Flow rate and hematocrit measurements for in-vitro blood processing with Doppler ultrasound

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Background, Motivation and Objective

Recently, microfluidics has emerged as a novel blood separation technology potentially capable of overcoming conventional methods. However, high throughput systems derived from microfluidics still perform at low flow rates, outside the range of commercial flow meters. Also, for in-vitro blood processing in general, measuring the hematocrit of flowing blood is essential for performing real-time diagnostics. We present in this study a simple and low-cost Doppler method for measuring blood flow rate and hematocrit in an acoustophoresis blood separation chip (Bohec et al. 2017). Our method uses recent theoretical developments for reducing the Doppler measurement to a basic minimization problem (Vilkomerson et al. 2014) and hematocrit measurement is performed using a packing factor model (Bascom and Cobbold 1996, Franceschini and Cloutier 2013).

Statement of Contribution/Methods

In-vitro Doppler measurement were performed using a Continuous Wave Doppler probe mounted on a 3D printed support with human blood flowing in a medical tube (ID: 760um). Post-treatment was performed in Matlab. The Nelder-Mead algorithm was employed to estimate flow rate using the theoretical model for Doppler spectrum developed by Vilkomerson et al. (2014). Accuracy of flow rate measurements in the range 0.5ml/min/ 1.5ml/min was evaluated on one blood bag as well as the optimal measurement time. The relationship linking the total energy of Doppler signals and hematocrit was experimentally evaluated on 4 blood bags. Hematocrit in a range under 8% was then estimated from Doppler signals for each blood bag using a packing factor model derived from the other three bags.

Results/Discussion

Flow rate estimation shows a mean measurement error under 3% for a measurement time of 2s. The mean error is still under 5% for a measurement time of 0.5s. Hematocrit estimation for the 4 blood bags shows errors of 1.4, 1.1, 0.67 and 0.70 %Hct. Results demonstrate that the proposed Doppler method is capable of measuring low blood flow rate in narrow medical tubing with a high accuracy. It is particularly suited for an acoustophoresis device but the system is easily applicable to any in vitro blood circuit. The hematocrit measurement under 8% finds interesting applications in blood sorting technologies but also demonstrates that Doppler ultrasound is a potential method for measuring hematocrit of flowing blood in vitro.

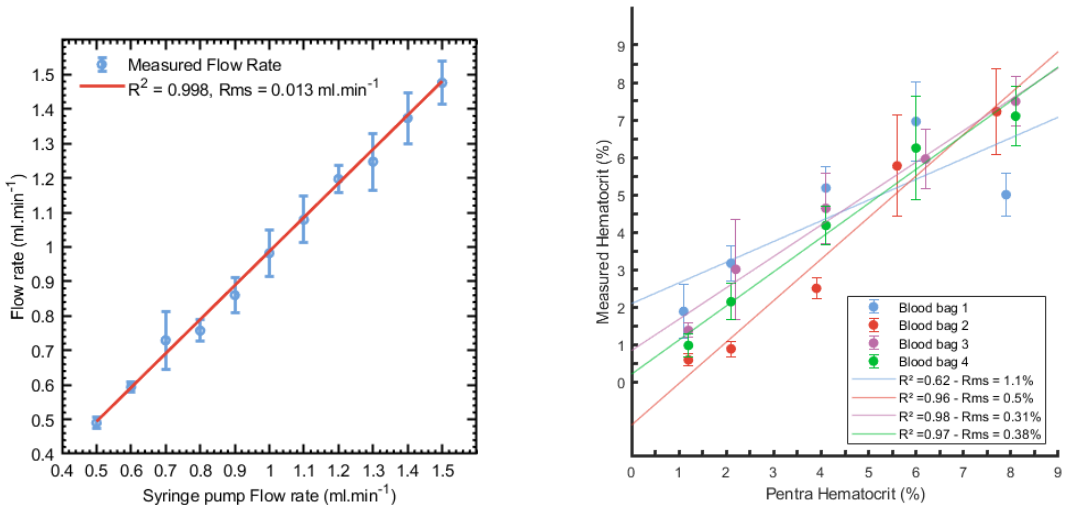

Figure 1 – Left: Measured flow rate compared to the syringe pump flow rate and regression line for an acquisition time of 2s. The slope is 0.987 (1.6% error) and the offset is 0.493 (1.3% error). Right: Mean estimated hematocrit from Doppler frequency integrals for an acquisition time of 5s and compared to measurements made by an ABX Pentra.