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Imaging method of tissue characteristics based on multi-Rayleigh model for fibrotic liver

マルチレイリーモデルを用いた病変肝の
組織性状画像化手法の検討

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1. Introduction

Ultrasound imaging is one of the typical diagnosis methods of liver fibrosis. However, the result of the diagnosis may be affected by an operator's skill and experiences; therefore, the realization of a quantitative diagnosis method of liver fibrosis using ultrasound echo signals is highly required.

We have been examining about the quantitative diagnosis method of liver fibrosis using amplitude distribution of echo envelope from fibrotic liver[1-3]. In our previous study, we have succeded in the quantitative evaluation of liver fibrosis in a region of interst (ROI) in clinical echo data using a multi-Rayleigh model[4]. However, subtle differences such as between normal and early-hepatitis liver are not reflected obviously in the result of the evaluation

In this study, we evaluated each pixel of the clinical echo image quantitatively using multi-Rayleigh model to realize the more accurate and robust evaluation method of liver fibrosis. Each amplitude value of a pixel in the echo image was transformed into probabilities that the pixel is fibrous, normal, and hypoechoic tissue. By using those probabilities, we made images which reflects tissue characteristics of fibrotic liver, and the change of the image along with the disease progression was examined.

2. Amplitude distribution model for liver fibrosis

Probability density function can be used to describe the statistical characteristics of the ultrasound echo envelope from fibrotic liver. It is known that amplitude distribution of the echo signal from the homogeneous medium with high scatterer density, like a normal liver, agrees well with Rayleigh distribution given by

$$p(x) = \frac{2x}{\sigma^2}\exp\left(-\frac{x^2}{\sigma^2}\right), \qquad (1)$$

where x and σ^2 are the echo amplitude and the power of the echo amplitude.

As liver fibrosis progresses, amplitude distribution of echo signal deviates from Rayleigh distribution. In this case, the liver is considered to be a heterogeneous medium consisting of normal, fibrous, and hypoechoic tissue like nodules or blood vessels. A multi-Rayleigh model with three Rayleigh distributions, given by Eq. (2), have been proposed to express the amplitude distribution of fibrotic liver.

$$p_{mix3}(x) = \alpha_L p_L(\mathrm{x}) + \alpha_M p_M(x) + \alpha_H p_H(x), \qquad (2)$$

where $p_L(x)$, $p_M(x)$, and $p_H(x)$ are Rayleigh distributions with low ($\sigma = \sigma_L$, hypoechoic), middle ($\sigma = \sigma_M$, normal), and high ($\sigma = \sigma_H$, fibrous) variance respectively. α_L, α_M, and α_H are the mixture rate of each Rayleigh distribution, and satisfy the condition $\alpha_L + \alpha_M + \alpha_H = 1$.

3. Quantitative evaluation of each pixel of clinical echo image

Tissue characteristics of each pixel of a clinical echo image can be evaluated based on the multi-Rayleigh model quantitatively. The weight of each Rayleigh distribution in the multi-Rayleigh model about a pixel with amplitude x can be considered to be the probability that the pixel is hypoechoic, normal, or fibrous tissue. For example, the probability that a pixel with amplitude x is fibrous tissue, $p_{fib}(x)$, can be calculated using the following equation.

$$p_{fib}(x) = \frac{\alpha_H p_H(x)}{\alpha_L p_L(x) + \alpha_M p_M(x) + \alpha_H p_H(x)}, \qquad (3)$$

where $p_L(x)$, $p_M(x)$, and $p_H(x)$ are the Rayleigh distributions shown in Eq. (2). We can obtain probabilities that a pixel is hypoechoic or normal tissue, by replacing the numerator in Eq. (3) with $\alpha_L p_L(x)$ or $\alpha_M p_M(x)$ respectively.

When liver fibrosis progresses, amplitude distribution of echo signal changes and consequently the probability given by Eq. (3) changes. In this study, we made images based on the probabilities, and examined the change of images along with the progression of fibrosis.

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4. Analysis of clinical data

Four clinical data classified into F0 (normal), F1 (early-hepatitis), F2 (moderate-hepatitis), and F3 (late-hepatitis) according to new-Inuyama classification based on the result of biopsy were analyzed. **Figure 1** shows the B-mode images of the clinical data. A large ROI was set in each data, and small ROI was scanned in the large ROI. The size of the small ROI was set 50×50 pixel. Parameters of the multi-Rayleigh model were estimated in each small ROI, and probabilities of each pixel in the ROI being hypoechoic, normal, and fibrous tissue were calculated using the method shown in section 3.

