3PL

Ultrasonic tissue characterization and quantitative diagnosis
生体組織の音響特性と超音波による定量診断

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1. Introduction

A development of a quantitative diagnostic method for various deseases using an ultrasound B-mode image is highly required from its real-time and noninvasive properties. To permit tissue characterization using the characteristics of the echo signal such as power spectrum, texture parameters, local attenuation, and statistical characteristics, the relation between complicated scatterer structures and the echo signal must be understood. In this review, acoustic properties of normal and diseased tissues, and an example of quantitative diagnosis using acoustic properties are presented.

2. Sound speed of normal and diseased tissue

The spatial distribution of sound speed is an important acoustic parameter for quantitative characterization of living tissues because it is fundamentally associated with the medium scattering behavior, and is therefore the interaction mostly observed in clinical diagnosis, and because it affects all other ultrasonic parameters. Measurements of sound speed in biological tissues have been performed by many investigators, but the relationship between ultrasonic characteristics and pathohistological changes in tissues was poorly understood [1,2]. We proposed a high-precision noncontact measuring method. In this method, the travel time of sound through the sample, and the difference in travel times with and without the sample are estimated based on frequency-time analysis which does not require physical contact of ultrasonic probes to tissue specimens [3].

Fig. 1 shows the sound speed versus density of normal rat liver and heart tissues. The sound speed of a normal heart is less than the rat liver, but individual difference is small -- the same as the rat liver. And density variation between individuals is also small. **Fig.** 2 shows the relationship between density and speed of sound in normal and diseased liver specimens. The closed circles and open circles correspond to speeds of sound in normal and diseased livers, respectively. The vertical bar is standard deviation of the sound speed. The speed of sound and density in diseased rat liver tissues are less than normal [4].

In microscopic view of a liver tissue specimen of a diseased rat, we observe many small fat droplets in the cell. The speed of sound in and density of fat tissues are known to be low, it is considered the decrease of sound speed in diseased tissues is caused by fatty degeneration. Assuming a mixture of normal liver and fat tissues, a theoretical curve can be obtained using the immiscible liquid model.

$$\frac{1}{\rho c^2} = \frac{x_1}{\rho_1 c_1^2} + \frac{x_2}{\rho_2 c_2^2}$$

$$\rho = \rho_1 x_1 + \rho_2 x_2$$

(x_1 and x_2 : volume fraction of each component)

It is considered that the speed of sound in fresh liver with fatty degeneration is responsible for the fat content.

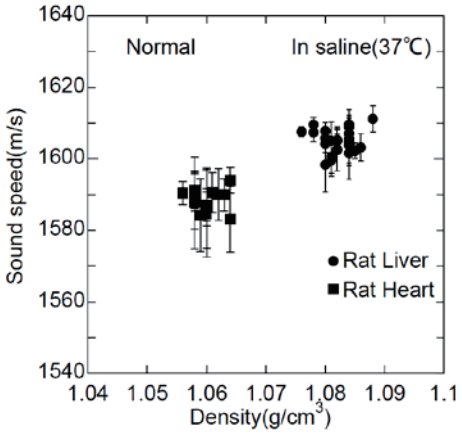


Fig. 1 Sound speed versus density of normal rat's liver and heart tissues.

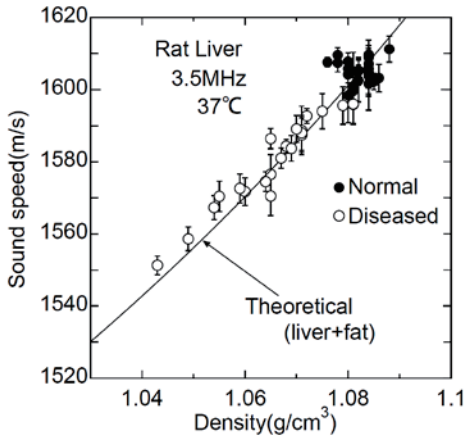


Fig. 2 Relationship between the speed of sound and the density in rat liver

3. Quantitative estimation of liver fibrosis

We have been examining a quantitative diagnostic method for liver fibrosis using the probability density function of ultrasound echo amplitude [5]. We proposed the multi-Rayleigh model as an amplitude distribution model of fibrotic liver and succeeded in the quantitative evaluation of liver fibrosis.

