EXTRACTION OF 3D FIBER INFORMATION FROM THE ULTRASONIC RF ECHO SIGNAL OF DIFFUSED LIVER DISEASES

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ABSTRACT

To realize a quantitative diagnosis of the diffused liver diseases, we have been analyzing the relationship between the change of liver tissue and the characteristic of echo amplitude in RF echo signal.

In this study, we proposed a technique to extract the quantitative 3D information of the diseased tissue from RF echo signal of liver cirrhosis and chronic hepatitis.

Also, we examined the difference of spatial correlation of echo information between the normal and diseased liver.

In the results of these examinations, the 3D volumetric information of fiber tissue structure was extracted quantitatively from RF echo signal of diseased liver.

Introduction

In the clinical diagnosis of liver diseases, it is becoming commonplace for medical doctors to use ultrasonic diagnosis equipment, but there are some differences between individual doctors' diagnosis results. Distinction between the early stages of liver cirrhosis and chronic hepatitis is a difficult problem. Hence, the realization of quantitative diagnosis of liver diseases is strongly required in the clinical field. In a previous study[1-14], we analyzed the relationship between the change of liver tissue and the characteristics of echo amplitude of the B-mode images and simulation images from normal and cirrhotic livers. In this study, we proposed a technique to extract quantitative information on the change in the distribution of scatterers from RF echo signal of liver cirrhosis and chronic hepatitis. We examine the spatial correlation of the echo using the coefficient of correlation, and examine the quantitative spatial relationship between the tissue structure and the echo information.

Data acquisition

In this study, we prepared various kinds of RF echo signals for normal and diseased livers using three-dimensional (3D) volumetric scanning with the digital ultrasonic diagnosis equipment (TOSHIBA SSA-370A) at Tokyo Medical University hospital. Using this equipment, medical doctors observe B-mode images by operating ultrasonic diagnosis equipment in the same way as in an ordinary diagnosis procedure, and they can send the RF echo signal to a computer with optional timing. The 3D data are acquired as a large number of consecutive tomograms by moving the ultrasonic probe. We manually scanned the ultrasonic probe on the body surface by parallel scanning (Fig. 1), and acquired information on the tissue of 10 mm thickness (60 frames). Data were acquired at the center frequency of 5.0 MHz, sampling rate of 20 MHz, and a 16-bit dynamic range. The measurement range for the liver was about 78 mm depth, and 1024 points of RF echo data were digitized on each scanning line. There were 239 lines in the horizontal direction in the case of single scanning. Thus, the data provide the information on 1024 points × 239 lines × 60 frames. We obtained the data from three volunteers for normal liver tissue, and three patients for each liver disease (Table 1).

Table 1.- Classification of acquired data.

Liver condition	Size of nodules	Number of cases
Normal liver	none	3
Chronic hepatitis	none	3
Micronodular cirrhosis	. 3 mm	3
Macronodular cirrhosis	. 8 mm	3

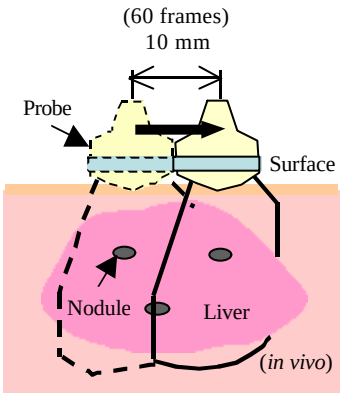


Fig. 1.- Data acquisition.

Extraction of non-Rayleigh information

To extract the information of the fiber tissue part in the each frame of RF echo signal, we proposed a LOG/CFAR processing technique[6)8)11)17)]. In previous studies, it has been shown both theoretically and experimentally that the echo amplitude x for the case with many scatterers per resolution cell, such as the normal liver tissue, has Rayleigh distribution. The Rayleigh distribution function is given by

$$p(x) = \frac{2x}{s^2} e^{-x^2/s^2} \qquad (1)$$

where x and σ^2 represent the envelope amplitude and the variance of the echo amplitude. In a radar system, CFAR techniques are used to target detection over various clutters such as ground or sea clutter which obey the Rayleigh distribution.

