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Numerical Study on the Complete Separation of Blood Cells using the Integrated Dielectrophoretic-Photophoretic Method in a New Microchannel

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ABSTRACT: In the present study, a numerical simulation was conducted to investigate the separation of blood cells using an integrated dielectrophoretic-photophoretic method in a new microfluidic device. In this simulation, the migration behavior of human blood cells under laser radiation with a wavelength of 522 nm and in the presence of fluid flow has been investigated. Studies show that the photophoretic migration of red cells under the irradiation of laser beam is higher than platelets and other blood cells so that the magnitude of the applied photoelectric force on the red blood cells has been calculated about nine times that of the white blood cells under the irradiation of laser beam of 50 . In this separation using photophoretic forces, red blood cells were first separated from the platelets and white cells. Subsequently, using the hydrodynamic forces induced by the fluid on the particles and the dielectrophoretic forces, the separation of the platelets from the white blood cells was carried out in different branches of the microchannel. The proposed design, in addition to high separation efficiency, has a negligible cell loss, so that it can be used as an effective method in many diagnostic processes and medical applications.

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1. INTRODUCTION

Blood transfusion is a necessary treatment that is needed for replacement of lost blood during diseases such as leukemia, anemia, and chemotherapy [1,2]. With the advancements in the field of medical science, blood transfusions are performed only using the necessary blood components such as platelets, red blood cells, and white blood cells [3].

Medical devices need to be developed in such a way that they can completely and efficiently separate blood into its components. One achievement for such needs is the photophoresis method in which the migration and identification of suspended microparticles in a fluid, is accomplished using the photophoretic forces.

The fundamental principles of the photophoresis phenomenon were developed by Ashkin [4,5]. This phenomenon has rarely been used to separate microparticles in fluids, except for some pioneering works which could sort or characterize a limited number of particles in the fluid using their refractive index and size [6,7]. However, the separation of microparticles and fluid-suspended cells has been extended to more particles in subsequent studies [8,9].

In previous studies, the separation of blood cells was more limited to the sorting of platelets or white cells from whole blood, and the sorting of the whole blood sample to all of its components was less considered. The difference in the size of the blood components (platelets, red, and white blood cells) can significantly affect the separation. Therefore, it is necessary to study carefully the effects of microchannel design, voltage applied to the electrodes and the input rate of the buffer solution to isolate the whole blood sample.

In this study, continuous separation of the whole blood sample is performed for utilization in diagnostic processes and medical applications. For this purpose, blood cells were irradiated with 532 nm laser beam, and their photophoretic behavior was observed. Also, the possibility of separation of red blood cells from other blood cells due to the difference in photophoretic force applied to them has been investigated. The white blood cells and platelets were then entered into the dielectrophoretic section of the microchip and experienced separation by dielectrophoresis method based on the field flow fractionation approach at the relatively low voltage (peak to peak voltage of 3 V).

2. MATERIALS AND METHODS

The governing equation for the blood cells affected by the drag force (F_D), the photophoretic force (F_P), and the dielectrophoretic force (F_{DEP}) is in accordance with Eq. (1).

$$\frac{\mathrm{d}}{\mathrm{dt}}(mv) = F_p + F_{DEP} - F_D \quad (1)$$

In Eq. (1), m and v are the mass and velocity of the cell, respectively. Previously, the forces mentioned have been further investigated and described [9,10].

Numerical simulations have been performed to

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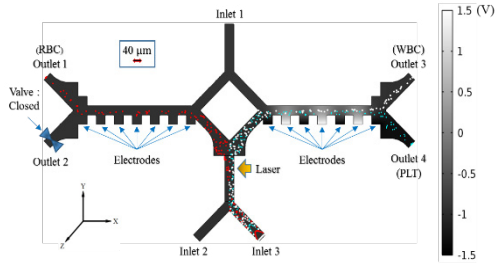

Fig. 1. Pathways for the separation of platelets, red blood cells, and white blood cells from each other

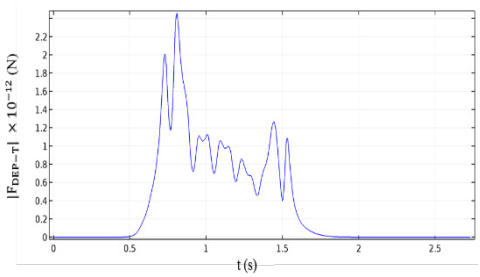

Fig. 2. The magnitude of the applied dielectrophoretic force on the white blood cells versus the time

Table 1. The average drag force applied on the red blood cells versus the mesh size at 1.07 s

Number of the model elements (Mesh size)	The drag force magnitude (N)
(Finer) 29391	2.94×10^{-14}
(Fine) 23207	2.65×10^{-14}
(Normal) 19024	2.73×10^{-14}
(Coarse) 10517	3.85×10^{-14}
(Coarser) 4392	35.01×10^{-14}

continuously separate the whole blood sample into white blood cells, red blood cells, and platelets. These simulations were performed in the software of the COMSOL Multiphysics 5.2, in which the photophoretic forces were used to simulate the effects of laser beams, the dielectrophoretic forces were used to simulate the effects of applied voltage on the electrodes and the forces exerted by the fluid on cells were used.

