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A method for estimating size of red blood cell aggregates using power spectrum measured from a point scatterer

点散乱体から計測したパワースペクトルによる赤血球集合体サイズ推定法

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1. Introduction

Excessive red blood cells (RBCs) aggregation is closely associated with diseases such as cardiovascular diseases and diabetes.[1)] We have proposed a non-invasive and quantitative method to evaluate the degree of RBCs aggregation by estimating the size of RBCs aggregate.[2)]

In our previous method, the size of RBCs aggregate was estimated by the frequency characteristics depending on the size extracted by normalizing the power spectrum from the vascular lumen with that from the rear wall. At that time, the reflection property of the rear wall was assumed to be independent of frequency. However, because the assumption is exactly not hold, its reflection property might have frequency dependence. Then, it might affect the accuracy of the size estimation.

In the present study, to estimate the size of RBCs aggregate directly using the scattering power spectrum obtained from the vascular lumen, the power spectra were measured for the wires assumed to be a single sphere scatterer to calculate the reference scattering power spectra. Then, the ratio of the measured power spectra was compared with that for the theoretical scattering power spectra corresponding to the diameters of the wires to evaluate the accuracy of the reference power spectrum. Then, the size of microparticles simulating RBCs aggregates was estimated using the calculated reference scattering power spectra.

2. Principle and method

2.1 Calculate reference scattering power spectra

Power spectrum $P_S(f,d)$ from the vascular lumen at a depth d includes not only the scattering property $S(f)$ but also the frequency dependence of applied signal $X(f)$, the transmission and reception property of the ultrasonic transducer $G(f)$, the sound pressure property of the ultrasound probe at depth $H(f,d)$, and the attenuation property $A(f,d)$. Therefore, the reference scattering power is given by

$$P_{\mathrm{RD}}(f,d) = |S_D(f)X(f)G(f)H(f,d)A(f,d)|^2, \quad (1)$$

where $S_D(f)$ is the theoretical scattering property from a single sphere scatterer with a size of D.[3)] The power spectrum $P_\phi(f,d)$ actually measured from a single sphere of diameter ϕ is given by

$$P_\phi(f,d) = \left|S_\phi(f)X(f)G(f)H(f,d)A(f,d)\right|^2. \quad (2)$$

Thus, the scattering power spectrum $P_{\mathrm{RD}}(f,d)$ for the scatterers with arbitrary diameter D can be calculated in advance as

$$P_{RD}(f,d) = P_\phi(f,d) \times \left|\frac{S_D(f)}{S_\phi(f)}\right|^2. \quad (3)$$

The size of RBCs aggregate is estimated by fitting the power spectrum $P_S(f,d)$ to the reference scattering power spectra $\{P_{\mathrm{RD}}(f,d)\}$ with the normalized scattering power as a weighting function.

2.2 Evaluate accuracy of power spectrum obtained from single sphere scatterer

If the accurate scattering property $S_\phi(f)$ is included in the power spectrum $P_\phi(f,d)$, the ratio of the scattering power spectra obtained from single sphere scatterers of different diameters ϕ_1 and ϕ_2 agrees with that of theoretical powers of diameters ϕ_1 and ϕ_2, as follows

$$\frac{P_{\phi_1}(f,d)}{P_{\phi_2}(f,d)} = \left|\frac{S_{\phi_1}(f)G(f)X(f)H(f,d)A(f,d)}{S_{\phi_2}(f)G(f)X(f)H(f,d)A(f,d)}\right|^2 = \left|\frac{S_{\phi_1}(f)}{S_{\phi_2}(f)}\right|^2. \quad (4)$$

Therefore, the accuracy of $P_{\mathrm{RD}}(f,d)$ in Eq. (3) can be evaluated by comparing $P_{\phi_1}(f,d)/P_{\phi_2}(f,d)$ with $\left|S_{\phi_1}(f)\right|^2/\left|S_{\phi_2}(f)\right|^2$.

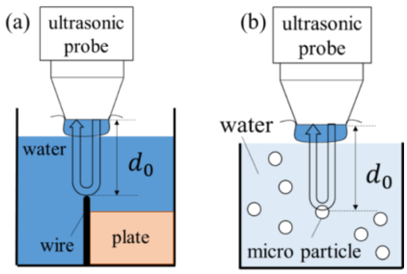

Fig. 1. Schematic diagram of the measurement. (a) Wire, (b) blood simulating phantom.

