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Effect of the ultrasonic beam width for quantitative evaluation of liver fibrosis using ultrasonic images

肝病変超音波画像を用いた線維組織量評価におけるビーム幅の影響

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1. Introduction

In order to realize quantitative diagnosis of liver fibrosis, we have been developing a method of quatntitative evaluation of liver fibrosis. In the previous study, we were able to estimate relatively well the fibrosis parameters.[1,2] However, we found that in a initial stage, the estimated values in the evaluation of liver fibrosis deviate from the true values in certain tendencies. As one of the reasons of this deviation, it is considered that the region of fibrotic tissues spreads in an ultrasonic image by the effect of ultrasonic beam width. In this paper, we examined the effect of ultrasonic beam width for quantitative evaluation of liver fibrosis.

2. Amplitude distribution model of liver fibrosis

When scattered points are distributed closely and uniformly, such as the normal liver tissue, the probability density function (PDF) of echo envelope can be approximated by Rayleigh distribution. On the other hand, in inhomogeneous medium, such as the liver fibrosis, the PDF of echo envelope deviates from Rayleigh distribution. It is considered that fibrotic liver is composed of normal liver and fibrotic tissues. We proposed the multi-Rayleigh model which the distribution is modeled by combination of Rayleigh distributions with different variances.[2,3] Rayleigh distribution is given by

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

where x, σ^2 is the echo amplitude and the variance of the echo amplitude, respectively.

The multi-Rayleigh model with two components is given by

$$p_{mix}(x) = (1-\alpha)p_{low}(x) + \alpha p_{high}(x) , \qquad (2)$$

where $p_{high}(x)$ is Rayleigh distribution with high variance (fibrotic tissues), $p_{low}(x)$ is Rayleigh distribution with low variance (normal liver). α $(0 \le \alpha \le 1)$ is the mixture rate of Rayleigh distribution with high variance. Therefore, model parameters are the variance ratio ($\sigma^2_{high}/\sigma^2_{low}$) and the mixture rate ($\alpha$). Variance ratio and mixture rate are related to the fibrosis stage and the amount of fibrotic tissues respectively.

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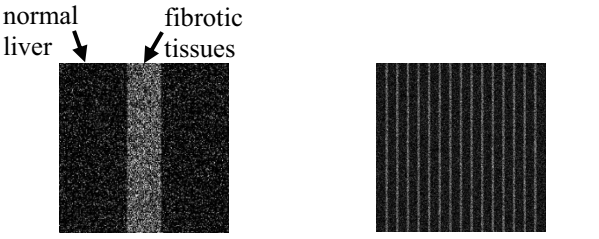


(a) Fiber width: 8mm (b) Fiber width: 0.53mm

Fig. 1 Scatterer distribution

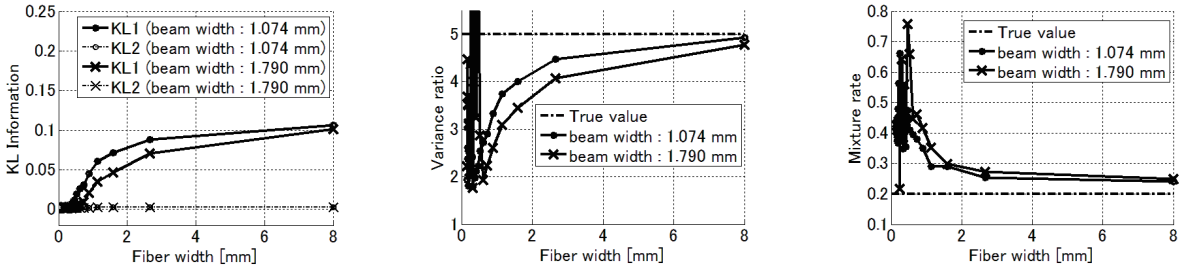
(a) Fiber width: 8mm (b) Fiber width: 0.53mm

