PLASMA SEPARATION FROM HUMAN BLOOD USING SPIRAL MICROCHANNELS FOR DRY EYE TREATMENT

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ABSTRACT

We demonstrated that spiral microchannels could efficiently separate plasma from whole human blood toward autologous serum eye drop, which provides benefits for all dry eye patients. The optimized spiral microchannels realized 100% separation of 10 μm particles and over 90% separation of blood samples.

KEYWORDS

Plasma separation, Spiral microchannels, Dry eye.

INTRODUCTION

Dry eye, which makes cornea scarred, is mainly caused by overuse of personal computers, leading to prevent our eye from tear spreading to eye surface; nevertheless, it is of most difficult to cure dry eye with commercially available eye drops. Recently, it is reported that the use of autologous serum or plasma as eye drop worked on dry eye efficiently [1]. However, preparation of autologous serum eye drop requires troublesome procedures such as centrifugation, filtration and dilution.

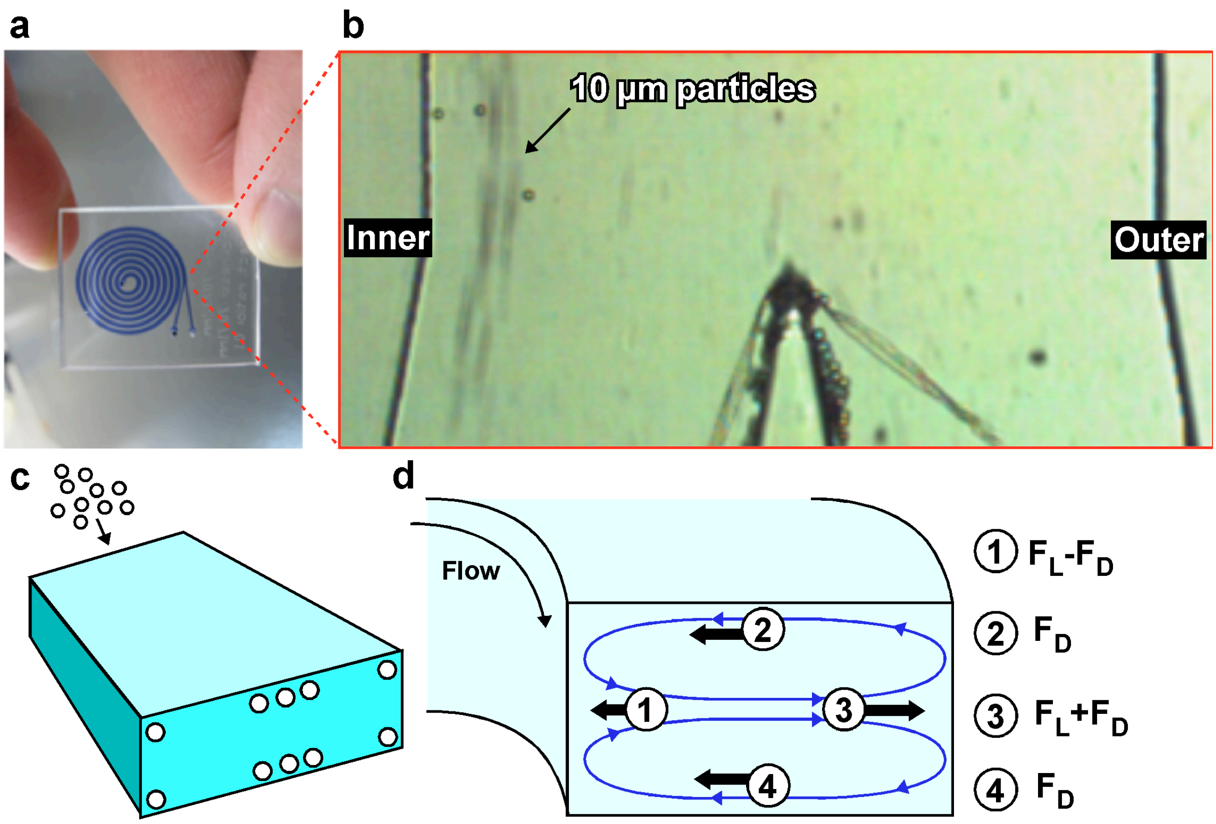

Figure 1. (a) Photograph of the spiral microchannel. (b) Micrograph of the spiral microchannel. 10 μm particles were focused at equilibrium position close to the inner wall of microchannel. (c) Schematic diagrams of particle focusing by inertial lift force. (d) Schematic diagrams of particle focusing by the combination between inertial lift force (F_L) and Dean drag force (F_D). Blue and black arrows showed the direction of Dean drag force and combined force, respectively.

