1. Introduction

We have investigated the relationship between the progress of liver fibrosis and the probability density function of echo envelope amplitude. Although the parameters of some statistical analysis models show sensitivity for the fibrosis grade in related study, the relationship between the tissue structures and the parameters of statistical analysis models have not been linked definitely because many factors can be considered as cause in change of the echo properties. To interpret the influence which complexity of the tissue structure gives in echo properties, the echo which reflected real tissue structure based on histology were tried by simulation and the statistical analysis was performed in this study.

2. Materials and methods of computer simulation based on histology

Figure 1 shows the schematic image of the simulation setup (a) and the emitted sound field with used transducer for simulation (b). Echo simulation was performed with Field II (Tech. Univ. of Denmark) based on calculation of spatial impulse responses in MATLAB [1]. A concave transducer with a single element, a diameter at 20 mm, and an elevation focus at 50 mm was simulated. The transmission and reception frequency was 5.0 MHz, and the sampling frequency was set to 50 MHz. The speed of sound was assumed to be 1540 m/s. Simulation echo data was acquired from the scattering field at 0.5 mm beam intervals in the lateral and slice, which was equivalent to half of lateral point spread function for this transducer.

The size of the scattering field was 50 mm × 50 mm × 20 mm, and scatterers were placed inside this domain. The scattering properties such as number density and scattering amplitude of each scatterer were defined from tissue maps which were manufactured from 20 pieces of consecutive histology. The consecutive histology were made from an excised liver from an autopsy sample of fibrosis liver, which was offered from Chiba University Hospital. After sliced at 4 μm in every
3. Statistical analysis

For the echo simulation data, the relationship between the tissue structures based on histology and the parameters of statistical analysis model was investigated. In this study, the multi-Rayleigh model, which has high sensitivity to the fibrosis grade [2], was examined for echo simulation data based on histology. The concept of this model is based on Rayleigh distribution. In homogeneous medium with high number density of the scatterers, it is known that the probability density function (PDF) \( p(x) \) of echo amplitude \( x \) can be approximated by the Rayleigh distribution given by

\[
p(x) = \frac{2x}{\sigma^2} \exp \left( -\frac{x^2}{\sigma^2} \right),
\]

where \( \sigma^2 \) is a scale parameter representing the variance in the echo amplitude envelope. With represented by mixture two Rayleigh distribution with different parameters of \( \sigma^2 \), multi-Rayleigh model is given by

\[
p_{\text{mix}} = (1 - \alpha)p_L(x) + \alpha p_H(x),
\]

where \( p_L(x) \) and \( p_H(x) \) are the Rayleigh distribution with low variance( \( \sigma^2 = \sigma_L^2 \), normal tissue) and high variance( \( \sigma^2 = \sigma_H^2 \), fibrotic tissue), respectively. \( \alpha \) (\( 0 \leq \alpha \leq 1 \)) is the mixture rate of the Rayleigh distribution with a high variance. This mathematical model has a major advantage in such as a correspondence to the physical state of liver fibrosis compared to other models [2-3].

4. Results

Figure 2 shows the scattering fields used for the echo simulation, the simulated B-mode images, and the results of the statistical analysis in the ROI. In addition, Table II shows the ratio of the scattering amplitude in the tissue maps and the parameters of the multi-Rayleigh model in the ROI. In the simulated B-mode image of No. 1, the fibrotic tissue structures were clearly. When the ratio of the scattering amplitude becomes close to 1, which means oncoming of homogeneous medium, the visibility of the tissue structures becomes lower in B-mode. In future work, the influence of the other properties such as number density will be examined for echo simulation. In addition, the influences of the sound field such as the difference of the sound pressure in depth should be considered.

4. Conclusion

To accurately interpret the relationship between the tissue structure and the echo properties, the statistical analysis for envelope amplitude was performed for the simulation data based on histology. The result showed that the parameters of multi-Rayleigh model can represent the tissue characteristic in case of unclear tissue structure in B-mode images. In future work, the influence of the other properties such as number density will be examined for echo simulation. In addition, the influences of the sound field such as the difference of the sound pressure in depth should be considered.

References