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Comprehensive scattering characteristics analysis of soft tissues with a high-frequency annular array

高周波アニュラアレイを用いた生体軟組織の
総合的な後方散乱特性解析

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1. Introduction

A lot of research has been progressing that the degree of disease progression can be quantitatively evaluated using the backscatter coefficient (BSC) as an index. On the other hand, it is necessary to understand the relationship between tissue properties and acoustic characteristics, such as tissue structure which reflects in quantitative values.

High-frequency ultrasound (HFU, >20 MHz) and quantitative ultrasound (QUS) methods provide a means to understand the relationship between anatomical and acoustical characteristics. However, the depth of field (DOF) of HFU transducers is limited which also constrains the range where QUS parameters can be estimated.

In the present study, we applied a sound field correction method using a reference medium to QUS analysis using an HFU annular array. We also verified the accuracy of the analysis for a healthy rat liver to confirm the correspondence with the tissue structure.

2. Methods

2.1 Scattering phantoms

The scatterering agar-gel phantoms were a mixture of distilled water, 2% (w/w) agar powder, and 0.5 % acrylic particles with a diameter of 10, 20 and 30 μm (MX-1000, MX-2000, and MX-3000; Soken Chemical). **Table 1** shows the average values of the speed of sound and the attenuation coefficient calculated from the echo signal measured by a planar transducer (v313, Panametrics-NDT). The attenuation coefficient was estimated with 9-17 MHz.

Tab. 1 Specification of phantoms.

Number	#1	#2	#3
Particle size [μm]	10	20	30
Att. Coefficient [dB/cm/MHz]	0.18	0.19	0.26
Speed of sound [m/sec]	1491	1492	1490

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2.2 Data acquisition

The rat liver was placed in a water bath for the scanning. As shown in **Fig. 1**, Hematoxylin-Eosin staining indicates hepatocytes (approximately 10-20 μm) were homogeneously distributed.

A 20 MHz annular-array transducer with 5 elements were used for measurement. The transducer has the 10-mm total aperture and the 31-mm geometric focus. All scans were performed using degassed water. 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.

2.4 QUS models

Among the methods for compensating the circuit and the sound field characteristics in the scanning systems, the reference phantom method was employed.[2] In the reference phantom method, a medium with known scattering conditions is required. The measured backscatter coefficient is calculated by equation (1),

$$\sigma_m(f) = \frac{\overline{P_m(f)}}{\overline{P_{ref}(f)}} \frac{A_m(f)}{A_{ref}(f)} \sigma_{ref}(f) \qquad (1)$$

Where the $\overline{P_m}$ is the average power spectrum for echo signals from the same depth as the ROI (region of interest) center position of the $\overline{P_m}$ (RF signals from the measuring subjects) in the reference phantom. The f is the frequency. The A_m and A_{ref} are the functions of the attenuation compensate. As an attenuation coefficient of normal rat liver, 0.6 dB/cm/MHz was employed in A_m. In

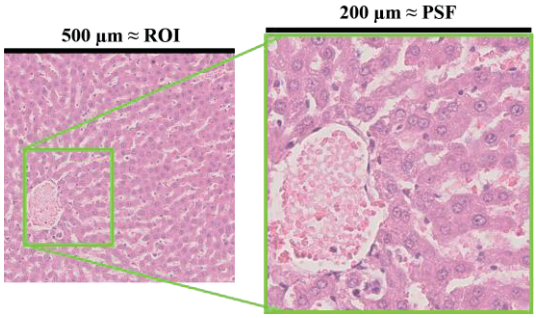


Fig. 1 The part of the pathological image where the same cross-section of B-mode image.

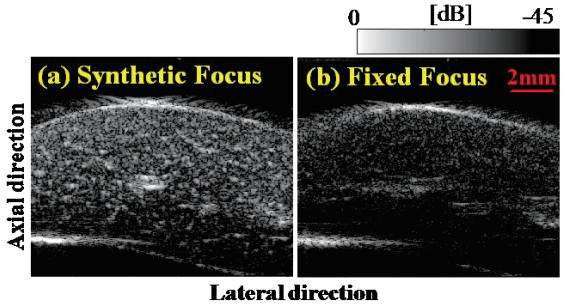


Fig. 2 Ultrasound tomography of the ex-vivo rat liver with two focusing.

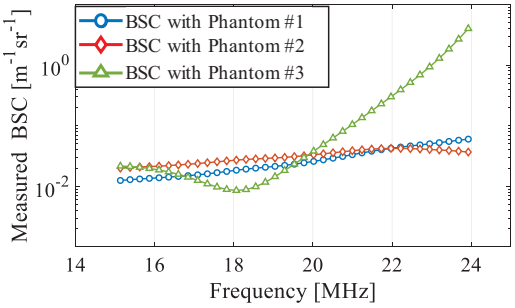
A_{ref}, attenuation compensation was conducted with the attenuation coefficient of the reference phantoms indicated in the Tab. 1. The σ_{ref} is the theoretical BSC of the reference medium. The theoretical values were calculated by setting the physical conditions of the reference medium in the Faran model.[3]

The bandwidth used for estimation of the BSC was 15-24 MHz, which corresponds to the range of -12 dB from the power spectra of the center frequency. The analyses were performed on the interior of each liver. 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 740 μm).

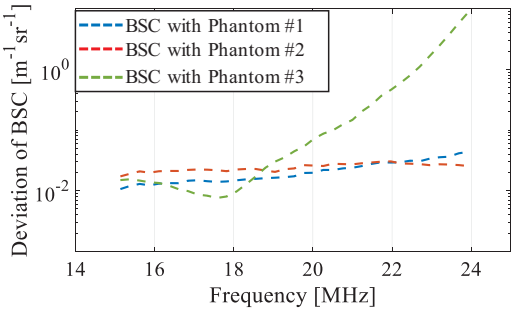
3. Results and discussion

Figures 2 (a) and 2(b) show the B-mode images of the rat liver with synthetic focus (SF) and fixed focus (FF), respectively. we employed to SF for because SF provided more stable sensitivity in previous study with homogeneous scattering medium.[4]

Figure 3 shows the BSC of rat liver calculated by using each phantom as a reference medium. **Fig. 3 (a)** shows the mean value of the BSC, and it was confirmed that the evaluated BSC of the rat liver had a frequency dependence depending on the conditions of the reference medium. It is considered that the characteristics of the liver could not be evaluated under the condition that the large particle medium. As shown in **Fig. 3(b)**, the standard deviation of the BSC increases as the particle size increases, and the evaluation accuracy decrease depending on the frequency. On the other hand, the particle size was



(a) Mean value



(b) Deviation value

Fig. 3 The BSC curves of the *ex-vivo* rat liver.

stable at 10 and 20 μm, especially the result of using the 10 and 20 μm case were highly correlated with previous research using the rabbit liver. [5] Moreover, the 10-20 μm was quite close to the hepatocyte diameter as in **Fig. 1**.

4. Conclusion

In the present study, we used three scatterer phantoms with different scatterer diameter as reference media, the BSC of the normal liver model rat was evaluated.

In soft tissue with a complex structure, it is assumed that the main scatterers differ depending on the frequency used for measurement. However, the frequency dependence was not recognized under the conditions that were evaluated stably in the presented result. Therefore, the tissue structure of approximately 10-20 μm was considered that the main scatterer in this rat liver.

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