In this work, we demonstrated high throughput plasma separation by using spiral microchannels towards the goal of dry eye treatment. A photograph and micrograph of the spiral microchannel are shown in Figures 1(a) and 1(b), respectively. Particles in solution flowing in the spiral microchannel were exposed to inertial lift force (F_L) and Dean drag force (F_D) as shown in Figures 1(c) and (d), respectively, resulting in particle focusing at the equilibration position close to the inner wall of the spiral microchannel [2].

The inertial lift force can be expressed as

$$F_L = \rho\left(\frac{U_{\max}}{D_h}\right)^2 C_L a_p^4 \quad (1)$$

where C_L is the lift coefficient, ρ is the density of fluid medium, U_{max} is the maximum fluid velocity, a_p is the particle diameter, and D_h is the microchannel hydraulic diameter.

The Dean drag force also can be expressed as

$$F_D = 5.4\times10^{-4}\pi\mu De^{1.63}a_p = 5.4\times10^{-4}\pi\mu\left(\mathrm{Re}\sqrt{\frac{D_h}{2R}}\right)^{1.63} a_p \quad (2)$$

where D_e is the Dean number, R is radius of circular channels.

A ratio of the inertial lift force to the Dean drag force was calculated as follow

$$\frac{F_L}{F_D} = \alpha\cdot a_p^3 = \beta\cdot\frac{1}{D_h^{3.53}} \quad (3)$$

where α and β are parameters witout a_p and D_h.

RESULTS AND DISCUSSION

The features of spiral microchannels, such as an aspect ratio, the number of spirals, and flow rates, should be a candidate of parameter for separation efficiency. By changing of the aspect ratio from 0.1 to 1.0 under fixed other conditions, we concluded that the aspect ration from 0.2 to 0.1 was suitable for 10 µm particle separation, especially, 0.1 showed 99% of separation efficiency (Figure 2(a)). Next, we considered the effect of the number of spirals on separation efficiency, and examined it from 0.5 to 7.5 spirals under fixed other conditions. Figure 2(b) showed that the separation efficiency increased as an increase of the number of spirals, leading to 99% separation efficiency in 7.5 spirals. From the above results, we used the spiral microchannel with 0.1 aspect ratio and 7.5 spirals to examine an influence of flow rates on separation efficiency. As we increased the flow rate from 100 to 5000 µL/min, the separation efficiency drastically improved, and finally we achieved 100% separation efficiency in 5000 µL/min; the Reynolds number and the Dean number were 217 and 14.2, respectively.

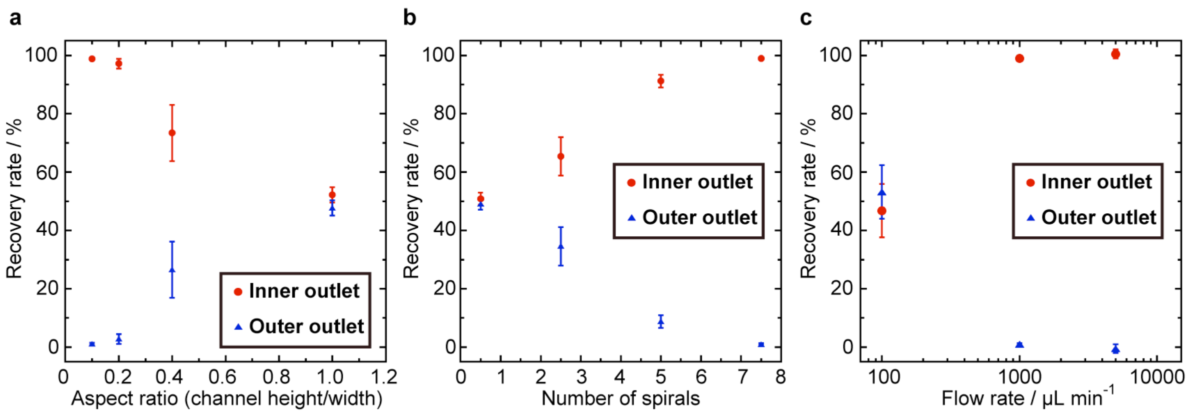

Figure 2. Recovery rate of 10 µm particles vs. each parameter. Red circles and blue triangles showed the recovery rate at inner and the outer outlet, respectively (N = 3). Cross sectional area is 50000 µm². (a) Recovery rate vs. aspect ratio of spiral microchannels. The aspect ratio meant the ratio of channel height to width. The number of spirals is 7.5, and flow rate is 1000 µL/min. (b) Recovery rate vs. the number of spirals. One spiral meant a circle. The aspect ratio is 0.1, and flow rate is 1000 µL/min. (c) Recovery rate vs. flow rate. The aspect ratio is 0.1, and the number of spirals is 7.5.