Figure 2 shows the change of the echo signal by LOG/CFAR and threshold processing. Figure 2(a) shows the B-mode (a single frame of RF echo signal which formed with 1024 points × 239 lines) and A-mode (vertical center line of B-mode) of macronodular cirrhosis. The first process of the LOG/CFAR technique is the log-compression of RF echo signals. The log-compressed output

y is given by

$$y = k \ln(kx) \qquad (2)$$

were k and l are constant, and Fig. 2(b) shows the result of log-compression. The variance of y is independent of the variance of the original echo signal x. It means that even if the STC characteristics in each scanning line are not ideal, CFAR processing is still effective. Therefore, v that is the result that reduced y with the mean value of y by using eq. 3 becomes Fig. 2(b).

$$v = y - \langle y \rangle \qquad (3)$$

After these processing, a variance of output v will become a constant. Figure 2(c) shows the z that is the result of reverse log-compression process of v which defined with eq.4 (m and n are constant). In fig. 2(c), the normal liver tissue such as expressed with speckle pattern is suppressed under the constant value.

$$z = me^{nv} \qquad (4)$$

This mean the echo information which obey the Rayleigh distribution are suppressed, and the information which has the different characteristics from normal liver tissue are emphasized by LOG/CFAR processing. Thus, we can acquire the abnormal tissue information from result of LOG/CFAR processing with threshold technique. Figure 2(d) shows the result of threshold processing from Fig. 2(c). The 2D echo information from the abnormal tissue such as fiber tissue is extracted.

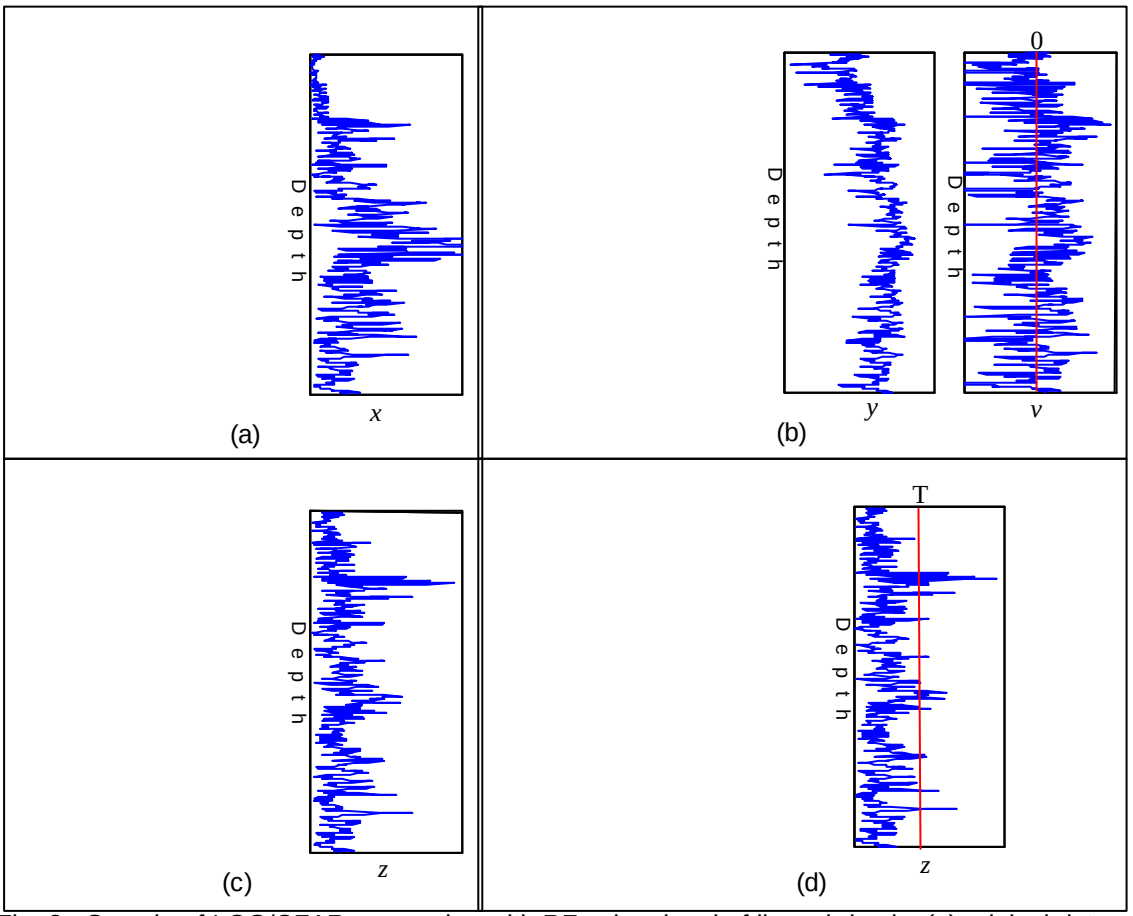


Fig. 2.- Sample of LOG/CFAR processing with RF echo signal of liver cirrhosis. (a) original data. , (b) result of log-compression and mean value reduction processing. , (c) result of LOG/CFAR processing. , (d) extracted information.

