3P5-9

Comprehensive backscattering characteristics analysis for quantitative ultrasound with annular array

定量的超音波診断にむけたアニュラアレイによる総合的な後方散乱特性解析

Takeru Mizoguchi[1 ‡], Kazuki Tamura[2], Jonathan Mamou[3], Jeffrey A. Ketterling[3], Kenji Yoshida[4], Tadashi Yamaguchi[4] ([1] Grad. Sc. Sci. Eng., Chiba Univ.; [2]Grad. Sc. Eng., Chiba Univ.; [3]Lizzi Center for Biomedical Engineering, Riverside Research; [4]Center for Frontier Medical Engineering, Chiba Univ.)

溝口　岳 [1‡], 田村　和輝 [2], Jonathan　MaUSmou[3], Jeffrey A. Ketterking[3], 吉田　憲司 [4], 山口　匡 [4*] ([1] 千葉大院　融合理工, [2] 千葉大院　工, [3] Lizzi Center for Biomedical Engineering, Riverside Research, [4] 千葉大　CFME)

1. Introduction

The quantitative ultrasound (QUS) methods with high-frequency ultrasound (HFU, >20 MHz) is one of the key technologies to understand the relationship between anatomical and acoustical characteristics. However, the depth of field (DOF) of HFU transducers is limited which also constrains the range where QUS parameters should be estimated.

The aim of this study is the improvement of the accuracy of HFU-QUS based-parameters on the envelope statistics and the backscattered power-spectrum analysis by using an annular-array transducer that allows for an extended DOF.

2. Methods

2.1 Synthetic focusing technique

A 20 MHz annular-array transducer with 5 elements (total aperture: 10 mm, geometric focus: 31 mm) were used for the measurements. A synthetic focusing technique (SFT) for digitized radio frequency (RF) echo signal was accomplished by applying appropriate round trip delays to each transmit-receive pair for a given focal depth, and then summing the data to create a locally focused region[1)]. These processes were repeated to create an arbitrary number of focal zone.

A 50 μm stainless wire was measured to evaluation of the DOF and the resolutions of the transducer. To accomplish this task, one element was excited and echoes were received by all five elements, simultaneously. Each echo was digitized to 12 bits/sample by oscilloscope (HDO6104; LeCroy) with the sampling frequency of 250 MHz. The interval of the scanning was 30 μm.

2.2 RF data acquisition

The RF echo data sets of all 25 transmit/recieve ring pairs from an agar gell phantom that contained 20 μm scatterers were acquired. The volume density of the scatterer is 0.3%. The phantom was putted in a water tank filled by degassed water.

2.3 QUS analysis

For the envelope statistics of RF data, we estimated the QUS parameters of Nakagami distribution model. Nakagami distribution is given by Eq. 1[2)] .

$$p(x) = \frac{2\mu^{\mu}x^{2\mu-1}}{\Gamma(\mu)\Omega^{\mu}} exp\left\{-\left(\frac{\mu}{\Omega}\right)x^2\right\} \qquad (1)$$

In Eq. 1, Γ is gummma function, μ and Ω are shape and scale parameter, respectively.

For the backscattered power-spectrum analysis, we estimated the scatterer diameter by using Eq. 2 that shows the relationship between the effntive scatterer rudius (a_{eff}) and the theoretical backscattered power-spectrrum ($W(f)$)[3)].

$$W(f) = \frac{185Lq^2a_{eff}^2\rho z_{var}^2 f^4}{\left[1+2.66\left(fqa_{eff}\right)^2\right]} e^{-12.159f^2a_{eff}^2} \qquad (2)$$

In Eq. 2, L is the length of the region of interest (ROI), q is the ratio of aperture radius to distance from the ROI, ρz_{var}^2 is the acoustic concentration, and f is the frequency.

Both QUS parameter were estimated with a small region of interest (ROI) that has the size of 500 μm in depth and 900 μm in lateral direction, and the ROI was scanned on whole data area to create two dimensional maps.

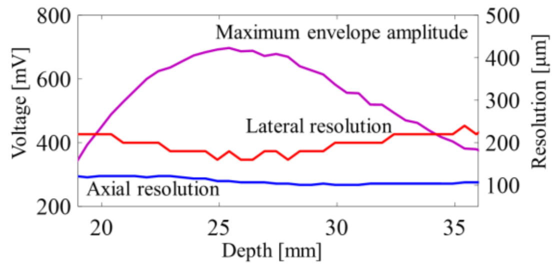

Fig. 1 Sound field property of annular array.

