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Quantitative evaluation method of liver fibrosis based on multi-Rayleigh model with number estimation of tissue components in ultrasound B-mode image

超音波肝画像中の組織成分数を推定した
マルチレイリーモデルによる肝線維化定量評価

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1. Introduction

To quantitatively diagnose liver fibrosis using an ultrasound B-mode image, we have been investigating evaluation methods for the probability distribution properties of ultrasound echo envelope. In previous studies, we proposed a multi-Rayleigh (MR) distribution model which can express the probability distirbution of echo envelope from the fibrotic liver [1, 2]. Using the model parameters of the MR model, the liver fibrosis can be quantitatively evaluated [1, 2]. In this paper, a number estimation method of tissue components in the ultrasound B-mode image is proposed to quantitatively and accurately evaluate liver fibrosis in clinical images using the MR model.

2. Multi-Rayleigh model for fibrotic liver

In a homogeneous tissue such as a normal liver tissue, scattered points are distributed randomly and densely; therefore, an ultrasound B-mode image of the homogeneous tissue shows a speckled pattern and the probability density function (PDF) of ultrasound echo envelope can be approximated by a Rayleigh distribution. The Rayleigh distribution is given as

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

where x is echo envelope and σ is a sale parameter estimated as $\sigma^2 = E[x^2]$.

On the other hand, the PDF of echo envelope from an inhomogeneous tissue such as a fibrotic liver deviates from the Rayleigh distribution. As a model of the PDF of echo envelope from the fibrotic liver, a multi-Rayleigh (MR) distribution model was proposed [1, 2]. The MR model with n components is given as

$$p_{\mathrm{MR}}(x;n) = \sum_{i=1}^{n} \alpha_i p_i(x). \quad (2)$$

α_i is a mixture rate of Rayleigh distribution ($p_i(x)$) with scale parameter σ_i, and $\sum_{i=1}^{n}\alpha_i = 1$. Each Rayleigh distribution in the MR model expresses each tissue such as nodule, normal, and fibrotic tissues in the fibrotic liver, independently; therefore, quantitative liver fibrosis parameters, fiber mixture rate (α_{fiber}) and fiber variance ratio ($\sigma^2{}_{\mathrm{fiber}} / \sigma^2{}_{\mathrm{normal}}$), can be estimated from the model parameters of normal and fiber components in the MR model [1]. In addition, the ultrasound B-mode image can be converted to the quantitative fibrotic probability image using the MR model [2].

3. Number estimation of tissue components in ultrasound B-mode image

To quantitatively and accurately evaluate liver fibrosis in clinical images using the MR model, the number of components (Rayleigh distributions) in the MR model should be changed depending on the number of tissue components of analysis data. In this paper, the number estimation method of tissue components is proposed because the tissue components in the ultrasound B-mode image of liver tissue are changed with the progression of liver fibrosis. To estimate the number of tissue components, we focus on the moment of ultrasound echo envelope. The moment is a statistical information and is used as the input parameter for estimating the MR model parameters [1]. The k-th moment around origin, $M_k(x)$, is given as

$$M_k(x) = E[x^k]. \quad (3)$$

The moment of echo envelope is distributed on different region depending on the number of tissue components; therefore, we propose the number estimation method of tissue components in the ultrasound B-mode image based on the threshold processing for the moment of the ultrasound echo envelope. To quantitatively determine the threshold, Mahalanobis squared distance was used. The Mahalanobis squared distance, D^2, is given as

$$D^2 = (\mathbf{X}-\boldsymbol{\mu})^{\mathrm{T}}\boldsymbol{\Sigma}^{-1}(\mathbf{X}-\boldsymbol{\mu}). \quad (4)$$