Examination of 3D characteristics of the echo information

Construction of 3D structure of fiber tissue We processed 60 frames using the LOG/CFAR technique to extract the fiber tissue information, which formed the surroundings of the nodular structure. From the result of processing, the echo amplitude from the fiber tissue was extracted from each frame. The volumetric structure of fiber tissue can be confirmed by 3D rearrangement of the extracted result for each frame. Figure 3 shows the rearrangement method and the result of macronodular cirrhosis, which was accumulated from 60 frames. The extracted information from the boundary tissues and liver tissue are shown in Fig. 3(b). The information that was extracted is the echo information from the fiber tissue that has characteristics different from normal tissue. The information that we perceived to be a characteristic part of the 3D information (Fig. 3 and other cases of liver condition) is presented in Fig. 4. Figure 4 shows information for areas with the size of 20 mm × 20 mm × 10 mm. In the result of the normal liver, no characteristic information was extracted, and only some pixels were extracted randomly as noise. On the other hand, many small structures were extracted for chronic hepatitis. Those are conceivably the fiber tissue formed in the portal vein part, because the size of each structure is less than 1 mm, and they do not show the spatial continuity.

However, in the micronodular cirrhosis case, the extracted information spreads toward three dimensions and forms several structures. This is in accordance with the characteristics of the fiber structure in liver cirrhosis. It is seen that all fiber structures that formed in the portal vein part connected to each other. The biggest continuous fiber structure is about 3 mm in the direction of the frame. This characteristic of the extracted information becomes conspicuous in the case of macronodule cirrhosis. The extracted information is more continuous in each direction in comparison with micronodular cirrhosis, and nodules are seen to be spherical. The size of fiber structures exceeds 5 mm. These results agree well with the actual tissue structure of liver cirrhosis[18].

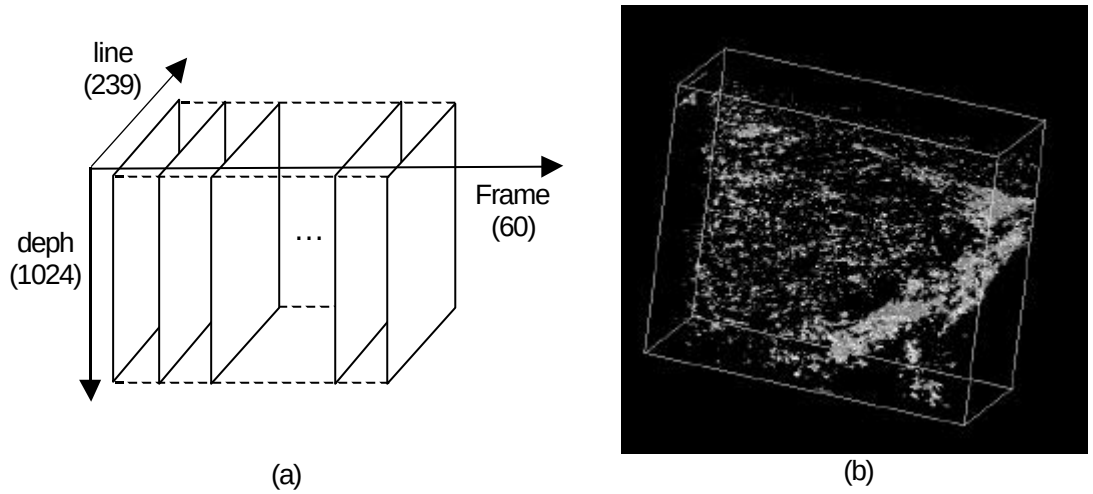


Fig. 3.- Construction of 3D structure of fiber tissue. (a) construction method , (b) extracted 3D information of macronodular liver cirrhosis

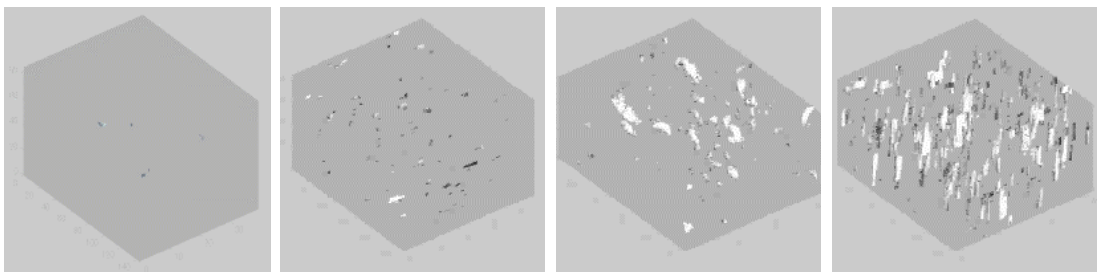


Fig. 4.- Characteristic part of the extracted results by LOG/CFAR processing. (a) normal liver , (b) chronic hepatitis , (c) micronodular cirrhosis , (d) macronodular cirrhosis

