Year 1979 #14

Microvas. Res. 17: 572 1979

16.5
LEUCOCYTE AND ERYTHROCYTE VELOCITY IN ARTERIAL MICROVESSELS

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Introduction: Leucocyte adherence to vascular endothelium is an integral component of the inflammatory process and is a phenomenon often observed during microscopic visualization of the microvasculature. One of the phases of the adherence process is characterized by transient leucocyte sticking and subsequent rolling and/or sliding of the leucocyte along the vessel wall. Though limited data in the literature suggest that in venules the speed with which the leucocytes roll (V_{wbc}) is directly related to the red blood cell velocity (V_{rbc}) to date no systematic study of this relationship has been carried out in arterial microvessels. The objective of the present work was to characterize the leucocyte dynamics in arterioles and to determine the extent to which V_{wbc} is related to V_{rbc}.
Methods: Using the wing vasculature of the unanesthetized little brown bat as an experimental model V_{wbc} was determined in first order arterial branches (diameter range 32-65 microns) by timing their transit over an axial distance of 50 microns. Simultaneously, by continuous on line measurement of center line V_{rbc} using a modified dual-slit method, the time averaged V_{rbc} during the transit of each leucocyte could be determined. All measurements were performed in unbranched vessel segments for a duration of 60 minutes. In each of the seven experiments a small region of the upper layer of epithelium covering the vessel segment was denuded 40 minutes prior to the start of data aquisition.
Results: Three classes of leucocyte dynamics were observed within the 50 μm axial zone. I) most entered the zone rolling along the wall and rolled throughout the length of the zone (V_{wbc} range 2-100 μm/sec) II) Some entered rolling, but rolled for a distance of less than the full axial zone (V_{wbc} range 100 - 200 μm/sec) and III) some were observable passing through the axial zone in the vessel wall-blood interface region but showed no obvious rolling (V_{wbc} range >200μm/sec). Whether analyzed on the basis of individual experiments or summated over all data (1892 leucocytes) paired comparisons of V_{wbc} with the corresponding V_{rbc} (V_{rbc} range 0.5-5.2 mm/sec) showed correlations insignificantly different from zero when compared with and without class separation. However, when mean V_{wbc} and V_{rbc} were computed for each experiment a comparison made across experiments revealed a linear relationship ($r = 0.9$) between these two quantities.
Conclusions: Under the conditions of the present experiments the velocity of individual leucocytes was independent of simultaneously measured red blood cell velocities. Contrastingly the mean values of these quantities when compared across experiments showed a linear dependence. The explanation of these apparently contradictory findings may be that the effective wall-leucocyte interaction forces are larger in animals in which the time averaged V_{rbc} is lower. This would account for the $V_{wbc} - V_{rbc}$ interdependence demonstrated across the experiments. The lack of demonstrable relationship within experiments may be accounted for by a number of possibilities including 1) a wall-leucocyte interaction force which was either much larger than prevailing hemodynamic forces or was strongly time-dependent and 2) a non uniformity in the adherence properties of the circulating leucocytes.
Research supported by Grant HL 22738 from NHLBI

16.6
IN VITRO DEMONSTRATION OF COLLATERAL BLOOD VISCIDATION: FLOW MEASUREMENT IN A MODEL OF VASCULAR NETWORKS.

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In vivo, blood behaves as an extremely non-Newtonian fluid, apparent fluidity variable between extremely high values at high, and extremely low (or even zero) values at low shear (CASSON-body behavior).
The pronounced heterogeneity of microvascular perfusion in low flow states was explained as the biological consequence of these properties (1). The concept of "collateral blood viscidation" attributes localized flow retardation in close proximity to normally perfused vessels to an inhomogenous microvascular distribution of shear stresses. In capillaries and venules positioned in parallel to the main thoroughfare channels (2), a general drop in perfusion pressure was invoked to reduce shear stresses below a value necessary to maintain the fluidity of blood.
We tested this concept in vitro by producing capillary networks (I.D. 30 - 160 μm, $l_1/l_2 \triangleq 1/10$) as shown schematically, capillaries are produced in transparent epoxy with the help of untensilized nylon threads. Two of such threads are glued by formic acid and are fixed in the resin mass before polymerization and removed subsequently after tensilation to form a branching and confluent microtube configuration (see Fig.) The channels are observed in a tiltable microscope:thus sedimentation effects in and against flow direction and under 90° (with respect to flow direction) can be studied. The flow is measured by video-correlation technique and the driving pressure is varied resulting in wall shear stresses between 20 Pa and zero.
In normal blood, (Hct. 55%) the fall of wall shear stress below in the longer capillary leads to reversible stagnation in this, but not in the shorter tube: thus, a yield point of blood can be clearly demonstrated - while in a rotational macro rheometer, there is not indication of a yield point. After reduction of hematocrit and/or tendency to aggregation (and thus more Newtonian-flow behavior) there is no indication of a yield point nor of collateral viscidation.
1.) H. Schmid-Schönbein, Intern. Rev. Physiol. Cardiovasc. Physiol. II, 9, 1976, p. 1-62
2.) R. Chambers and B.W. Zweifach, Amer. J. Anat. 75, 1944

Figure

1 reservoir
2 pressure measurement
3 module
4 microscope