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Robust Estimation of Red Blood Cell Aggregation *in vivo* Using the Spectrum Analysis of High-Frequency Ultrasound

高周波超音波の周波数解析を用いた赤血球凝集度の *in vivo* ロバスト計測

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1. Introduction

Red blood cell (RBC) aggregation is one of the primary determinants of blood viscosity that defines the resistance of blood to flow[1)]. Since blood viscosity is linked to the risk factors of cardiovascular diseases, the evaluation of RBC aggregation is important to assess the cardiovascular risk in the early stage of several diseases such as hypertension, atherosclerosis, obesity, and diabetes. As a qualitative assesment, it is known that smoke-like echo appears during RBC aggregation[2)]. On the other hand, the quantitative evaluation of RBC aggregation has a potential that brings a new indicator of cardiovascular risk .

Our group has reported a method that evaluates RBC aggregation[3), 4)]. In this study, we evaluate the performance of the method for the diagnosis of Cardiovascular diseases. We estimate RBC aggregation of normal subjects and patients with diabetes using the frequency characteristic of ultrasound signal backscattered by blood.

2. Materials and Methods

2.1 Characteristics of Ultrasonic Backscattering

A small scatterer such as a single RBC exhibits Rayleigh scattering, and the power spectrum of its scattered echo is proportional to the fourth power of the frequency. On the other hand, when the size of a scatterer is large, the scatterer is regarded as a reflector, and power spectrum does not show frequency dependence. In this study, a scatterer is modeled by placing an infinite number of infinitesimal point sources on the surface of a spherical scatterer[5)].

2.2 Normalization of Power Spectrum

The measured power spectrum $P_s(f)$ of the echo from lumen of the dorsal hand vein depends not only on the scattering property from scatterers, $S(f)$, but also on the frequency response of transmitting and receiving transducers, $G(f)$, and attenuation property of the propagation medium, $A_1(f)$. Therefore, we extract the scattering property of the aggregated RBCs by the normalization using the power spectrum $P_r(f)$ of a flat vein wall. This process is expressed by the following equation:

$$10\log_{10}\frac{P_s(f)}{P_r(f)} = 10\log_{10}\frac{|S(f)G(f)A_1(f)X(f)|^2}{|R(f)G(f)A_2(f)X(f)|^2} \approx 10\log_{10}\frac{|S(f)|^2}{|R(f)|^2} \qquad (1)$$

where $R(f)$ is the reflection property which does not have frequency characteristics, $A_2(f)$ is the attenuation property of the propagating medium at the measurement of the venous wall and $X(f)$ is the spectrum of the voltage applied to the transducer. In the present study, $A_2(f)$ is assumed to be same as $A_1(f)$.

2.3 Calculation of Reflector Power Spectrum

In the present study, the power spectrum of the reflector is estimated from the echo from the venous wall. Since the reflector power spectrum should be estimated from the echo returns from a single flat interface, the existence of plural interfaces in a window function deteriorates the accuracy in estimating the reflector power spectrum. Therefore, reflector power spectrum should be estimated from several echoes of lumen-intima interface. We excluded the cases that the echo from lumen-intima interface and the echo from media-adventitia interface are close to each other, and reflector power spectrum was estimated from the average echoes from lumen-intima interface.

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2.4 Method for Estimating Scatterer Size

Scatterer size is estimated by fitting the theoretical power spectrum to the measured power spectrum $S(f)$, where the proposed method minimizes the sum of squares of the difference between the measured normalized power spectrum and the theoretical power spectrum of each scatterer diameter. In this fitting process, we use a weighting function to consider the signal-to-noise ratio (SNR). The weighting function is calculated by the scatterer power spectrum which is removed by the power spectrum of the echoes from the water with no object.

