O5: Flow Visualization and Modeling

O5-1 Velocity and erythrocyte aggregation characteristics for surface tension-driven flow of blood in rectangular microfluidic channels.

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Surface tension as a flow-drive mechanism is used in various microfluidic applications due to its simplicity and low construction cost. Microfluidic blood flows based on such mechanism have been examined in the literature, however, the majority of the studies have not investigated in detail the influence of the red blood cell aggregation phenomenon on the flow characteristics. In the present study, we examine the flow of aggregating and non-aggregating blood, for surface tension driven flows in rectangular microchannels. The flow characteristics of the samples in the micro channel were analysed utilising micro-PIV based techniques, and aggregation was assessed via image processing methods. Preliminary analysis shows that RBC aggregation is supressed during the initial stages of the flow, and it has a small impact in the velocity profile compared to the non-aggregating case. This is mainly due to the elevated shearing conditions developing in the flow. The shear strength is higher at the onset of the flow, where the meniscus front is found accelerated, and persists at relatively high levels for all observation times. The results indicate that the surface tension mechanism may be a promising alternative for blood manipulation in microfluidic devices.

O5-2 A new approach of blood viscosity : hemodynamic viscosity

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The aim of this talk bears on viscosity of blood as a complex flowing liquid. The liquid layers inside the vessels flows are not homogeneous. Blood composition in vascular flow is organized as a sheath and a plug flow, from Thurston works.
Blood viscosity is the number one parameter for biomechanical studies of the blood flow behavior in cardiovascular net.
Various techniques for blood viscosity estimation do not give a true viscosity: instead, they give an apparent or effective viscosity.

But being able to measure a true and unique viscosity parameter is challenging for physicians, researchers, etc. In a first part, basing our work on high speed visualizations of blood flow, we will define hemodynamic viscosity, by its equation, and how it is usable and which protocol to be used to have a consistent value. Hemodynamic viscosity is adequate to a unique estimation of viscosity, which value refers exactly to the friction coefficient between blood layers in vessel flows. In the second part, we will develop this method, the applications to routine measurements, a database of blood numeration related to viscosity, and comparable results for diagnostics.
In the last part, we compare blood and plasma viscosity, either estimated by several approaches of fluids mechanics based on perfect fluids (Poiseuille, Couette, plan-cone) either

qualified by several indirect techniques like hematocrit which are influencing onto viscosity.
We show here joint protocols such as creep, flow curves at under controlled shear rate or shear stress, We show how the organization of the compounds modify the flow behavior and viscosity. We will present viscosity data on both blood and plasma.
Application to sepsis case shows that "hemodynamic viscosity" is a specific indicator.

O5-3 Evaluation and comparison of haemodynamic parameters of vascular end-to side anastomoses

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100/100 000 inhabitants receive vascular sutures or anastomosis (artificial connection between vessels). 20-60% of these vascular sutures lost their function in 10 years. Since the beginning of coronary surgery, it is a problem in every-day practice that surgeons are not able to control the quality of vascular sutures. Apart from some indirect assessment tool, there is no objective method for analysing the vascular suture's quality even during the education of medical students and trainees.
We have developed a detailed and easy to understand method for anastomosis analysis. The method can be used in surgical education, clearly presenting the technical aspects of surgical technique.
A novel educational tool has been introduced for graduate students and trainees. The method applies a reconstruction of high-resolution 3D morphological assessment of vascular anastomosis. Based on the data of the detailed 3D model of vascular anastomosis, computational simulations (computational fluid dynamics, CFD) of blood flow properties were performed. The attendees used a realistic replica of different surgical situations during the training. Attendees were informed about the results of the morphological and functional assessment and a gamified scoring system was used to inspire them for better performance.
The novel training system was proven to be more effective for surgical skill training compared to the conventional method. The attendees of courses and workshop gave more satisfied feedback.
The detailed, feedback based education method can be used as an effective tool in surgical skill training.

O5-4 Similarities in Erythrocyte Senescence and Microfluidic High Shear Environment Damage

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Medical devices can impose supra-physiological flow on the cellular components of blood as it passes through the unit. Increased shear stresses and pressures may alter blood cell biology in a way that is detrimental to their routine function. We hypothesized that membrane alterations and other changes after exposure to high stress might be similar to that seen in senescent cells. As red blood cells (RBCs) age, certain changes in their cellular properties begin to be evident. Senescent RBCs have reduced deformability as do mechanically traumatized cells. Using microfluidic channels and a set flow rate, washed RBCs were subjected to a known shear stress for varied exposure times between 1 to 15 ms. The collected effluent was then tagged using fluorescent antibodies towards known senescent markers and the samples analyzed using flow cytometric techniques. Flow cytometry enabled detection of subtle changes to RBCs below the threshold for complete hemolysis of the cell. Trends similar to those seen with senescent RBCs were found for exposure to high shear stresses in the explored time range, including formation of 0.5-1.0 μm microparticles, a presence of externalized phosphatidylserine on microparticles shed from the RBCs and the aggregation of Band 3 transmembrane protein with subsequent binding of IgG. According to the literature, aggregation of Band 3 with increased IgG binding to the RBC promotes clearance of the cell by means of macrophages. The changes found in senescent RBCs, as well as the cells exposed to shear stresses, affect their flow properties and can ultimately result in their removal from the circulatory system by the spleen.

O5-5 Investigation of bright collapsing ring by Lattice Boltzmann method

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Bright collapsing ring is a characteristic phenomenon of RBCs exposed in pulsatile flow. Paeng DG et al (2009) used Doppler flowmeter to measure blood flow in microchannel and have found that RBCs frequently aggregated in a ring shape. By controlling bright ring phenomenon, it might be able to passively control the cell migration inside cell chips. However, yet the cause of bright ring is unclear and needs to be studied by computational method.

Two main factors that affect bright ring are analyzed: the flow deceleration and shear stress. When flow velocity reduces as it is shifted from systolic phase to diastolic phase, plasma and RBCs experience the flow acceleration force which is the opposite direction of main flow. However, velocity itself is lower near wall and faster at center of the channel. Due to this velocity gradient, flow acceleration force also shows gradient, which is high at center and low near wall. This causes RBCs to move away from the center toward the wall.

However, flow deceleration does not explain the cause for RBC aggregation near wall. The cause of aggregation is mainly due to low shear stress of flow. Shear stress becomes lower when flow velocity decreases, which becomes enough for RBCs to aggregate at diastolic. Therefore, at diastolic phase, RBCs which already migrated away from the center of channel aggregates each other and forms ring-shaped formation.

The purpose of this paper is to analyze the bright ring phenomenon by computational method in terms of flow deceleration and shear stress. Lattice-Boltzmann method along with immersed boundary method is used for the simulation. Flow characteristics related to RBC migration are analyzed along with cell-to-fluid and cell-to-cell interaction.