Evaluation of Backscattering Properties in Skin Tissue by High-frequency Annular Array
高周波アニュラアレイを用いた皮膚組織の後方散乱特性評価

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1. Introduction

Much of research has been progressing that the degree of disease progression can be quantitatively evaluated using the backscatter coefficient (BSC) as an index. In our previous study, we quantitatively evaluated the skin (dermis and hypodermis) by backscattering analysis in the lower limbs with lymphedema. We have been studying using a clinical scanner and a linear array probe, but there are many points to consider due to the complexity of transmission-reception conditions. So we aim to realize a wide range of applications using high-frequency annular array with simple system and sound field.

In this study, we verified the effect of the difference in the upper layer thickness on the evaluation accuracy of the BSC using layer phantoms that simulates the difference in acoustic impedance between the dermis and hypodermis. We also verified the accuracy of the analysis for a skin tissue of chicken thigh.

2. Materials and Methods

2.1 Homogeneous phantom

The two layers agar-gel phantoms were a mixture of distilled water, 2% (w/w) agar powder, and 10 wt% acrylic particles with mean diameters of 20 µm (MX-2000; Soken Chemical) for upper layer and 0.5 wt% nylon particles with mean diameters of 10 µm (ORGASOL 2002 EXD NAT 1; Alkema) for lower layer. The theoretical acoustic impedances of the upper and lower layer are 1.6659 and 1.4937 Mrayl, respectively. The upper and lower layer expresses dermis and hypodermis. **Table 1** shows the average values of the speed of sound and the attenuation coefficient (AC) of the phantoms calculated from the echo signal measured by a planar transducer with center frequency of 15 MHz (V313, Olympus). A single layer phantom with the same composition as the lower layer and 1 wt% nylon particles with mean diameters of 10 µm were also created as a reference phantom.

Tab. 1 Specification of phantoms

Layer	Upper layer (Dermis)				Lower layer (Hypodermis)
Thickness [mm]	1	2	3	4	20
Speed of sound [m/s]	1529.2	1527.5	1516.1	1517.7	1501.7
Att. coefficient [dB/cm/MHz]	3.21	3.15	3.32	3.07	0.14

2.2 Data acquisition

A 20 MHz annular array transducer with 5 elements was used for measurement. The transducer has the 10 mm total aperture and the 31 mm geometric focus. The phantom and the chicken thigh were placed in a water bath for the scanning. An experimental system permitted the acquisition of RF data from all 25 transmit/recieve ring pairs. The RF echo data were sampled and digitized with 250 MHz and 12-bits/sample, respectively. The scanning step was 30 µm.

2.3 Synthetic focusing technique

Synthetic focusing technique [1] for echo signal data was accomplished by applying an appropriate round trip delay to each transmit-receive pair for a given focal depth and then summing the data to create a locally-focused region. These processes are repeated to create an arbitrary number of focal zones. In the present study, the 25 transmit-receive data were synthetically focused on each pixel.

2.3 Attenuation coefficient analysis

In the process of sound wave propagation, attenuation occurs due to absorption and scattering. The local attenuation α [dB/m] was calculated from average power spectrum of the reference and analysis medium at any depth d_1 and d_2 [2,3]. The local attenuation was calculated as

$$\alpha(f) = \alpha_{ref}(f) + 8.686 \frac{\ln\left(\frac{P(d,f)}{P_{ref}(d,f)}\right)\Big|_{d_2} - \ln\left(\frac{P(d,f)}{P_{ref}(d,f)}\right)\Big|_{d_1}}{4(d_2 - d_1)}. \qquad (1)$$

where the P and P_{ref} are the power spectra for the sample and reference, at frequency f, respectively, and d_1 and d_2 are depths in the ROI, here $d_2 > d_1$. The BSC was assumed to have a constant difference at any depth. The AC was calculated by linearly approximating of local attenuation. The distance difference $d_2 - d_1$ was set to 2.5 mm.