In the simulation, the Reynolds number is very small ($Re\ll1$), and therefore, the creeping flow module is used to simulate the fluid flow. This simulation is also based on finite element analysis in two dimensions in which the third dimension (Z) is ignored. Because the fluid flow rate in the third dimension is negligible and the geometric length in this dimension is smaller than other dimensions.

In Fig. 1, pathways for the separation of platelets, red, and white blood cells within the microchannel, can be seen. In this Figure, blood cells are first introduced into the microchannel through Inlet 3. Then, red blood cells were separated from other blood cells following exposure to laser irradiation with power of 0.82 W and diameter of 184.8 µm. Because the red blood cells under this irradiation, have shown greater photophoretic efficiency and horizontal migration speed than other blood cells.

After separation the red cells from other blood cells, white blood cells and platelets have entered the region of the electrodes. In this region, due to the different effects of dielectrophoretic forces on the white blood cells and platelets and after applying voltage to the electrodes, the white cells and platelets have also been separated from each other and have been removed from Outlets 3 and 4, respectively.

3. RESULTS AND DISCUSSION

Table 1 shows the average drag force applied to the red blood cells versus the mesh size when the blood cells have passed through the laser irradiated area (1.07 s). According to this Table, when the number of the model elements is very large (4392 elements), the magnitude of the average drag force is 35.01×10^{-14} Newton (N). However, for the greater number of elements, the magnitude of the drag force is reduced so that for the normal, fine and finer grid sizes, the magnitude of the drag force is independent of mesh with an uncertainty of 1×10^{-15} N.

Fig. 2 illustrates the fluctuations of the applied dielectrophoretic force on the white blood cells due to the application of nonuniform electric fields. As shown in Fig. 2, no dielectrophoretic force is applied to the cells until 0.47 seconds. Gradually, as the cells approach the electrodes zone (0.47 s to 2 s), the slope of the diagram increases so that the cells experience the most magnitude of the dielectrophoretic force in the regions near the first and last electrodes. After 2 seconds, the graph slope tends to zero again.

4. CONCLUSIONS

In this paper, the scheme of separation of different blood cells using the integrated dielectrophoresis-photophoresis method in a new microfluidic device is discussed in which separation of the blood cells based on their size is performed using the fluid forces, the photophoretic forces and the dielectrophoretic forces. The proposed microchip provides a simple structure in which the peak to peak voltage of 3 V is used. The proposed design is applicable to other types of microfluidic devices so that it can be used in medical and diagnostic processes as a laboratory chip. Future microfluidic devices should have simple structure, high separation efficiency, low cellular damage, and reasonable costs.

REFERENCES

[1] E. Bakker, M. Qattan, L. Mutti, C. Demonacos, M. Krstic-Demonacos, The role of microenvironment and immunity in drug response in leukemia, Biochimica et Biophysica Acta (BBA)-Molecular Cell Research, 1863(3) (2016) 414-426.

[2] I. Rădulescu, D. Candea, A. Halanay, Optimal control analysis of a leukemia model under imatinib treatment, Mathematics and computers in Simulation, 121 (2016) 1-11.

[3] J.-L. Cheng, S.-F. Han, Y.-Q. Li, Y.-P. Chu, Y.-M. Sun, J.-F. Guo, An experimental study on RBC count and serum potassium

concentration changes during compression transfusion of WBC-removal whole blood, Chinese Nursing Research, 2(2-3) (2015) 89-92.

[4] A. Ashkin, Atomic-beam deflection by resonance-radiation pressure, Physical Review Letters, 25(19) (1970) 1321.

[5] A. Ashkin, Forces of a single-beam gradient laser trap on a dielectric sphere in the ray optics regime, Biophysical journal, 61(2) (1992) 569-582.

[6] T. Imasaka, Y. Kawabata, T. Kaneta, Y. Ishidzu, Optical chromatography, Analytical Chemistry, 67(11) (1995) 1763-1765.

[7] A. Hirai, H. Monjushiro, H. Watarai, Laser photophoresis of a single droplet in oil in water emulsions, Langmuir, 12(23) (1996) 5570-5575.

[8] M. Zabetian, M.S. Saidi, M.B. Shafii, M.H. Saidi, Separation of microparticles suspended in a minichannel using laser radiation pressure, Applied Optics, 52(20) (2013) 4950-4958.

[9] H. Monjushiro, Y. Tanahashi, H. Watarai, Laser-photophoretic migration and fractionation of human blood cells, Analytica chimica acta, 777 (2013) 86-90.

[10] P. Gascoyne, J. Satayavivad, M. Ruchirawat, Microfluidic approaches to malaria detection, Acta tropica, 89(3) (2004) 357-369.

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