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Acoustic attenuation of rat liver measured by high frequency pulsed ultrasound
高周波パルス超音波を用いたラット肝臓の音響減衰測定

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1. Introduction

Quantitative ultrasound (QUS) methods, e.g. elastgraphy and statisitical analysis of envelop of RF signal, are effective for detecgting fatty liver and cirrhotic liver. Knowledge on quantitative acoustical properties such as speed of sound (SoS), acoustic impeadance and attenuation are very important to develop the conventional QUS method. This report focus on the tissue structure and the acoustical properties in micrometer range. The acoustical properties of normal and cirrhotic livers of rat animal model was measured by uisng scannning acoustic microscope. The acoustic attenuation was especially discussed in this reports

2. Material and Method

The modified SAM system (AMS – 50SI, Honda electronics co. Ltd) was used. A PVDF TrEE transducer with center frequency of 80-MHz was used. Aperture size, focal length and lateral resolution were 1.2 mm, 3.2 mm and 20 μm. A ZnO transducer was served for the measurement. It had 250 MHz center frequency, aperture size of 520 μm, focal length of 500 μm, and lateral resolution of 4 μm. By scanning the transducer, the echo signals can be obtained in 2-D plane.

A rat animal models were developed. The model is cirrhotic liver harvested at 19-weeks age. In this model, the rats were injected in their back and under anesthesia with carbon tetrachloride and olive oil (1×10-3 mml per 1g of rat weight). After the liver was harvested, the tissue samples were fixed in formalin for two weeks. The sliced specimen with 10 μm thickness was prepared for SAM.

3. Theory

High frequency pulsed ultrasound is exposed to the specimen on slide glass via water. Assuming that the focused ultrasound is approximated near focal point by plane wave, the received echo can be expressed as the sum of the multiple reflections in the specimen[1]. The frequency component of the received echo was written as

$$X(\omega) = X_0 + \sum_n^\infty X_n \quad (1),$$

where X_0 means wave reflected from water-tissue interface, and X_n means reflected wave undergoing n-times reflection in the tissue. By dividing eq.(1) by reference echo from glass without tissue $X_{ref}(\omega)$, the normalized frequency component was expressed as

$$\frac{X}{X_{ref}} = \frac{R_{12}}{R_{13}} + \sum_n^\infty \frac{(1-R_{12}^2)(-R_{12})^{n-1}R_{23}^n}{R_{13}} e^{2n(\gamma-\gamma_0)d} \quad (2)$$

where

$$R_{ij} = \frac{Z_j - Z_i}{Z_j + Z_i}, \quad (3)$$

$$\gamma = \alpha + jk. \quad (4)$$

R_{ij} and Z_i means reflection coefficient between the interface and the acoustic impedance, respectively. The subscripts 1, 2 and 3 indicate the water, tissue and glass. d is the thickness of specimen. γ, α and k are complex propagation coefficient, acoustic attenuation and wave number of tissue, respectively. γ_0 is complex propagation coefficient of water. Acoustic attenuation of tissue is assumed to be as

$$\alpha = \alpha_0 f^n. \quad (5)$$

4. Estimation of parameters

We obtained experimental RF echo signal and calculated normalized frequency spectrum by Fourier transform. Figure 1 shows the results. SoS, thickness, acoustic impedance, attenuation of tissue was estimated by fitting the experimental data and theoretical prediction based on eq.(2). The fitting was conducted by following procedure.

1) Theoretical prediction for phase spectrum was fitted to the experimental data by changing SoS and thickness of tissue so that root mean square error became minimum.
2) Theoretical prediction for power spectrum was fitted to the experimental data by changing attenuation coefficient α_0 and n in eq.(5) and the acoustic impedance so that root mean square error became minimum. Attenuation at center frequency was calculated by substituting α_0 and n into eq.(5)

