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Estimation of QUS parameters in diffused liver disease

びまん性肝疾患における QUS パラメータ推定

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1. Introduction

Ultrasonic diagnostic equipment as a non-invasive and real-time imaging modality has been widely used in clinical diagnosis of liver disease. It is still difficult to identify the early stage of diffused liver disease by the skill of US image-reading even for experienced clinicians. It is necessary and critical to propose a quantitative ultrasound (QUS) method and estimate QUS parameters for ultrasonic tissue characterization. As useful QUS methods, several different models for the amplitude distribution of the envelope signal have been proposed in various medical fields recently.

In our previous studies, we proposed a novel QUS method based on the quantile-quantile probability plots (Q-Q plots) of Rayleigh distribution with five estimation parameters and chose three of them for quantitative evaluation. In this study, we add five new parameters by modeling the generalized Nakagami (Gen-N) and the Homodyned-K (H-K) distribution in order to perform comparison verification with the QUS parameter currently used widely. We estimated QUS parameters with the simulation data by changing scatterer density, and investigated the correlation between them.

2. QUS parameters

The Rayleigh distribution is expected for fully developed speckle in a homogeneous medium with randomly-located scatterers. The probability density function (PDF) of the Rayleigh distribution is defined by

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

where σ is a scale parameter representing the variance of the amplitude of the echo signal. The original Q-Q plot was used to compare PDFs between two different statistical models. In our previous studies, we proposed a modified QQ-based estimation algorithm to quantify liver fibrosis[1]. To form the Q-Q plot for the Rayleigh distribution, the accumulative distribution function, *F(x)*, was used

$$F(x) = \int_0^\infty p(x)dx\,. \qquad (2)$$

In a Q-Q plot of the Rayleigh distribution, the horizontal axis is the log-compressed amplitude $X(=\log(x))$, and the vertical axis is $\log(-\log(1-F(x)))$. If the variance of data is 1, Q-Q plot would be a straight line with a slope of 2 and intercept 0.

In our method, the result of Q-Q plot was divided into high-amplitude part and low-amplitude part. Then the regression line L_h and L_l were determined, respectively, and the intersection C of them was calculated. Then five QUS parameters were obtained. S_h the slope of L_h, S_l the slope of L_l, X and Y coordinate of C, and S_a the slope of regression line of whole Q-Q plot[1].

The Gen-N distribution is a three-parameter distribution that likely fits the envelope of the backscattered echo signal much better than tow-parameter distribution (e.g. Nakagami or K distribution). It is versatile enough to model the envelope of the backscattered echo signal under various scattering conditions of interest in medical ultrasound because of an additional parameter to account for the tails of density function[2]. The probability density function (PDF) of the Gen-N distribution is defined by

$$p(x) = \frac{2sm^m}{\Gamma(m)\Omega^m} x^{2ms-1} \exp(-\frac{mx^{2s}}{\Omega}) \qquad (3)$$

where m is the Nakagami parameter and Ω is the scaling factor, s is a shape adjustment parameter. It reverts to the Nakagami density function when $s = 1$. The three parameters of the generalized Nakagami distribution can be obtained using maximum likelihood estimation (MLE) techniques derived by a number of researchers[2].

The PDF of H-K distribution does not have a closed-form expression, but it can be expressed by

$$p(A) = A\int_0^\infty xJ_0(sx)J_0(Ax)\left(1+\frac{x^2\sigma^2}{2\mu}\right)^{-\mu} dx \quad (4)$$

where J_0 is the zeroth order Bessel function of first kind, s^2 is the coherent signal energy, σ^2 is the coherent signal energy, and μ is estimates of the number of scatterers per resolution cell. A derived parameter $k=s/\sigma$ is estimates of the ratio of coherent to incoherent backscatter signal component. We estimate the μ and k as QUS parameters using an improved parameter estimation algorithm for the H-K distribution that based on SNR, skewness, and kurtosis of fractional-order moments were developed[3].

3. Method and Results

We estimated QUS parameters using the simulation data of with different scatterer density. Computer simulation was performed with Field II (Tech. Univ. of Denmark) in MATLAB. A linear-array probe with 64 elements, 6.0 MHz of transmission and reception frequency, and 100 MHz of sampling frequency were set to, respectively. The speed of sound was assumed as 1,540 m/s. The scatterer densities were set to 1, 10 and 60 scatterers/psf (sc/psf), respectively. It is known when the density is large than 10 sc/psf, the scatterer distribution has no correlation between the speckle pattern. The size of region of interest (ROI) was 5 mm * 12 mm located at focal point.

Table 1 is the estimation results of all QUS parameters, and **Fig. 1** shows the estimated PDFs in each scatterer density. In **Fig. 1**, The estimated result of PDF has the best H-K distribution when scatterer density is 1 sc/psf. When the scatterer density is larger than 10 sc/psf, S_l and S_a are the value near two. It shows the PDF of echo amplitude envelope is approximated as Rayleigh distribution. However, since only S_h is smaller than two in 60 sc/psf, it is assumed that many high amplitude signals are included as compared with the complete Rayleigh distribution. In this case, it has the characteristic for the tail of a distribution function to become long (a peak of PDF shifts to the low-intensity side when it normalizes like Fig. 1), and Gen-N is a model suitable for presuming this character.

4. Conclusion

A high correlation was observed in S_h, s and μ. These parameters are sensitive to changing of components of the echo signal caused by changing of scatterer density[4]. Also in homogeneous medium, the characteristics of echo amplitude envelope has diversity by the physical structure of tissue and sound field. It is assumed that the characteristics of a homogeneous medium or a heterogeneous medium can be quantified by using the correlation of the parameters of several distribution functions.

References

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Table 1 estimated QUS parameters

Sccatterer density (sc/psf)	Q-Q_based			Gen-N			H-K	
	S_h	S_l	S_a	m	s	Ω	k	μ
1	1.28	1.16	1.33	0.68	0.86	0.91	0.15	3.09
10	1.95	1.99	1.95	1.31	0.86	0.95	0.90	7.76
60	1.44	1.96	1.85	1.86	0.67	0.89	0.81	3.63

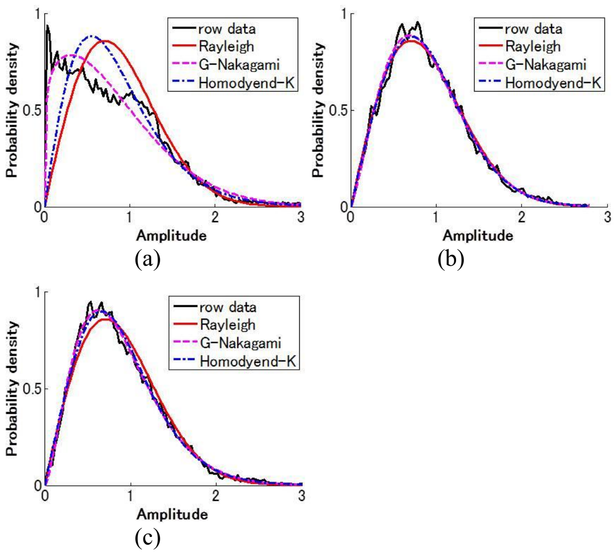

Fig. 1 Estimated three PDF in different scatterer density: (a) 1sc/psf, (b) 10 sc/psf, (c) 60 sc/p