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Effect of absorption attenuation on backscattering characteristics analysis of scattering media

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1. Introduction

Several methods focusing on the back scattering coefficient (BSC) has been reported as an attempt to estimate the structure of the scatterer from the echo signal and quantitatively evaluate it. So far, we have conducted studies based on focused imaging using ultrasonic diagnostic equipment, but since the sound field is complicated. We aim to evaluate with high accuracy using plane wave imaging that can easily correct the sound field.

In this study, assuming that two types of attenuation, scattering and absorption, are related to the properties of the echo signal in biological tissues, this study examines the effect of absorption attenuation, which is often ignored in the general BSC analysis method.

2. Materials and Methods

2.1 Scatterer phantoms

The components of two target phantoms used for evaluation of BSC were distilled water, 2% (w/w) agar powder, and 1 wt% nylon particles with mean diameters of 10 μm (ORGASOL 2002 EXD NAT 1; Arkema) for phantom A, and 1 wt% same scatterer plus 40 wt% evaporated milk for phantom B. The evaporated milk was added to adjust the absorption attenuation of the phantom[1]. The phantom C with 0.1wt% nylon particles with mean diameters of 10 μm was created as a reference phantom for the calculation of attenuation coefficient (AC). All phantom sizes were 80 mm × 80 mm × 30 mm to ensure sufficient depth and thickness for the probe.

2.2 Data acquisition

Two-dimensional RF echo signals of 2,600 pixel × 192 pixel were acquired by plane wave irradiation using an ultrasound platform for development (Vantage256, Verasonics) and a 1D linear array probe (9L, GEHealthcare) with the center frequency of 6.57 MHz. The RF echo data were sampled and digitized with 26.3 MHz and 15-bits/sample.

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2.3 Attenuation coefficient analysis

The local attenuation α [dB/cm] was calculated by using a medium with a known AC as a reference, and the difference in frequency spectra at different depth[2,3]. The local attenuation was calculated as

$$\alpha(f) = \alpha_0(f) + 8.686\frac{\ln\left(\frac{P(d_2,f)}{P_{ref}(d_2,f)}\right) - \ln\left(\frac{P(d_1,f)}{P_{ref}(d_1,f)}\right)}{4(d_2 - d_1)} \quad (1)$$

where P and P_{ref} are the average power spectram of target and reference media at any depths d_1 and d_2 ($d_2 > d_1$) and f is the frequency. α_0 is the attenuation coefficient of the reference medium, $d_2 - d_1$ was set to 0.5 mm. The attenuation coefficients were calculated by a linear approximation of the local attenuation.

The bandwidth used for estimation of BSC was 5-8 MHz, which corresponds to the range of -6 dB from the power spectra of the center frequency. A 2D ROI size was 256 pixel × 15 pixel, and the entire phantom was scanned. The ROI overlapped 50% in the axial direction and 30% in the lateral direction.

2.4 Backscatter coefficient analysis

A reference phantom method was used to evaluate the BSC from the acquired echo signal, excluding the characteristics of the transmitter/receiver system, sound field, and intrinsic attenuation, using a medium with known scattering conditions as a reference[2]. BSC was calculated as

$$BSC(f) = \frac{P(f)}{P_{ref}(f)}\frac{A(f)}{A_{ref}(f)}BSC_{ref}(f) \quad (2)$$

where P and P_{ref} are the average power spectra of target and reference media at any depth. A and A_{ref} are terms that correct for the frequency dependence of the attenuation of the target and reference media. The theoretical values were calculated by setting the physical conditions of the reference medium scatterer and the surrounding medium to the Faran model[4]. The bandwidth and ROI conditions for evaluating the BSC are the same as in 2.3.

3. Results

3.1 Accuracy evaluation by different attenuation correction methods

Figure 1 shows the average amplitude envelopes of phantom A and B. Phantom B has a large attenuation compared with phantom A, and the sound pressure is extremely reduced at a depth of about 50 mm. Therefore, it is suggested that different ACs should be used to the attenuation correction in the BSC evaluation, with 50 mm as the boundary.