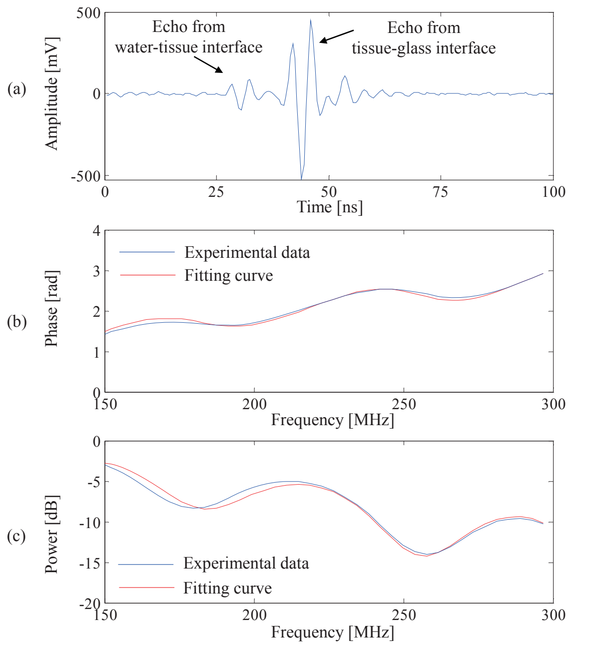


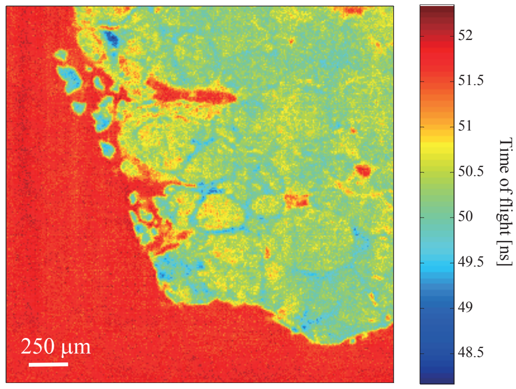
Fig. 1 Typical analysis result: (a) RF signal from specimen. (b) Normalized phase spectrum. (c) Normalized power spectrum.

4. Results

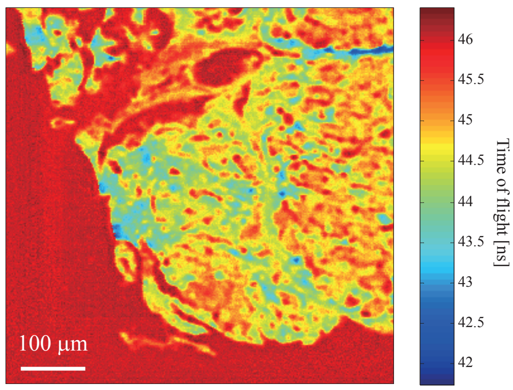
In order to roughly confirm the tissue structure, 2-D image of the time of flight (TOF) of echo from tissue-glass interface [see Fig.1(a)] was obtained. Fig. 2 shows 2-D image of TOF in case of 80 MHz and 250 MHz. In both cases, "line structure" is found. Especially in case of 80 MHz, this line structure forms netlike structure like typical fiber structure. In case of 250 MHz, patchy pattern, probably corresponding to individual cell in the tissue, was also found between the linear structures.

To quantify acoustical tissue property, regions of interest (ROIs) were selected in the TOF image. The ROIs were positioned in the line structure and the other portions. The ROI size were 40×40 μm^2 at 80 MHz and 10×10 μm^2 at 250 MHz. Figure 3 show the results of the ROI analysis in case of (a) 80 MHz and (b) 250 MHz. The Mann-Whitney U-test was used to establish significant difference between linear structure and the other portion. As a result, there were significant difference in both cases of 80 MHz and 250 MHz. The large difference in case of 250 MHz possibly resulted from the fine lateral resolution of ultrasound beam.

Validity of our data for attenuation is discussed. In previous work, the attenuation of normal liver in 25 MHz was approximately 15 dB/cm[2]. In our result, n in eq.(5) estimated to be ranged in 1.8-2.8 Assuming of n =2, therefore, the value in the previous work corresponded to 0.015 at 80 MHz and 0.15 dB/μm at 250 MHz. These values are close to the attenuations in the portion not line structure (0.04 dB/μm at 80 MHz and 0.15 dB/μm at 250 MHz.).



(a) 80 MHz



(b) 250 MHz

Fig. 2 2-D image of TOF in case of (a) 80 MHz and (b) 250 MHz.

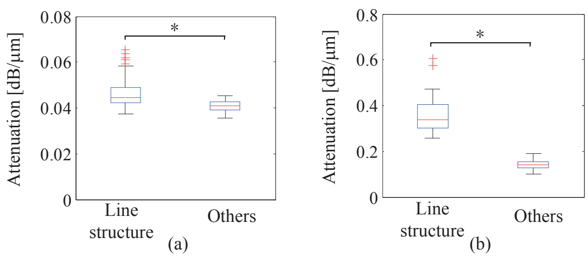


Fig. 3 2-D image of TOF in case of (a) 80-MHz and (b) 250-MHz. ($p<0.01$)

5. Conclusion

The acoustical properties of rat cirrhotic liver were estimated by fitting the normalized frequency spectrum of echo signal to theoretical prediction. There are significant difference in the attenuation between the line structure (probably fiber structure) and the other portions.

References

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