Calculation of the coefficient of correlation In the RF echo signal from diseased liver, it was

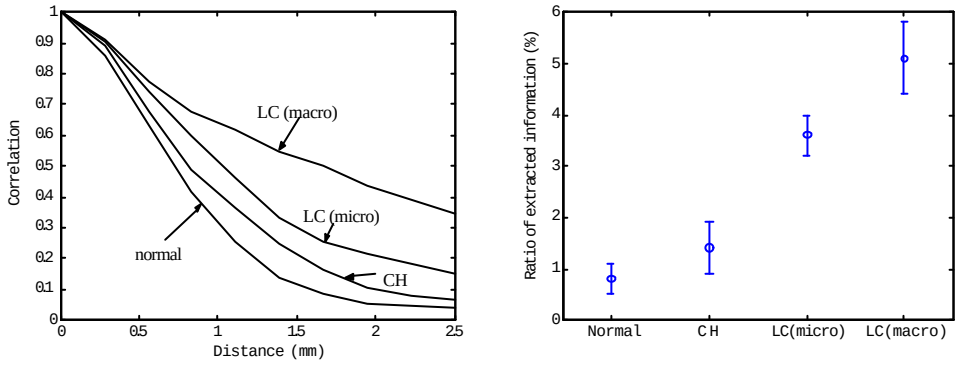
confirmed that the information of diseased tissue existed continuously. Thus, we examined the spatial correlation of amplitude of the RF echo signal between the frames using the coefficient of correlation $\tilde{n}$, which is calculated from eq. 5.

$$p = \frac{\sum\{[p(1)-\langle p(1)\rangle][p(n)-\langle p(n)\rangle]\}}{\sqrt{\sum\{[p(1)-\langle p(1)\rangle]^2\}\sum\{[p(n)-\langle p(n)\rangle]^2\}}} \qquad (5)$$

Here, $p(1)$ and $p(n)$ are the amplitude information of a standard frame and the n frame tip from the standard frame, and $\langle p(1)\rangle$ and $\langle p(n)\rangle$ show the mean value. We established that the number of frames n was 15, which means one quarter of the 60 frames. The ROI of sample echo information was 20 mm × 20 mm. We selected two ROIs for all data sequences, thus we obtained 24 ROIs in all from each liver condition.

Figure 5(a) shows the mean value of the calculated result of the coefficient of correlation in 24 ROIs. The horizontal axis and vertical axis show the distance from the standard frame, and the coefficient of correlation $\tilde{n}$. In the normal liver, the correlation is extremely low when the frame was only moved slightly from the standard frame (less than 1.0 mm). It is conceivable that the tissue structure and echo information are almost uncorrelated, because the scatterers are distributed randomly in the normal liver. On the other hand, it is possible to confirm that the correlations with the standard frame in liver cirrhosis are higher in comparison with normal liver. It is clear that the size of nodules and fiber structures influence the correlation. Thus there are some scatterer structures which have a size over the influence range of the wavelength of the ultrasonic pulse. In the case of chronic hepatitis, the correlation is higher than with normal tissue, and smaller than in the case of micronodular cirrhosis. A conceivable cause is that there are no large structures spatially, because the nodules do not exist in chronic hepatitis. Therefore, it was shown that there is a relationship between the spatial correlation of tissue structure and echo information.

Figure 5(b) shows the other characteristics of a relationship between the echo information and liver tissue. The horizontal axis and vertical axis show the liver condition and ratio of extracted information with LOG/CFAR technique. The ratio was calculated with 24 ROIs, as in the calculation of $\tilde{n}$. The ratio is increase with the progression of diseases.



(a) (b)

Fig. 5.- Examination result of 3D characteristics of the echo information. (a) coefficient of correlation , (b) Ratio of extracted information

From the results of examining extracted 3D information and the coefficient of correlation, the characteristics of the size and the structure of fiber tissue was found to agree with the actual tissues.

Conclusion

In this study, we examined the relationship between the liver tissue and the echo information using the RF echo signal of normal and diseased liver, which acquired as a large number of consecutive

tomograms. Result of the LOG/CFAR processing, 3D structure of fiber tissue was extracted from RF echo signal on each case of diseased liver. The size and ratio of the information that were extracted increased along with the progress of the diseases. We analyzed the spatial correlation of RF echo signals from normal and diseased liver, using the coefficient of correlation between the frames. In the analysis result, we confirmed that there is a relationship between the tissue structure of liver and the spatial correlation of echo information. From these results, it understands that the characteristic of the echo information is reflecting 3D structure of the fiber tissue strongly, and the analysis of statistical characteristics in echo amplitude from 3D volumetric information is effective for the quantitative diagnosis of diffused liver diseases.

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