3. Results

We used an ultrasound diagnostic equipment (Tomey UD-8000) with a probe of 40 MHz center frequency to acquire RF data of the cross-sections of human dorsal hand veins. **Figure 1** shows the reflector power spectrum of venous wall obtained by three subjects. Each power spectrum was obtained by averaging at least 15 echoes. **Figure 2** shows the normalized power spectrum, theoretical power spectrum, and weighting function measured for each measurement phase. Scatterer diameter estimated at rest was 10 μm, that estimated during avascularization was 26 μm. **Figure 3** shows the transient change of average scatterer diameter in health subjects, where a error bar represents the standard deviation for three times measurement on different days. The estimated diameter of scatterers during avascularization was larger than that at rest and after recirculation. This result is consistent with the previous studies because RBC aggregation occurs during avascularization. **Figure 4** shows the average scatterer diameter with respect to HbA1c during avascularization in diabetic patients. HbA1c is linked to hemoglobin and glucose, and it is one of the diabetes indicators. The scatterer diameters of high HbA1c group were large compared with those of low HbA1c group.

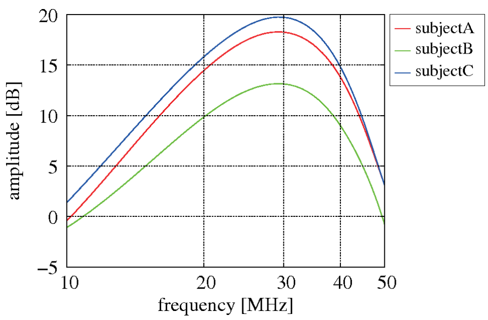

Fig. 1 Power spectrum of the reflector for different subjects.

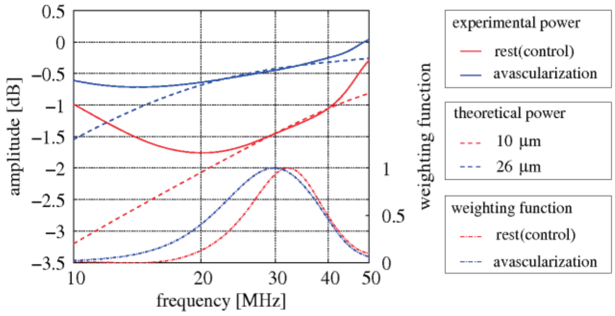

Fig. 2 Experimental power spectrum, corresponding theoretical power spectrum, and weighting function.

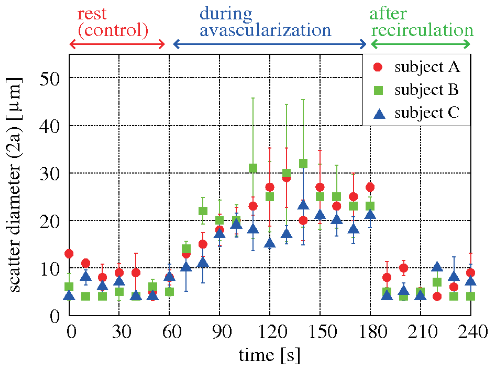

Fig. 3 Transient change of the scatterer diameter.

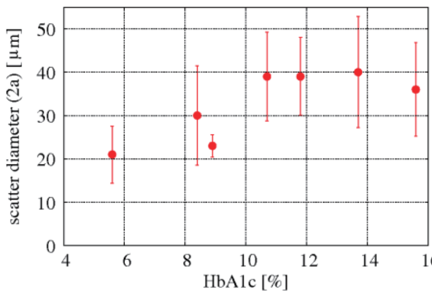

Fig. 4 Averaged scatterer diameter with respect to HbA1c during avascularization.

4. Conclusion

Transient change of the estimated scatterer diameter in healthy subjects showed the reproducibility of the proposed method. The scatterer diameter estimated by the proposed method during avascularization in diabetic patients had a correlation with the value of HbA1c, one of the diabetes indicators. These results show the possibility of the quantitative and non-invasive assessment of RBC aggregation in clinical conditions.

References

1. C. C. Huang, *et al.*: Jpn. J. Appl. Phys. **45** (2006) 7191.
2. X. Wang, *et al.*: Am. Heart J. **124** (1992) 961.
3. N. Saitoh, *et al.*: Jpn. J. Appl. Phys., **48** (2009) 07GJ08-1-07
4. T. Fukushima, *et al.*: Jpn. J. Appl. Phys. **50** (2011) 07HF02.
5. P. M. Morse, *et al.*: Methods of Theoretical Physics (McGraw-Hill, NY, 1953).