

Assessment of Wall Shear Flow in Blood Vessel Models

by

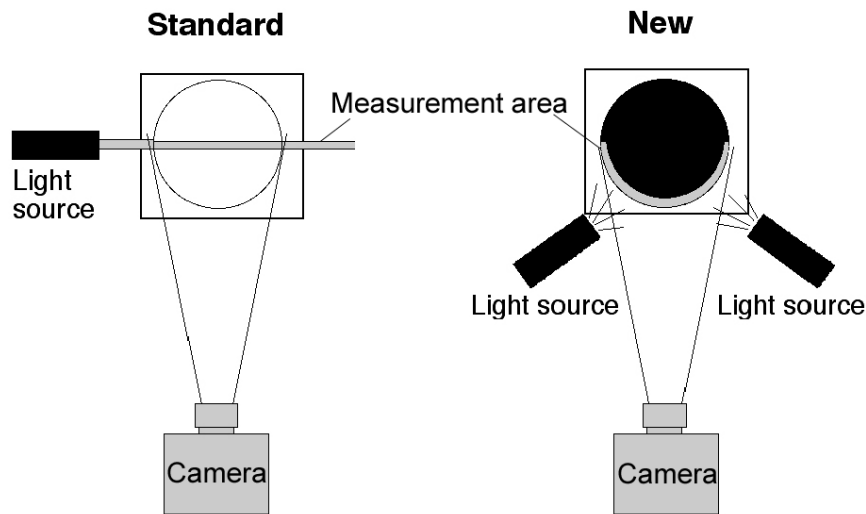
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ABSTRACT

Flow properties in artificial organs are of special interest in blood carrying systems, since a relationship between flow and thrombus formation exists. In particular, the wall shear rate is important. A new method to visualize the wall shear rate is proposed, based on the observation of light reflecting particles, which are suspended in the fluid. This method can be considered as being a special development of particle image velocimetry (PIV). Instead of having a light sheet illuminating a cross section in the center of the flow, here, we illuminate the particles near to the wall. Using a fluid, which permits the light to penetrate only the fluid close to the wall, makes this selection. Water is mixed with black Indian ink allowing the light to penetrate only about 0,5 mm. A transparent flow model is illuminated from the outside by a diffuse light source. The light illuminates only the wall region, so that only the particles moving close to the wall are seen. Reflecting particles are used. The size of the particles is of the same order as the depth of light penetration. The flow is recorded with a digital video camera. The resulting images are processed using the Particle Image Velocimetry. A vector field of the flow close to the wall is the result.



Comparison between standard flow visualization and the new method in a laminar pipe flow. The flow direction is perpendicular to the plane of this figure.

The results of experiments in different flows show the viability of the method. The direction of the flow at the wall can be assessed very well, as well as the detection of the stagnation lines and flow separation zones. Since such zones are linked to lesions of the wall, this new method can serve as a tool to investigate the flow related causes for alterations of the wall.

INTRODUCTION

The blood flow close to the wall of a blood vessel or an artificial surface is of great interest, because it defines the shear stress at the wall. This shear stress on the other hand determines the function of the endothelial cells and also the behavior of platelets. Both cell types as different as they are require a certain shear stress:

- The endothelial cell needs a certain shear stress or will convert into a smooth muscle and with other conditions initiate a atherosclerotic lesion.
- The platelet needs a certain shear stress or will deposit and initiate the generation of a thrombus.

Thus the flow and the reaction of the vessel wall are connected. This has been first observed by Rudolf Virchow. In 1854 he postulated the interaction of blood flow, vessel wall and blood properties, today known as „Virchow’s Triad“. Clinical experience has largely confirmed Virchow’s triad, however, the quantification is still lacking.

Numerous biological factors influence the interaction and make a correlation between wall shear stress and wall alterations difficult. But the measurement of the wall shear stress is a precondition to solve the problem. In general the measurement of shear stress or shear rate is a challenging experimental problem and many methods have been developed. All of the known methods have disadvantages, when they are used for the investigation of flows in blood vessel models. Reasons are the pulsatile flow, the curved and moving walls, and the small diameter.