After the optimization, we introduced whole human blood into spiral microchannels. As same as 10 μm particles, the separation efficiency of blood samples increased as the flow rate increased, however we could not attain 100% efficiency due to the shape of red blood cells (8 μm diameter and 2.5 μm thickness) in Figure 3(a). As expected, the viscosity from blood samples affected on separation efficiency, and the separation efficiency degraded as the concentration increased (Figure 3(b)). While the separation efficiency is not enough to make autologous serum eye drop, spiral microchannels with large radius circular channels could be preparation devices for plasma separation toward dry eye treatment.

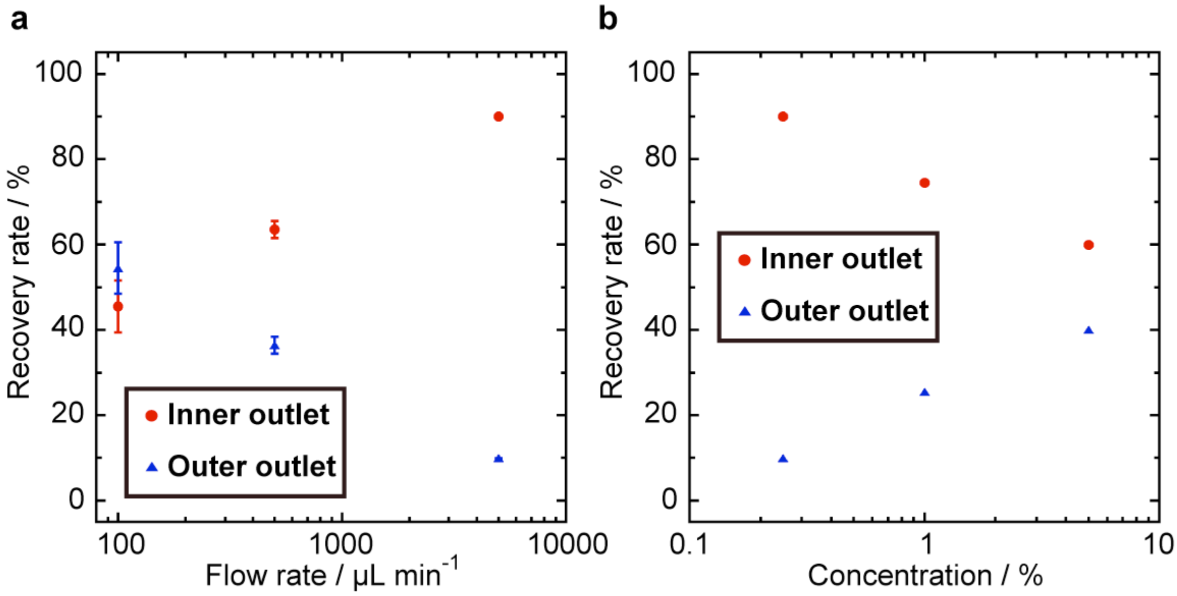

Figure 3. Recovery rate of blood samples vs. (a) flow rate and (b) blood concentration. Cross sectional area is 50000 μm^2, the aspect ratio is 0.1, and the number of spirals is 7.5. (a) Initial concentration is 0.25%. Red circles and blue triangles showed the recovery rate at inner and the outer outlet, respectively (N = 2). (b) Flow rate is 5000 μm/min. Red circles and blue triangles showed the recovery rate at inner and the outer outlet, respectively.

CONCLUSIONS

In this paper, we demonstrated that spiral microchannels could efficiently separate plasma from whole human. The features of spiral microchannels significantly affected on the separation efficiency, and we found the optimized design of the microchannels and flow rates; the aspect ratio (channel height/width) was 0.1; the number of spirals was 7.5; the flow rate was 5000 μL/min. The optimized spiral microchannel and flow rate realized 100% separation of 10 μm particles and over 90% separation of blood samples.

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