3Pa5-3

A Study of Noninvasive Observation of Blood Viscosity based on Ultrasonic Echo Correlation Method

超音波エコー相関法に基づいた血液粘性の非侵襲観測法の研究

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1. Introduction

In recent years, importance of measurement of the blood viscosity has enhanced. The mechanism of increase of the blood viscosity is known as a result of the aggregation of the red blood cells (RBC). The increase of the flow resistance and the further aggregation would be conducted by the viscosity increase. We propose a measurement technique which estimates the blood viscosity with a cross-correlation process between the ultrasonic echoes acquired on a blood vessel model.

In the case of a low viscosity blood, which corresponds to less RBC aggregation as mentioned above, each RBC flows free changing its relative position within the blood flow. On the other hand, in the case of a high viscosity blood in which grown-up aggregations of the RBC can be found, it is assumed that the relative positions of the each RBC would be maintained within an aggregation in the blood flow (Fig. 1). Thus, variations between two ultrasonic echoes obtained at the upstream and the downstream is considered to reflect the degree of the aggregation. According to this concept, the length of a higher correlation region on the echo signal suggests the aggregation size in the axial direction. In this study, the cross-correlation technique was applied to estimate the degree of the aggregation, and *in vitro* experiments were performed.

2. Method
2.1 Experimental setup

The diagram of the experimental set-up is shown in Fig. 2. A silicone tube with an inside diameter of 8 mm which was used to imitate the blood vessel was embedded in gelatin gel. Blood mimicking sample was consisted of "graphite cube" and "graphite fluid", thus graphite powder was used as the aggregation of the RBC. The former was prepared with the cube-cut 10% gelatin gel, in which 4% graphite power was randomly distributed, and the latter was 2% aqueous solution of polyvinyl alcohol (PVA) involving the graphite powder as the same one as the graphite cube.

The blood mimicking sample was flowed inside the silicone tube with an average flow velocity of 4.0cm/s. A 5.0MHz ultrasonic transducer (1.2mmϕ, non-focused) which was connected to a pulser-receiver, was placed directly above the silicone tube to acquire the echoes. During the blood mimicking sample was flowed, the first and the second echoes were acquired with the time interval of 5msec, and digitized by an oscilloscope. These experimental datasets were forwarded to a personal computer, and off-line cross-correlation processes were performed to them.

2.2 Preliminary experiments

A preliminary experiment which confirmed the repeatability and the stability was demonstrated with a "plug-flow" in the blood vessel model. In plug flow, the velocity of the fluid is assumed to be constant across any cross-section of the pipe perpendicular to the axis of the pipe. The "plug" was prepared by coagulating the same materials as the graphite cube inside the blood vessel model. The plug-flow was equivalently produced by a position shift of the transducer along the axis of the tube. The result of the preliminary experiment is shown in Fig. 3. The echo signals were first acquired at the initial position, then at five shifted positions with a step size of 100 μm. Then, the cross-correlation processes with the window size of 0.45 mm were performed between initial signal and the other signals acquired at the each position. The plotted correlation coefficients were the averages through the tube depth, and they could be regarded to represent a linear relationship that the further from the initial position, the lower the correlation coefficient.
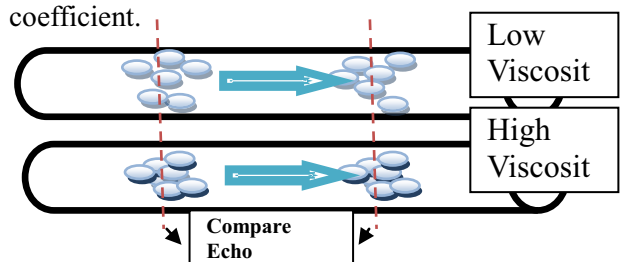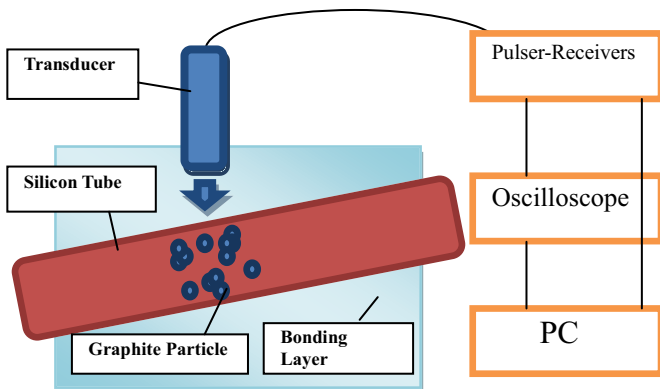

