the signals obtained by each transducer by eq. (1).

$$BSC_{meas}(f) = BSC_{ref}(f)\frac{\overline{P_{meas}(f)}}{\overline{P_{ref}(f)}}[A(f,\alpha) - A(f,\alpha_{ref})] \quad (1)$$

Parameter f is the frequency and $BSC_{ref}(f)$ is expressed as follows using polydisperse

$$BSC_{ref}(f) = m\int_0^{\infty} p(r)\sigma_b(k,r)\,dr, \quad (2)$$

where $p(r)$ is the sphere radius probability distribution function that measured from the microscopic images of each medium for creating phantoms. $\sigma_b(k,r)$ can be computed the theory developed by Faran. The Faran model provides an exact solution for the scattering of sound by a solid sphere in a surrounding fluid medium. The number density m is related to the total sphere concentration $\emptyset$ as

$$m = \frac{\emptyset}{(4/3)\pi\int_0^{\infty} p(r)r^3 dr}, \quad (3)$$

were $\overline{\overline{P_{meas}(f)}}$ and $\overline{P_{ref}(f)}$ in Eq. (2) are the power spectra for the measured phantom and reference phantom respectively. Attenuation compensation function $A(f,\alpha)$ is defined as Eq. (4).

$$A(f,\alpha) = e^{4\alpha(f)x}\left\{\frac{2\alpha(f)L}{1-e^{-2\alpha(f)L}}\right\}^2\left\{1 + \left\{\frac{2\alpha(f)L}{2\pi}\right\}^2\right\}^2 \quad (4)$$

Parameters α and α_{ref} are attenuation coefficient of the analyzed and reference phantoms, and x is the distance between the surface of the phantom and the top of an analysis window. The analysis area was defined as the entire phantom except for the surface of phantom. 3D ROI that have the size of 10 times of the wavelength and 5 times of the lateral resolution of each transducer was scanned in the analysis area.

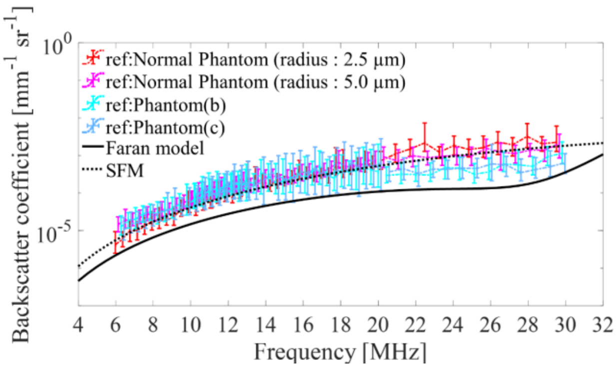
3. Results and discussion

Figure 2 shows the BSC evaluation results using the reference phantom method. The solid black lines in Fig. 2 are the calucurated BSC with Faran model, which is the theoretical model, and the black broken lines are BSC calcurated with the SFM considering structure factor. The warm-colored group and the cold-colored group are the results of using the single scatterer normal phantoms as a reference and the phantom with two scatterers (Phantom(a), (b), (c)) as a reference, respectively.

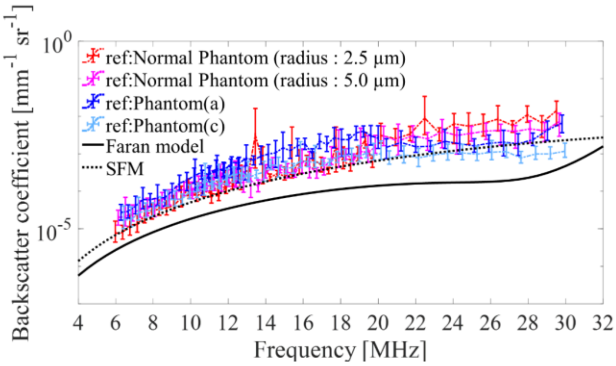
It was confirmed that the BSC calculated using the reference phantom method fits the SFM in all bands in each medium containing multiple scatters with different particle size distributions, and overall below 30 MHz. It seems that it is slightly more effective to use a phantom in which multiple particles are mixed for reference.

4. Conclusion

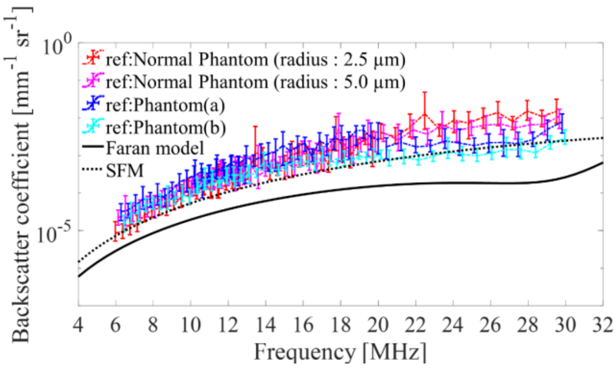
It was confirmed that the BSC can be estimated accurately by the reference phantom method even when there are multiple types of scatters in the target medium with the same tendency as that of a medium containing a single scatterer in phantom study. Since it is assumed that multiple scatterers with extremely different sizes coexist in the actual biological tissues, it may be necessary to devise a reference phantom more than the results of this study.



(a) BSC of Phantom(a)



(b) BSC of Phantom(b)



(c) BSC of Phantom(c)

Fig. 2 Evaluated BSCs using three transdusers

Acknowledgment

This work was partly supported by JSPS Core-to-Core Program, and KAKENHI 19H04482, and the Institute for Global Prominent Research at Chiba University.

References

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