When many scattered points are distributed randomly and homogeneously, such as in normal liver tissue, the probability density function (PDF) of the echo amplitude can be approximated by a Rayleigh distribution. On the other hand, in an inhomogeneous medium, such as a fibrotic liver, the PDF of the echo amplitude deviates from the Rayleigh distribution. It is considered that a fibrotic liver is composed of various tissues, such as normal and fibrotic tissues. We proposed a multi-Rayleigh distribution model that is modeled using a combination of Rayleigh distributions with different variances. The Rayleigh distribution is given by

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

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

The multi-Rayleigh model with three components is given by,

$$p_{\mathrm{mix}}(x)=\alpha_{\mathrm{L}}(x)p_{\mathrm{LR}}(x)+\alpha_{\mathrm{M}}(x)p_{\mathrm{MR}}(x)+\alpha_{\mathrm{H}}(x)p_{\mathrm{HR}}(x)$$

where $p_{\mathrm{LR}}(x)$, $p_{\mathrm{MR}}(x)$, $p_{\mathrm{HR}}(x)$ is Rayleigh distributions with low variance (hypoechoic tissue), moderate variance (normal liver tissue), and high variance (fibrotic tissue), respectively. α_{L}, α_{M}, α_{H} are mixture rates of the each Rayleigh distribution. Using the multi-Rayleigh model, an information about each component can be independently extracted, and by comparing the each component's information, the ultrasound B-mode image of liver fibrosis can be converted to the each component probability image [6-7]. For example, the fibrotic probability of the pixel of ultrasound B-mode image with the amplitude x, $p_{\mathrm{fib}}(x)$, can be calculated using

$$p_{\mathrm{fib}}(x)=\frac{\alpha_{\mathrm{H}}p_{\mathrm{HR}}(x)}{p_{\mathrm{mix}}(x)}$$

This diagnostic method is effective to detect the initial stage of liver fibrosis.

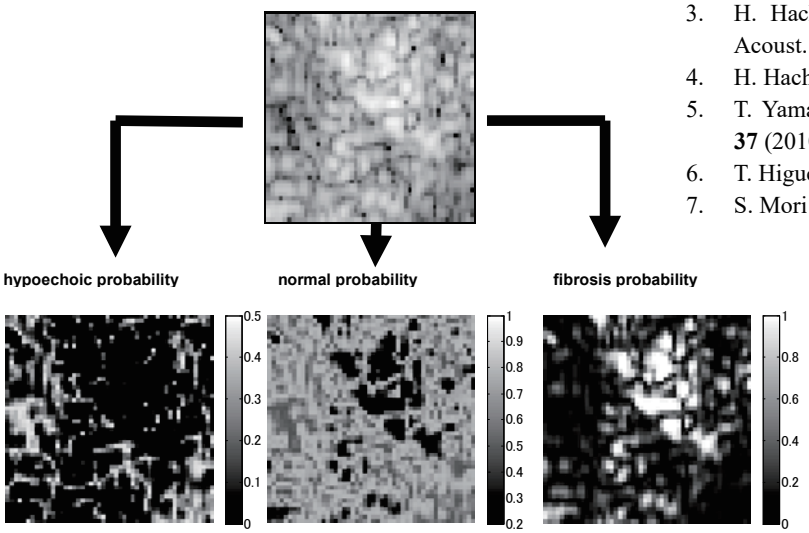
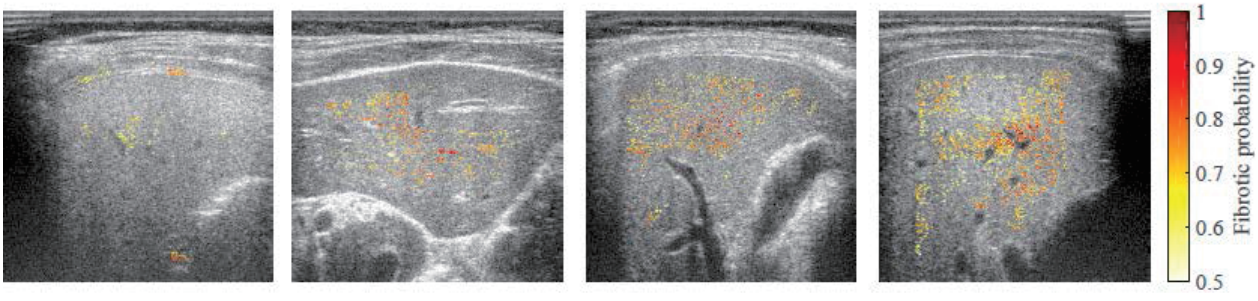


Fig. 3 Probability images of each component



(a) F0 (b) F1 (c) F2 (d) F3

Fig. 4 Fibrotic probability images

(F0: normal, F1, F2: hepatitis F3: late hepatitis)

References

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