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A NOVEL SCANNING METHOD TO MEASURE SHEAR RATE AROUND A THROMBUS USING MICRO PARTICLE IMAGE VELOCIMETRY

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The ability of platelets to adhere and aggregate to form a stable thrombus plays a key role in the normal haemostatic process at sites of vascular injury. However, thrombus formation plays a sinister role in arterial diseases leading to heart attacks or strokes.

Platelet activation depends on both chemical stimuli and hemodynamic forces. Irregular arterial geometries such as bifurcations, curved or stenotic vessels affect the hemodynamic forces experienced by platelets and may lead to thrombus formation.

Platelet signaling responses and shape changes induced by chemical stimuli have been extensively studied over the last decade [1,2].

Moreover, a link between platelet behavior and levels of mean shear stress has also been established [3].

Thrombus formation affects the vessel wall geometries and causes surface irregularities and changes in local shear stress. Thus the local shear may be completely different from theoretical mean values.

To the authors knowledge mapping of the thrombus growth with respect to the local shear rate has not yet been addressed in the literature.

This study measures the local shear rate around a fixed thrombus using a novel scanning micro particle image velocimetry (μPIV) technique. This allows investigation of the relationship between the local shear rate and platelet adhesion in thrombi formation.

The two-dimensional velocity gradient (xy shear) around a fixed thrombus in a rectangular glass microslide (cross-section 2mm × 0.2mm) was measured using μPIV in different z planes from the top wall (z=0.0) to z=4.0 μm. The x, y and z coordinate are along the length, width and height of the microslide (figure 1). The wall shear rate is calculated using multiple planes of velocity data and the continuity equation. This allows the local wall shear to be directly related to sites of platelets activation and thrombus growth.

The thrombus was fixed prior to the μPIV experiments using the following technique. First the microslide was coated with immobilised collagen and then washed out immediately with Tyrode’s buffer. Then whole blood from a healthy donor was perfused through the coated-microslide generating thrombi on the microslide surface. The thrombi were fixed with parafomaldehyde.

The working fluid was physiological saline seeded with 1.0-µm -diameter red fluorescent microspheres, 10% washed red blood cells and 2% Bovine serum alumin (BSA). The fluorescent particles were illuminated by a green continuous laser. PIV images were processed using in-house PIV software [4] to extract the xy velocity field by cross-correlation multi-window algorithm. Finally the in-plane shear, γ_{xy}, and the wall shear, γ_z, were calculated.

Figure 2 illustrates γ_{xy} and wall shear rate contours around the fixed thrombus. These results show the value of wall shear rate is significantly higher than γ_{xy} shear. This indicates the importance of measuring wall shear using the scanning technique as opposed to simply measuring γ_{xy}.

Figure 3 illustrates a three-dimensional wall shear rate in half section of field of view. Figures 2b and 3, show that the wall shear rate is low in the vicinity of the thrombus. The rear section of the thrombus where platelets adhesion is anticipated to be highest corresponds to the region of lowest overall shear stress.

REFERENCES

1. Ruggeri, Z. M., 2002, "Platelets in Atherosclerosis," Nat. Med., Vol. 8, pp. 1227-1234.
2. Gibbins, J. M., 2004, "Platelet adhesion Signaling and the Regulation of Thrombus Formation," J. Cell Sci., Vol 117, pp. 3415-3425.
3. Maxwell, M. J., Dopheide, S. M., Turner, S. J., ans Jackson, S. P., 2006, "Shear Induces a Unique Series of Morphological Changes in Translocating Platelets – Effects of Morphology on Translocation Dynamics," Arterioscler. Thromb. Vasc. Biol., Vol. 26, pp. 663-669.
4. Fouras, A., Lo Jacono, D., and Hourigan, K., 2007, "Target-free Stereo PIV: A Novel Technique with Inherent Error Estimation and Improved Accuracy," Experiments in Fluid, DOI: 10.1007/s00348-007-0404-1.

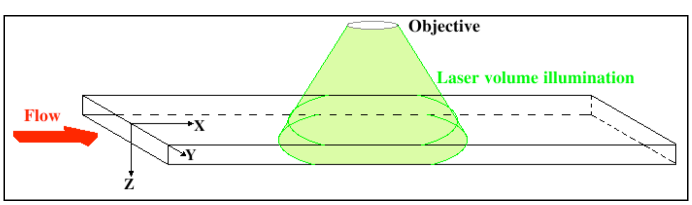
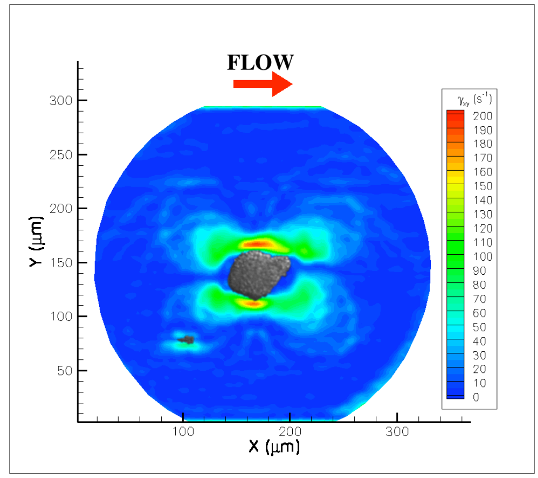
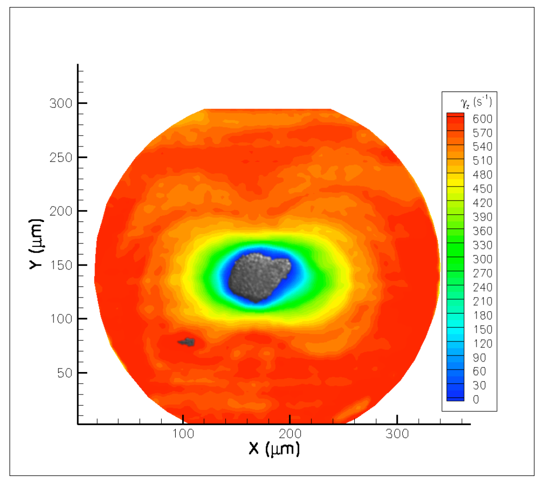


Figure 1. Schematic of microslide geometry



(a)



(b)

Figure 2. Contour plot of shear rates around a thrombus for a) xy shear and b) wall shear, γ_Z

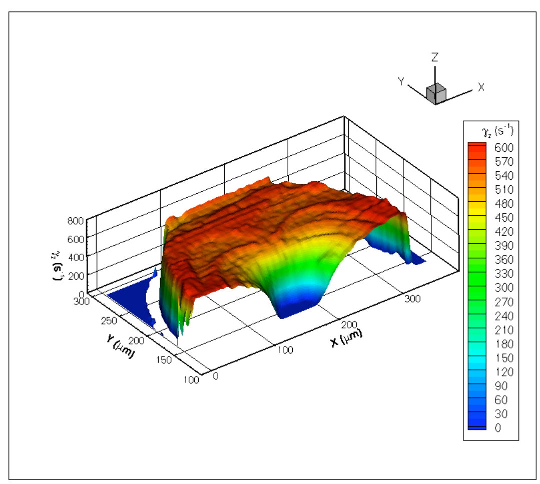


Figure 3. Three-dimensional wall shear rate