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Examination of optimal input parameters for evaluation of liver fibrosis based on multi-Rayleigh model

マルチレイリーモデルを用いた肝線維化定量評価のための最適な入力パラメータの検討

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1. Introduction

We have been developing a quantitative diagnostic method for liver fibrosis using an ultrasound B-mode image. In our previous study, we proposed a multi-Rayleigh model to express a probability density function(PDF) of echo amplitudes from liver fibrosis and proposed a probability imaging method of tissue characteristics on the basis of the multi-Rayleigh model.[1-2] To quantitatively evaluate liver fibrosis using the multi-Rayleigh model, it is important to increase estimation accuracy of multi-Rayleigh model parameters. The main purpose of this study is to evaluate the relationship between the optimal input parameters for evaluation of liver fibrosis based on multi-Rayleigh model and the estimation accuracy of multi-Rayleigh model parameters.

2. Evaluation method for liver fibrosis based on multi-Rayleigh model

2.1 Multi-Rayleigh model

When many scattered points are distributed randomly and homogeneously, such as in normal liver tissue, the PDF of the echo amplitude can be approximated by a Rayleigh distribution. The Rayleigh distribution is given by

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

where x and σ^2 are the echo amplitude and the variance of the echo amplitude, respectively.[1]

On the other hand, in an inhomogeneous medium, such as a fibrotic liver, the PDF of the echo amplitude deviates from the Rayleigh distribution. We proposed a multi-Rayleigh distribution model using a combination of Rayleigh distributions with different variances.

The multi-Rayleigh model with two components is given by

$$p_{\mathrm{mix2}}(x) = (1 - R_{\mathrm{m}})p_{\mathrm{low}}(x) + R_{\mathrm{m}}p_{\mathrm{high}}(x), \quad (2)$$

where $\mathrm{p_{low}}(x)$ is the Rayleigh distribution with a low variance(normal tissue), σ_{low}^2, and $\mathrm{p_{high}}(x)$ is the Rayleigh distribution with a high variance (fibrotic tissue), σ_{high}^2. R_{m} is mixture rate of Rayleigh distributions with high variances. By approximating the PDF of echo amplitudes using the multi-Rayleigh model, the fiber mixture rate R_{m}, and the fiber variance ratio $R_{\mathrm{v}} = \sigma_{\mathrm{high}}^2/\sigma_{\mathrm{low}}^2$, which is an indicator of the fibrosis progressive ratio can be estimated.

2.2 Estimation method of multi-Rayleigh model

In the evaluation of liver fibrosis based on multi-Rayleigh model, moments are the input parameters. Moments are indicators of the shape of the PDF. The n-th moment around average value, M_n, for normalized echo amplitudes is calculated as

$$M_n = E\left[\frac{(x-\mu)^n}{\sigma^n}\right], \quad (3)$$

where x is the echo amplitude. μ and σ are the average value and the standard variance of the echo amplitude, respectively. To estimate the multi-Rayleigh model parameters, moments of echo amplitudes are used as input parameters; therefore, the combination of moments used in the estimation algorithm affects the estimation accuracy of multi-Rayleigh model parameters. Thus, the selection of the optimal combination of moments is important to estimate the multi-Rayleigh model parameters stably.

3. The relationship between statistics of ultrasound echo envelope and the estimation accuracy of multi-Rayleigh model parameters

By using the ultrasonic simulation, the relationship between statistics of ultrasound echo envelope and the estimation accuracy of multi-Rayleigh model parameters is studied.

3.1 Ultrasonic simulation

From the scatterer distribution model, an ultrasound image was calculated. The scatterer distribution model was located 10 to 40 mm from the transducer. The center frequency was 7.5 MHz. The lateral size of the scatterer distribution model was 15mm. As shown in **Figs. 1(a)** and **1(b)**, the B-mode image of normal and fibrotic tissues can be made by the change of reflection strength of the scatterer. The mixture rate and variance ratio are 0.3 and 3,

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respectively.

3.2 Evaluation of estimation accuracy of multi-Rayleigh model parameters

Figure 2(a) shows the distribution of moments of echo amplitudes following the multi-Rayleigh model with the setting model parameters ($R_m = 0.3, R_v = 3$). This trial was iterated 1000 times. Then, the boundary of the area which statistically contains 95% of the data is shown in black. The black boundary is converted into the multi-Rayleigh model parameters' space as shown in **Fig. 2(b)**. When the distribution area shown in **Fig. 2(b)** becomes smaller, the estimation accuracy of multi-Rayleigh model parameters becomes higher. In order to determine the optimal input parameters which have high estimation accuracy, the deviation of mixture rate and variance ratio with different combination of moments are calculated. The results are shown in **Fig. 3(a)** and **3(b)**. The combinations of moments which cannot determine the multi-Rayleigh model parameters uniquely, are excluded. From **Fig. 3(a)** and **3(b)**, we can see that the estimation accuracy is higher when the value of **Fig. 3(a)** and **3(b)** is smaller. These results show that the multi-Rayleigh model parameters can be estimated with high estimation accuracy by using 0.15th and 1.5th moment.