‡ t.mizoguchi@chiba-u.jp, *yamaguchi@facility.chiba-u.jp

3. Result and Discussion

3.1 Sound property of annular-array

Figure 1 shows the result of the SFT of echo sets from the 50 μm wire by annular-array transducer. The purple line, blue line, red line shows the maximum envelope amplitude, axial resolution and lateral resolution, respectively. The lateral and axial resolution on the focus depth were 180 and 100 μm, respectively equal to the values assumed from the maximum aperture. As a special mention, it can be confirmed that a wide DOF which is about 17 mm is obtained by the effect of SFT.

3.2 B-mode images

Figure 2 shows the B-mode images of the phantom constructed with the arithmetic addition **(a)** and SFT **(b)**. It can be confirmed that the resolution is high in wide area in SFT, but only the fixed focal area is high resolution in the arithmetic addition similarly to the single-element transducer.

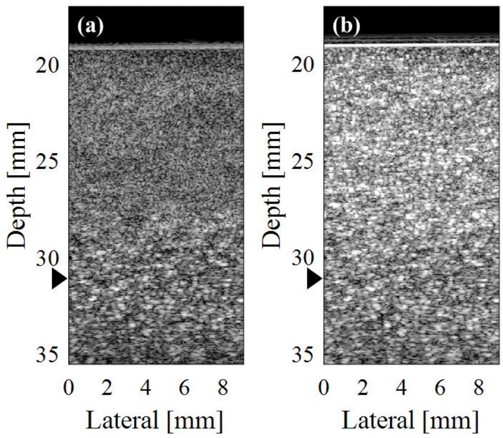

Fig. 2 B-mode images of the phantom (Dynamic range: 40 dB). **(a)** fixed focus, **(b)** synthetic focus. Black triangle arrows signify geometric focus.

3.3 QUS analysis

Figure 3 shows the mean value and standerd diviation of QUS parameters of μ on Nakagami model **(a)** and the effective scatterer diameter (ESD) $2a_{eff}$ **(b)**.

In the result of Nakagami model, the values of both are close in the vicinity of the focus depth, but in the shallow part, the value of the fixed focus is close to 1, in spite of the number of scatterers is insufficient for μ to be 1 (since the number of scatterers in the phantom is 1.09/resolution cell as calcurate from the result of Fig.1[2]). This is because echoes from discretely arranged scatterers has large randomness and dispersness due to low spatial resolution, and the influence of noise components is strong because of low SNR. In the synthetic focus case, the resolutions are maintained in wide depth in DOF. Therefore, the value of μ became constant in each depth.

In the result of the backscatter poewr-spectrum analysis, it can be observed same tendency as the result of the envelope statistics. Compared to the case of the fixed focus, the depth dependence of ESD is low with SFT result. However, it is considered that matching between the size of the scatterer actually included in the phantom and the estimated ESD value is not sufficient. This is because the impedance distribution of each scatterer is defined by the Gaussian model. The Fluid-Sphere model will applies for improbvement of ESD estimation.

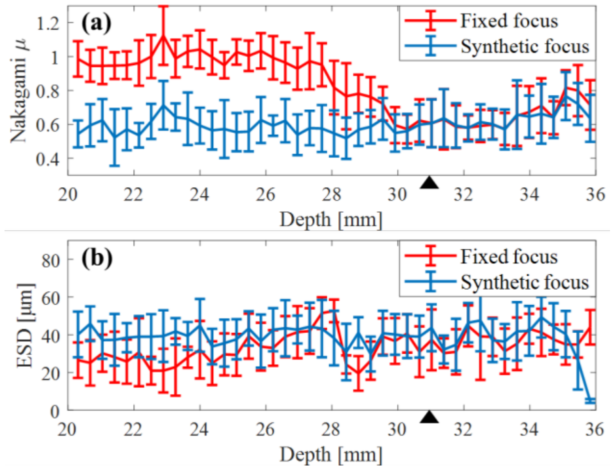

Fig. 3 Result of QUS analysis. Red and blue lines are fixed focus and synthetic focus, respectively. Black triangle signifies geometric focus.

4. Conclusion

As the results of examining the effectiveness of QUS analysis by using the annular-array transducer, stable analysis could be performed over the expanded DOF in both of the envelope statistics and the backscattered power-spectrum analysis. In the current study, verification is carried out in some actual living tissues having a more complicated scatterer structures.

Acknowledgment

This work was partly supported by JSPS Core-to-Core Program (A. Advanced Research Networks), and KAKENHI Grant Numbers 15H03030, 17H05280 and the Institute for Global Prominent Research at Chiba University.

Reference

1. Ketterling et al., IEEE TUFFC, 53(3), 623-630, 2006.
2. Shankar, IEEE TUFFC, 47(3), 727–736, 2000.
3. Oelze, et al., J. Ultras. Med., 112(3), 1201–1210, 2002.