2.4 Backscatter coefficient analysis

The reference phantom method was employed to compensate the properties of transmission-reception sound field and attenuation [2]. The BSC was calculated in the domain of wavenumber k as

$$BSC(k) = \frac{P(k)}{P_{ref}(k)} BSC_{ref}(k) \exp\left[\frac{4dkc(\alpha - \alpha_{ref})}{8.686 \cdot 2\pi}\right]. \qquad (2)$$

where the P and P_{ref} are the power spectra obtained from the sample and the reference, respectively, BSC_{ref} is the theoretical BSC, d is the distance between the transducer and central position of the analysis window, and α and α_{ref} are the AC of the sample and reference, respectively. As ACs of dermis (upper layer) and hypodermis (lower layer), the **Tab. 1** or average of AC calculated from each data were employed in α. The theoretical values were calculated by setting the physical conditions of the reference medium in the Faran model [4].

The bandwidth used for estimation of BSC was 15-23 MHz, which corresponds to the range of -12 dB from the power spectra of the center frequency. A 3D ROI was defined as a region 3x the -6 dB lateral resolution and 10x the wavelength of the center frequency (540 μm by 750 μm).

3. Results

Figure 1 shows the calculated BSCs of layer phantoms with different upper layer thickness and the theoretical BSCs. In the upper layer, the thicker the upper layer, the larger the BSCs. This is because the scattering intensity of the target phantoms are higher than that of the reference medium. On the other hand, in the lower layer, BSCs are evaluated to be about 2-3 dB larger than the theoretical value. This is because the power of the sound wave that reaches the lower layer becomes smaller, and the deviation reference medium and the attenuation used in the calculation of theory becomes larger when the upper layer is thick. Therefore, it is necessary to apply high power to the lower layer using a system that can irradiate high sound pressure when the upper layer is thick or apply a correction method (or change the standard of theoretical calculation) when the attenuation is extremely large.

Figure 2 shows the calculated BSCs of skin with chicken thigh using each reference phantom and the theoretical BSCs of reference phantoms. In the dermis and hypodermis, it can be confirmed that the tendency of BSC is the same regardless of the theoretical BSC of the reference phantom.

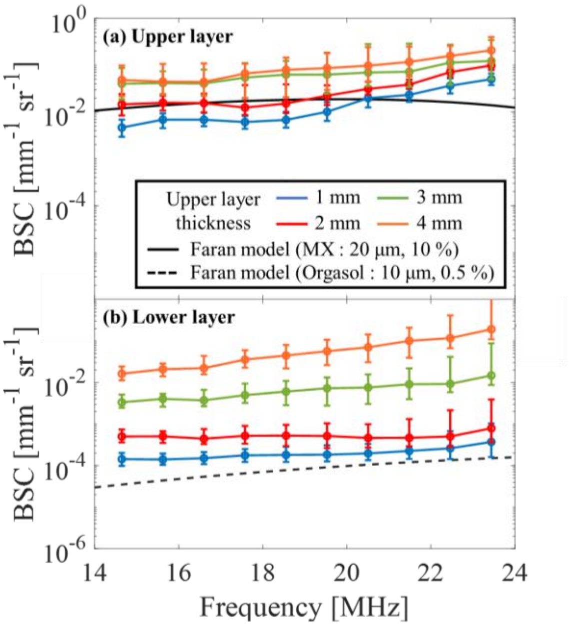

Fig. 1 Frequency dependency of BSC in layer phantoms

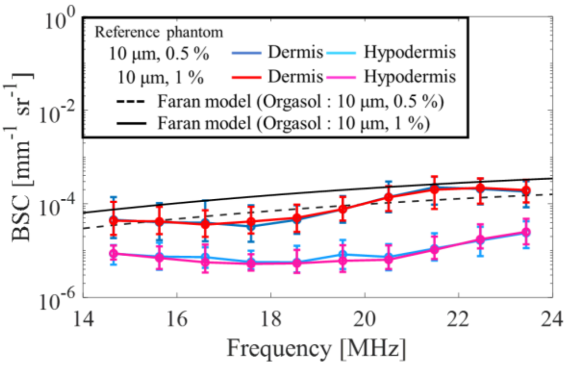

Fig. 2 Frequency dependency of BSC of the *ex vivo* skin with chicken thigh

4. Conclusions

As a result of evaluating BSC using layer phantoms with different upper layer thickness, it was suggested that the BSC evaluation of the skin tissue by annular array is possible. The next step is to construct a system with the improvement of real-time performance for clinical application and use *in vivo* data.

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