METHOD

The method presented here is designed to overcome the problems of other methods. The method permits the selective investigation of the flow close to the wall. This is achieved by using a fluid which permits light to penetrate it only very close to the wall. Here, water is mixed with black Indian ink allowing the light to penetrate only about 1mm. A transparent flow model is illuminated from the outside by a diffuse light source. The light illuminates only the wall region, so that only the particles moving close to the wall are seen. Reflecting particles are used. The size of the particles is of the same order as the depth of light penetration. The flow is recorded with a digital video camera. The resulting images are processed using the Particle Image Velocimetry. A vector field of the flow close to the wall is the result.

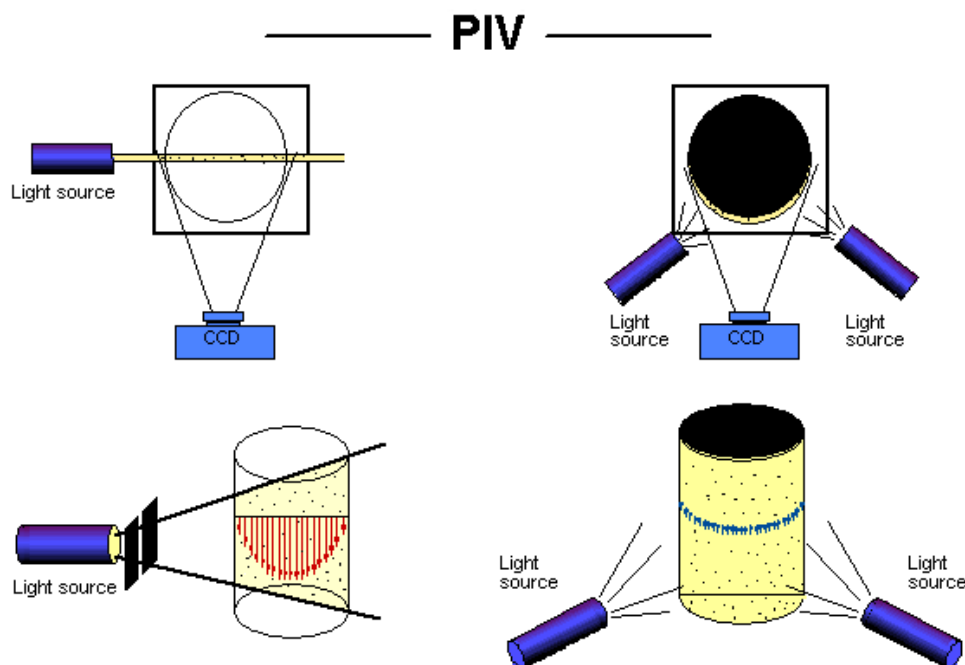


Fig. 1. Comparison between standard flow visualization and the new method in a laminar pipe flow. Flow is perpendicular to the plane of this figure.

RESULTS

To evaluate the method, we performed measurements in a sudden expansion flow to detect the reattachment region. Similar results as in other investigations are found. Then, the method has been used to investigate the flow in a model of a blood vessel, the carotid bifurcation. An example of the flow measurement close to the wall with a comparison with a standard visualization method is shown in fig. 2.

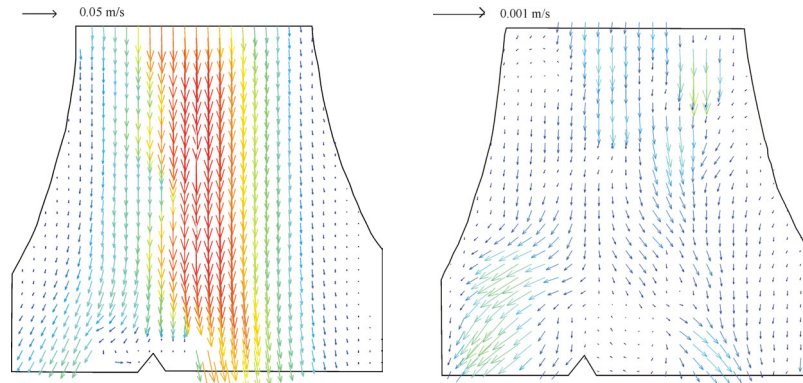


Fig. 2: Velocity fields in the central plane (left) and close to the wall (right) of a carotid bifurcation ($Re=200$)

CONCLUSIONS

The results of the flow experiments show the viability of the method. The direction of the flow at the wall can be assessed very well, as well as the detection of the stagnation lines and flow separation zones. Since such zones are linked to lesions of the wall, this new method can serve as a tool to investigate the flow related causes for alterations of the wall.

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