2.3 Method

A thin wire with a hemispherical tip was set parallel to the beam direction of the ultrasonic probe as shown in **Fig. 1(a)**, and it was assumed to be a single sphere scatterer. An ultrasound system (Tomey UD-8000) was used. The sampling frequency was 240 MHz. An ultrasonic probe with an operating center frequency of 30 MHz (frequency range: 19-40 MHz) was used. The focal length of the ultrasonic probe was 8.75 mm. Two thin wires with diameters ϕ of 20 µm and 30 µm were used, and the distance between the probe and the tip of the wire, d_0, was set to 9 mm. The power spectrum was calculated by windowing the averaged signal of 113 RF signals obtained from the wires by the M-mode measurement with a rectangular window.

Moreover, phantom simulating blood was prepared by suspending microparticles with a diameter of 20 µm in water. The volume ratio of particles was 0.7%. The number of beams was 113 and 19 frames were acquired. Fig. 1(b) shows a schematic diagram of the measurement. The power spectrum was obtained by windowing the RF signal with Hanning window with a width of 0.15 µs centered at $d = d_0$.

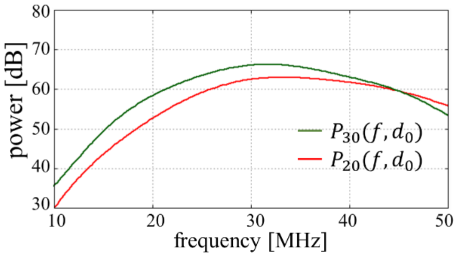

Fig. 2. The power spectra $P_\phi(f, d_0)$ obtained from the wires.

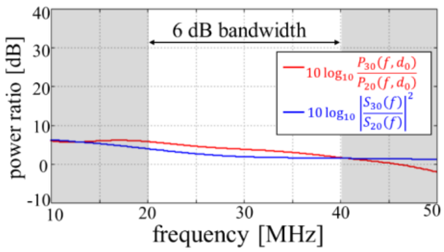

Fig. 3. The ratio of the power spectra obtained from the wires with different diameters and theoretical power ratio corresponding to the diameters of the wires.

3. Results

Figure 2 shows the power spectra $P_\phi(f, d_0)$ obtained from the wires. **Figure 3** shows the ratio of the power spectra $P_\phi(f, d_0)$ obtained from the wires with different diameters and the theoretical scattering power $|S_\phi(f)|^2$ corresponding to the diameters of the wires. The averaged difference and the standard deviation between them in the 6 dB-bandwidth were 1.6 dB and 0.51 dB, respectively. Since $P_{30}(f, d_0)/P_{20}(f, d_0)$ and $|S_{30}(f)|^2/|S_{20}(f)|^2$ show the similar frequency characteristics, the power spectrum of the wire $P_\phi(f, d)$ is considered to be suitable for calculating the accurate reference scattering power spectra $\{P_{RD}(f, d)\}$.

Moreover, the averaged power spectra $P_s(f, d_0)$ of 113 RF signals obtained from the blood-simulated phantom were calculated. The average standard deviation of scattering power spectra in 6 dB bandwidth among 19 frames was 2.4 dB. Also, the difference in attenuation characteristics caused by the different propagation media between the measurements for the wire and the blood-simulated phantom was corrected.[2] The sizes of the particles were estimated by fitting the corrected scattering power spectrum with the reference scattering power spectra $\{P_{RD}(f, d)\}$ calculated from $P_{20}(f, d_0)$ as Eq. (3).

Figure 4 shows a fitting result of the measured and reference scattering power spectrum. The average and the standard deviation of the estimated sizes among 19 frames were 17.8 µm and 2.4 µm, respectively, which shows that the estimated sizes were close to the true value of 20 µm. Therefore, the calculated reference scattering power spectrum is useful for the accurate size estimation of RBCs aggregate.

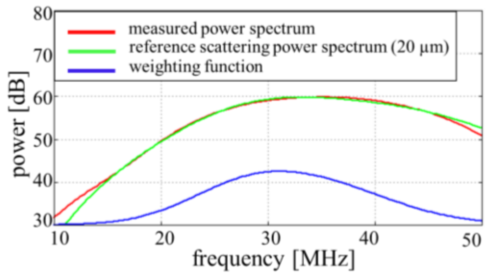

Fig. 4. A fitting result of the measured and reference scattering power spectra.

4. Conclusion

The scattering power spectra $P_\phi(f, d)$ were obtained from the wires assumed to be a single sphere scatterer. Also, the accuracy of the reference scattering power spectrum was evaluated. Moreover, the sizes of microparticles with a diameter of 20 µm were estimated using the reference scattering power calculated from $P_{20}(f, d_0)$. As a result, the estimated sizes were close to the true value of the particles. This result suggests that the reference scattering power can be used to accurate size estimation of RBCs aggregate.

Acknowledgment

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