Figure 2(a) shows the BSC map at the center frequency for phantom B evaluated with the averaged attenuation coefficient of all ROIs. The BSC depends greatly on depth, with a difference of about 2 dB between shallow and deep areas. On the other hand, **Fig. 2(b)**, which is the result of evaluating the BSC using the averaged partial attenuation coefficients calculated from the respective shallow and deep ROIs, shows that the depth dependence of the BSC is small and is estimated to be a homogeneous medium.

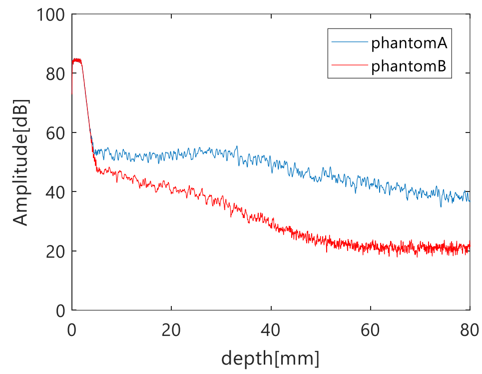
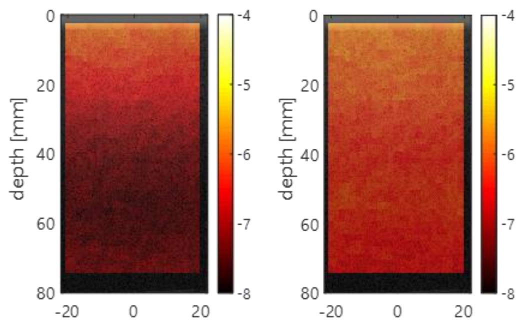


Fig. 1 Amplitude envelopes of two phantoms.



(a) averaged AC (b) partial ACs

Fig. 2 BSC maps of phantom B.

3.2 Effect of absorption attenuation on BSC evaluation

The frequency dependence of the BSC for phantom A and phantom B is shown in **Figure 3**. In the evaluation of the BSC, a phantom of the same quality as Phantom A was used as the reference. For the evaluation of phantom B, the method shown in Fig. 2(b) was used for attenuation correction. The black dashed line and the solid black line show the theoretical line of phantom A and phantom B calculated by Faran model, respectively. The scatterer size and concentration, the speed of sound of the agar gel (1,500 m/s), or the speed of sound of 40 wt% evaporated milk solution (1,545 m/s) were given as parameters for Faran model.

Phantom A is on the theoretical line because it has the same composition as the reference medium. Phantom B was confirmed to have a slower frequency dependence than Phantom A. This is because the echo signal is more attenuated at high frequencies due to the effect of absorption attenuation. In addition, the BSC of phantom A is generally lower than its theory. Although the accuracy of the attenuation correction has been improved by 3.1, there is currently a discrepancy between the theory of the Faran model and actual medium conditions.

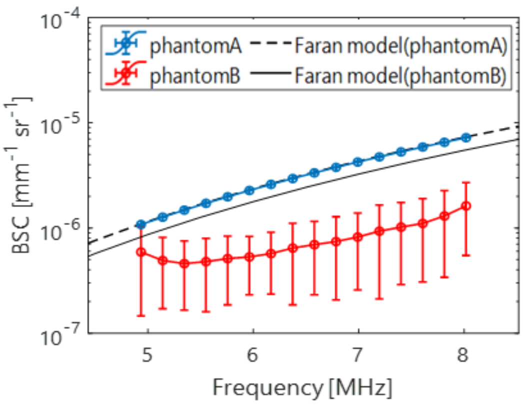


Fig. 3 Frequency dependency of BSC

3. Conclusions

Even in media with high absorption attenuation, the accuracy of BSC evaluation can be improved by applying partial attenuation coefficients. However, verification by comparison with mathematical theory is limited, so verification by actual measurement in a variety of media or by a computer model that takes acoustic impedance into account is necessary.

Acknowledgment

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