Figure 2 shows the probability that each pixel is fibrous tissue. We found that the number of pixels with high probability of greater than 0.5 increases as the liver fibrosis progresses. These results are caused by the increase of the fibrous tissue in the liver. Additionally, larger cluster of pixels with high probabilities exists in Fig. 2(d). We can consider that this result reflects the bridging structure in the late hepatitis.

Figure 3 shows the probability of each pixel being normal tissue, and **Fig. 4** shows the probability of being hypoechoic tissue for data shown in Fig. 1(a) (normal) and Fig. 1(d) (late-hepatitis). We can see that more pixels have low probabilities of less than 0.5 in Fig. 3, and high probabilities of greater than 0.5 in Fig. 4 in late-hepatitis data compared with the normal liver data. These results mean that normal tissues decrease and nodules increase in the fibrotic liver.

5. Conclusion

In this study, we evaluated each pixel of the clinical echo image quantitatively using multi-Rayleigh model. Each amplitude value of echo images was transformed into probabilities that the pixel is fibrous, normal, and hypoechoic tissue.

We found that the number of pixels that have high probability of being fibrous and hypoechoic tissue increases, on the other hand, probability of normal tissue decreases as the liver fibrosis progresses. These results mean that normal tissue is replaced with fibrous tissue and nodules in the fibrotic liver. Additionally, bridging structure of fibrous tissue was found in the image of fibrous tissue.

Acknowledgment

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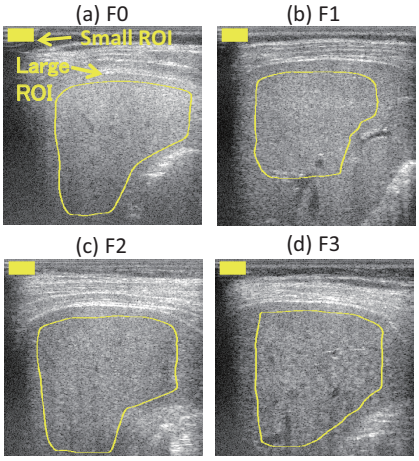

Fig. 1 B-mode images of clinical echo

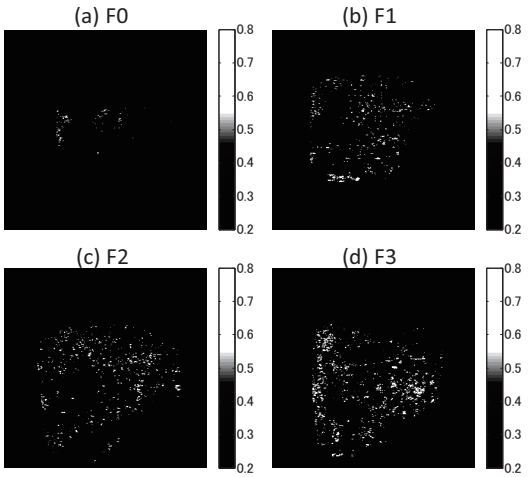

Fig. 2 Images of probability that each pixel of clinical echo image is fibrous tissue.

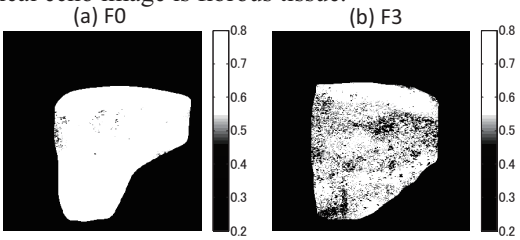

Fig. 3 Images of probability that each pixel of clinical echo image is normal tissue.

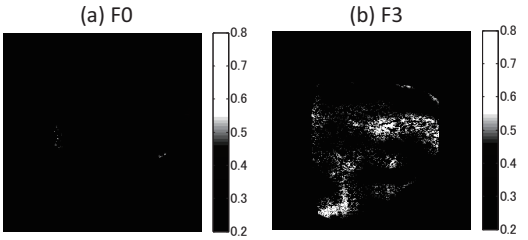

Fig. 4 Images of probability that each pixel of clinical echo image is hypoechoic tissue.