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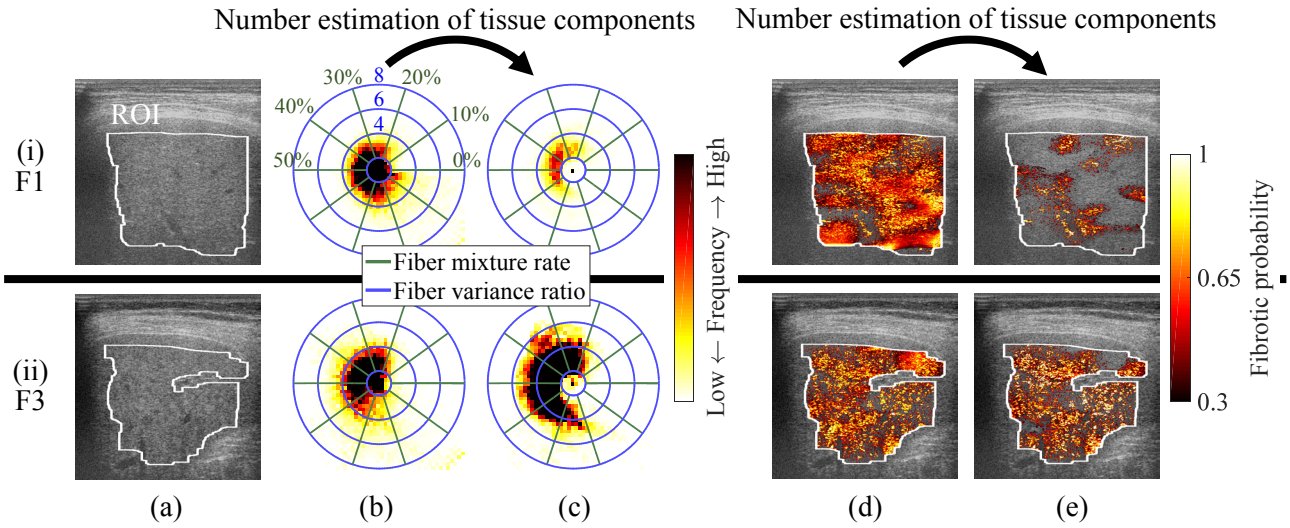

Fig. 1 (a) Ultrasound B-mode images of clinical data of (i) early-stage (F1) and (ii) late-stage (F3) of liver fibrosis. (b, c) Distributions of liver fibrosis parameters estimated for (a). (d, e) Fibrotic probability images estimated for (a). (b, d) Using MR model with three components. (c, e) Using MR model with estimating number of tissue components.

where $\mathbf{X}$ is the vector of moments which have different order, $\boldsymbol{\mu}$ is the vector of theoretical moments and $\boldsymbol{\Sigma}$ is the covariance matrix of moments. Using the Mahalanobis squared distance, the distance between the moments of analysis data and theoretical each number's region of tissue components can be quantitatively evaluated; therefore, the number of tissue components can be quantitatively estimated based on the threshold processing for the Mahalanobis squared distance. The theoretical each number's region of tissue components is calculated using the numerical simulation which is performed by generating the random variables following the MR model.

4. Evaluation for clinical data

The proposed number estimation method of tissue components is applied to the clinical data. The ultrasound B-mode images of clinical data are shown in **Fig. 1(a)**. The clinical images are classified into (i) early-stage (F1) and (ii) late-stage (F3) of liver fibrosis in accordance with the new Inuyama classification based on the liver biopsy. The clinical images were quantitatively evaluated using the MR model. **Figs. 1(b), 1(c)** show the distributions of liver fibrosis parameters [1] and **Figs. 1(d), 1(e)** show the fibrotic probability images [2] estimated using the MR model. Figs. 1(b), 1(d) show the results using the MR model with three components and Figs. 1(c), 1(e) show the results using the MR model with estimating the number of tissue components. In Figs. 1(b), 1(c), the estimated fiber mixture rate (α_{fiber}) is plotted for the angular direction and the estimated fiber variance ratio ($\sigma^2_{\text{fiber}} / \sigma^2_{\text{normal}}$) is plotted for the radial direction. Using the MR model with estimating the number of tissue components (Figs. 1(c), 1(e)), tissue characteristics of fibrotic liver could be accurately estimated so that the difference in evaluation results of liver fibrosis between the early-stage (Fig. 1(i)) and the late-stage (Fig. 1(ii)) became clear compared with the results using the simple MR model with three components (Figs. 1(b), 1(d)).

5. Conclusion

In this paper, a number estimation method of tissue components in the ultrasound B-mode image was proposed to quantitatively and accurately evaluate liver fibrosis in clinical images using the MR model. By using the threshold processing for the Mahalanobis squared distance of moment, which is a statistical information about the ultrasound echo envelope, the number of tissue components could be quantitatively estimated. Quantitative evaluation results of liver fibrosis using the MR model with estimating the number of tissue components well reflected the tissue structural change caused by liver fibrosis.

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References

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