AR 기술이 도입된 격자볼츠만 기법을 활용한 Bright ring 현상에 대한 분석

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Analysis of bright ring phenomenon by augmented reality aided LBM simulation

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Abstract : Simulation with RBCs in pipe channel with pulsatile condition is performed to observe bright ring phenomenon. It is found that at systolic phase RBCs aggregate into a ring shape, causing decrease of cell free layer and showing unique velocity profile. Comparison of pulsatile flow case with steady flow case have shown that drag force concentration have caused the unique velocity profile by RBC aggregation. Further analysis were performed on flow velocity, BPM, RBC stiffness, and hematocrit. It is found that those factors that increase RBC aggregation have also enhanced bright ring phenomenon.

1. Introduction

One of the interesting phenomenon due to RBC aggregation is “bright ring”. Bright ring is the phenomena that RBCs repeat aggregating and scattering under pulsatile blood flow condition. This bright ring was observed by ultrasound imaging, in which the repeating bright ring shaped zone was found where RBCs scattered away from the center of the channel at certain conditions.(1) The most important factor for bright ring was the pulsatile condition of blood flow. This bright ring phase, or when RBCs scatter away from the center of channel, happened when the blood flow velocity started to decrease after maximum velocity, until velocity began to increase at minimum velocity.

Many studies tried to observe this bright ring phenomenon experimentally.(2) However, there are yet not many studies trying to make use of this phenomenon for practical purposes. Bright ring phenomenon has high potential when used for cell separation or other microchip devices. Controlling cell aggregation passively by inlet flow and channel geometry is one of most effective method for solving cell chip problems. To achieve this, better understanding of bright ring effect must be analyzed in advance.

In this paper, the Lattice Boltzmann method is used to control this bright ring phenomenon. The purpose of this paper is to analyze the effect of bright ring phenomenon on blood viscosity. First, comparison between pulsatile flow case and steady flow case is performed to observe the effect of bright ring phenomenon. Then, velocity, BPM, RBC stiffness, and hematocrit are analyzed to find their effect on bright ring phenomenon.

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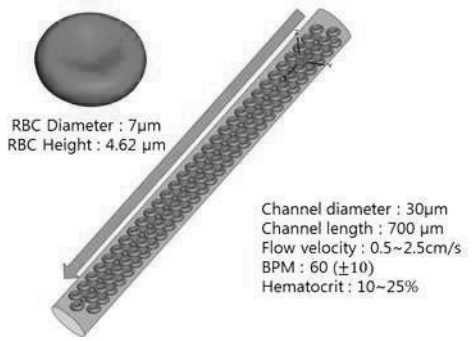

Fig. 1 Reduction of efficiency with the tip clearance and attack angle (Cal. by WFM)

2. Numerical Methods

To analyze the bright ring phenomenon, maximum velocity, BPM, RBC stiffness, and hematocrit are set as control variables.

Then, velocity, BPM, RBC stiffness, and hematocrit are analyzed to find their effect on bright ring phenomenondfv The solver used in this simulation is LBM(Lattice Boltzmann Method). This method is widely used to solve microfluidics.(3) The single-relaxation-time Bhatnagar-Gross-Krook model is used to solve an incompressible fluid. Also, to solve deformable particles inside the fluid, IBM(Immersed boundary method) is used along with LBM. The deformability of RBCs are defined by following the paper of Moon et al.(4) The boundary conditions for the simulation is drawn in fig. 1.

3. Results

It is shown that RBCs aggregate in the form of donut shape during increase of flow velocity, and disaggregate by decrease of flow velocity. During the aggregation phase, cell free layer has decreased and velocity profile has changed due to the concentration of drag force. By comparing systolic flow with diastolic flow, it is proved that bright ring effect changes cell free layer along with drag coefficients. In addition, it is shown that friction drag coefficient is larger than pressure drag coefficient. Further analysis were performed by controlling flow velocity, BPM, RBC stiffness and hematocrit. Those factors which enhances RBC aggregation have shown to also enhance the bright ring effect.

References

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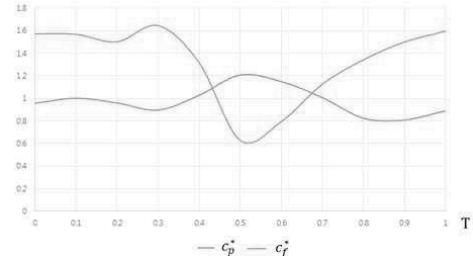

Fig. 2 Pressure drag coefficient and friction drag coefficient by pulse time.

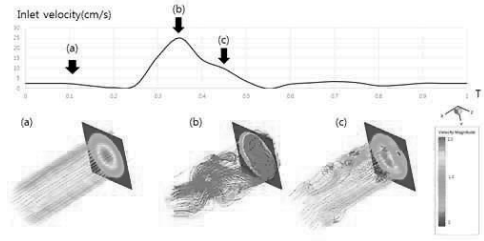

Fig. 3 Streamlines by pulsatile flow.