Fig. 2 B mode image of scatterer

3. Simulation method

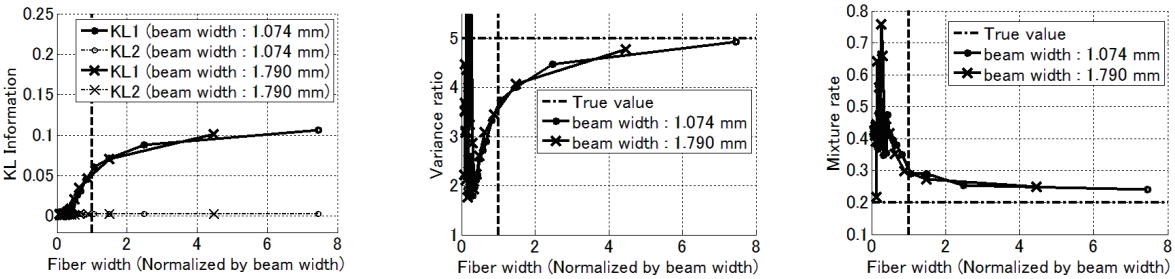
It is considered that by the effect of the ultrasonic beam width, the information of normal liver and fibrotic tissues are averaged at the border of them in an ultrasonic image, and as a result, the estimated values in the evaluation of fibrotic tissues deviate from the true values. To examine this effect, we make a scatterer distribution model (**Fig. 1**) composed of zonal normal liver and fibrotic tissues. We set the scattered points per point spread function (PSF) of ultrasonic beam at 10 points / PSF on the normal liver and 50 points / PSF on the fibrotic tissues. We also set the mixture rate at 0.2. **Fig. 1 (b)** is made from **Fig. 1 (a)** by dividing the fibrotic tissues. This distribution model is made only by division, so number of scattered points does not change by change of the width of fibrotic tissues.

Then, we calculated the B mode images (**Fig. 2**) using the scatterer distribution model. Scatterers' intensity is identical. The center frequency is 5.0 MHz and the sampling frequency is 100 MHz. The focal length is from 35 mm to 75 mm at 5 mm intervals to control the ultrasonic beam width. The scatterer distribution model is at 30 mm to 70 mm from the transducer. In addition, we use the area equal in half-value width of PSF as a ROI and set the beam width at 1.074 mm and 1.790 mm in the ROI by changing aperture width.



(a) KL divergence (b) Variance ratio (c) Mixture rate

Fig. 3 Simulation Results



(a) KL divergence (b) Variance ratio (c) Mixture rate

Fig. 4 Simulation Results (Normalized by beam width)

4. Simulation result

From the first and third standardized moment of the PDF of echo envelope obtained from **Fig. 2**, we estimated the fibrosis parameters, variance ratio and mixture rate. We use five B mode images calculated from randomly distributed scatterers, and estimate fibrosis parameters from them respectively. These distributed scatterers have equivalent scatter density and fiber width structure but the positions of scattered points are different. Then, we obtained the average of these estimated values.

The estimation result is shown in **Fig. 3**. The x-axis is the width of one line of the fibrotic tissues. We show KL divergence in **Fig. 3 (a)**. KL divergence is given by

$$D_{KL}(p \,\|\, q) = \sum_{x} p(x) \log_2 \frac{p(x)}{q(x)} \quad , \qquad (3)$$

where $p(x)$ is probability distribution of data, and $q(x)$ is probability distribution of a model. The more similar $p(x)$ and $q(x)$ are, the smaller $D_{KL}(x)$ is. KL1 in Fig. 3(a) is KL divergence with $q(x)$ as Rayleigh distribution model, and this result shows that as the width of fibrotic tissues narrows, probability distribution comes close to the Rayleigh distribution. KL2 in Fig. 3 (a) is KL divergence with $q(x)$ as estimated multi-Rayleigh model, and this result shows that multi-Rayleigh model is always able to express the PDF of B mode images stably. We show the variance ratio in **Fig. 3 (b)** and the mixture rate in **Fig. 3 (c)**. From Fig. 3, we can see the estimated value is different by the ultrasonic beam width. Then, we normalize x-axis in Fig. 3 by dividing the width of fibrotic tissues by the ultrasonic beam width. The result is shown in **Fig. 4**. A dotted line shows the point that the width of fibrotic tissues is equal to the ultrasonic beam width. From Fig. 4, we can see that the effect of the ultrasonic beam width is related to the ratio between the ultrasonic beam width and the width of fibrotic tissues. We can see that as the width of fibrotic tissues narrows, estimated variance ratio become smaller and estimated mixture rate become larger than true values. We can also see when the width of fibrotic tissues becomes smaller than the ultrasonic beam width, the estimated fibrosis parameters deviate from true values.

5. Conclusion

In this paper, we examined the effect of the ultrasonic beam width for quantitative evaluation of liver fibrosis using ultrasonic images. By the effect of ultrasonic beam width, the region of fibrotic tissues spreads in an ultrasonic image and the estimated fibrosis parameters deviate from the true values when the width of fibrotic tissues becomes smaller than the ultrasonic beam width. The effect of ultrasonic beam width is related to the ratio between the ultrasonic beam width and the width of fibrotic tissues. We will develop a method of evaluation of quantitative liver fibrosis considering effect of the ultrasonic beam width.

Acknowledgement

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