Figure 4(a) shows the histogram of fibrotic parameters estimated using the 0.15th and 1.5th moment. To compare with the result of **Fig .4(a)**, the histogram of fibrotic parameters estimated using the 1.1th and 3rd moment which have low estimation accuracy is shown in **Fig. 4(b)**. From these results, we can see that the multi-Rayleigh model parameters can be estimated with high estimation accuracy by using 0.15th and 1.5th moment.

4. Conclusions

In this paper, by using the simulated ultrasound B-mode image, the relationship between the input parameters for evaluation of liver fibrosis based on multi-Rayleigh model and the estimation accuracy of the multi-Rayleigh model parameters was examined. From the simulation results, we can determine the moments which have high estimation accuracy by using the distribution area in the multi-Rayleigh model parameters' space. We concluded that the optimal input parameters for the estimation of the multi-Rayleigh model parameters with high estimation accuracy can be determined.

References

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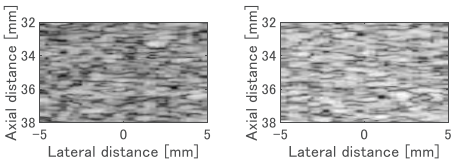
2. T. Higuchi, *et al.*: Jpn. J. Appl. Phys., **53**, No. 7, pp. 07KF27-1-5, Jun. 2014.



(a) b)

Fig. 1 (a) B-mode image of normal tissue. (b) B-mode image of fibrotic tissue.

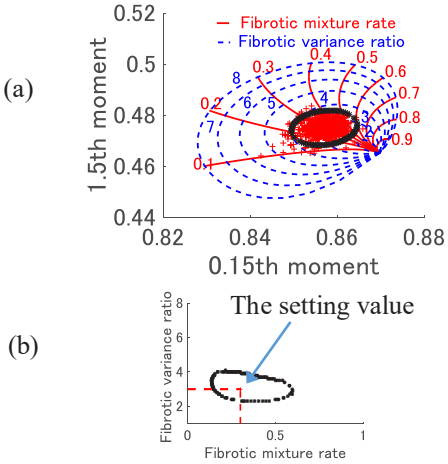
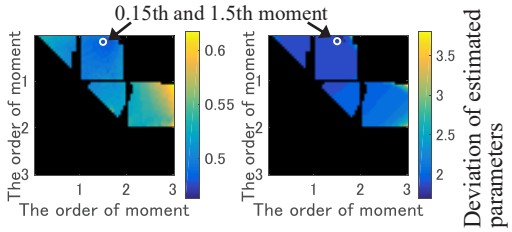


Fig. 2 (a) The 0.15th and 1.5th moment calculated from B-mode images. (b) The projection of contour line.



(a) (b)

Fig. 3 (a) The range of mixture rate. (b) The range of variance ratio.

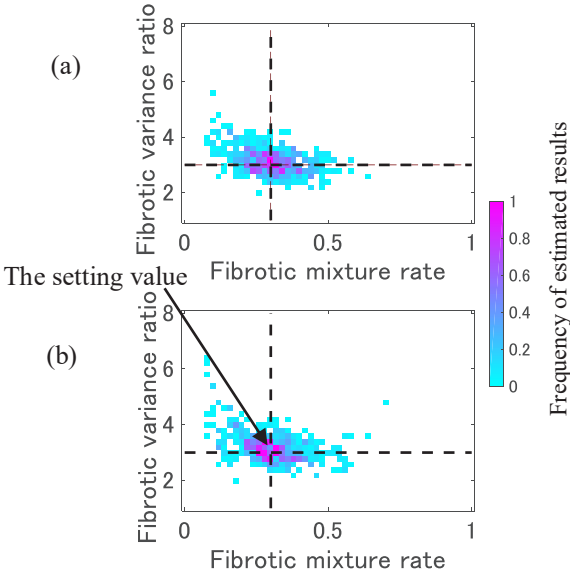


Fig. 4 Histogram of fibrotic parameters estimated using (a) the 0.15th and 1.5th moment, and (b) the 1.1th and 3rd moment.