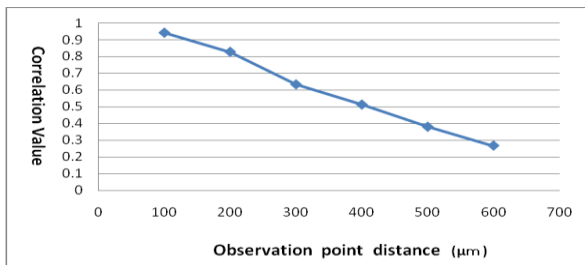Fig.1　Concept of echo correlation method.

Fig.2 Experimental setup.

Fig.3 Relationship between position shift and correlation level in plug flow.

2.3 Detection of graphite cube

Three kinds of the blood mimicking sample were prepared, namely, the plug-flow, the graphite fluids with and without the graphite cubes which were shaped to 2 mm × 2 mm × 2 mm. In the each case of the sample, the initial echo signal was acquired, then the sample fluid was flowed with an average flow velocity of 4.0cm/s (corresponded to the average flow of 200 μm), and the echo signals were acquired with a time interval of 5 msec. The results of the correlation coefficient distributions in the cases of the plug-flow and the graphite fluids without the graphite cube were shown in Fig. 4. The dimension of correlation window was equivalent to 0.45 mm. A high correlation level was maintained through the depth of the tube in the case of the plug flow. On the other hand, in the case of the graphite fluids, an unstable correlation level was observed, reflecting the changes in the relative positions among the graphite particles.

The correlation distribution in the case of with the graphite cubes was shown in Fig. 5. The curve drawn in Fig. 5 with two peaks was obviously differed from the curves in Fig. 4. As shown in Fig. 2, the correlation coefficient of 0.8 which was plotted at the position shift of 200 μm was considered to be a suitable detection level, because the result of the plug flow should be referred to detect a high correlation region. The regions surrounded with the dashed lines in Fig. 5 were over the detection level. Both of the widths of the two peaks were corresponded to the size of the graphite cube.
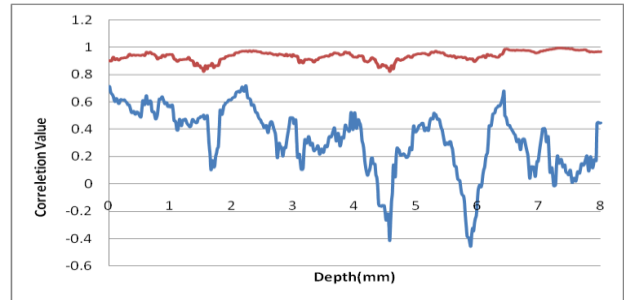

Fig.4 Correlation coefficients distributions (average flow distance: 200 μm). Solid line: plug flow, Dashed line: graphite fluid.
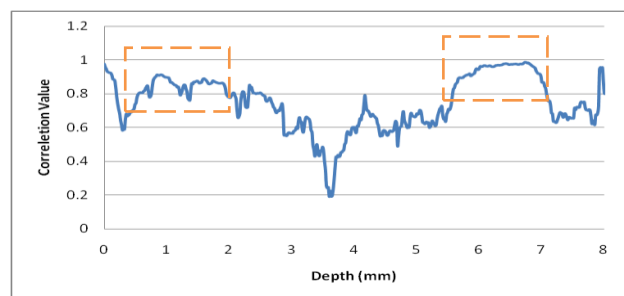

Fig.5 Correlation coefficients distributions of graphite fluids with graphite cubes (average flow distance: 200 μm).

4. Conclusion

Therefore, a possibility that the RBC aggregation in the blood flow could be detected was suggested in this study. A future work is to quantify the dimension of the RBC aggregation and to measure its distribution.

5. References

1. S.Maeda: JOURNAL OF THE PHYSIOLOGICAL SOCIETYOF JAPAN 66(9), 287-297, 2004-09-01