Meetings

Hemorrheology

The first meeting of the International Society of Hemorrheology, held at the University of Iceland, Reykjavik, 10–16 July 1966, brought together scientists from disciplines as diverse as clinical medicine and physiology on the one hand and the physical and engineering sciences on the other. The meeting covered topics in hemorrheological theory and techniques, model studies, in vivo and clinical hemorrheology as well as certain aspects of blood cellular elements, phase separation, plasma expanders, and cellular and fibrin clotting.

Hemorrheology may be said to have its origins in the work of the French physician and physiologist, Jean-Leonard-Marie Poiseuille (1797–1869) who endeavored to interpret his observations of blood flow in the microcirculation of small animals from the results of experiments on water in straight glass capillary tubes. This led to the discovery of the well known law governing the flow of a Newtonian fluid through a cylindrical tube. However, as has been shown by workers in the last 40 years, many disperse systems such as suspensions of rigid spheres and discs, clay pastes, and a variety of emulsions do not obey Poiseuille's law. The same is true of blood, as first reported by the Swedish pathologist Robin Fahraeus, now professor emeritus at the University of Uppsala. In addition to his work on the measurement of the apparent viscosity of blood in small glass tubes, Fahraeus demonstrated the existence of a phase separation between red cells and plasma and was the first to investigate systematically the formation of rouleaux (linear aggregates) of red cells and the effect of aggregation on the sedimentation rate. The Society, in recognition of Fahraeus' pioneer work, made him the first recipient of the Poiseuille medal.

J. Joly (France) discussed the relations between hemorrheology and basic rheology, pointing out that the complicated nature of blood demands the development of a theory very different from that used by classical rheologists. Moreover, such a rheology must consider the relative sizes of the cellular elements and vessels, their deformability, and how this varies in time and space. It is to be hoped, that by a suitable choice of models based on experimental facts, to arrive along different roads at a comprehensive theory. Although still a long way from this goal, the sessions on theoretical hemorrheology showed that in one case, that of pulsatile flow in large arteries and veins, the model approach was very advanced and had yielded good agreement with experiment. M. G. Taylor (Australia) discussed the influence of blood viscosity and elasticity of the arterial walls upon the transmission of pressure oscillations through the arterial systems. A simple model of a branching arterial system takes into account viscous losses, the branching and changing cross sectional area of the vessels, and the changing elasticity of their walls. Such a model shows that in major arteries the influence of the wall on viscous expenditure of energy was considerably greater than that of the blood itself.

A model which accounts for the observed distributions in cardiac output and pressure wave velocities at various points in the arterial and venous bed was proposed by E. O. Attinger (United States). The model uses the linearized equations of motion and divides the circulation into eight parallel beds each having four terminal networks. The calculated wave velocities and impedances in the model agreed well with the corresponding values measured in animal experiments.

Another theoretical problem is the effect of the condition of the wall surface on the flow of blood in tubes. S. Oka (Japan) calculated the decrease in blood viscosity which would be brought about by the existence of a hypothetical slip at the interface of the fibrin-coated vessel wall and plasma. Experimentally, however, the effect of adsorbed macromolecules on the walls of capillaries is also explicable by a decrease in tube diameter. Using polyvinylpyrrolidinone solutions, F. R. Erich (United States) showed that the adsorbed monolayer of polyelectrolyte has a thickness approximately one third of the undisturbed dimensions of the random free coil in solution.

Finally, R. L. Whitmore (England) proposed a simple two-phase model for flow in the capillaries where red cells follow each other down in single file, separately, or in groups; and R. S. Rivlin (United States) described the effects which can arise in the flow of non-Newtonian liquids.

H. L. Goldsmith and S. G. Mason (Canada) described a microrheological technique. The individual particle and suspending fluid motions are observed through the microscope and analyzed quantitatively. Such analyses are used to predict the macroscopic flow properties of dilute and concentrated suspensions. Among the results, illustrated by a cine film, were the rotations of rod-like, rigid and flexible chains of spheres and discs in shear flow and the behavior of rigid and deformable spheres in oscillatory flow through tubes. The technique has been adapted to the study of red blood cells and rouleaux in tubes; it was shown that the former rotate as rigid discs and the latter as the flexible chains of model particles. In accord with hydrodynamic theory, the cells and rouleaux, while rotating, spend more time aligned with the flow than across it.

Experiments conducted on a larger scale in which rigid spheres were followed in laminar flow along tubes over a wide range of Reynolds numbers were described by A. H. Sacks (United States). In addition to the migration of spheres away from the tube wall, previously observed by other workers, the author reported the interesting finding that at the highest flow rates nearly all the spheres moved with a constant velocity parallel to the tube axis.

The redistribution of erythrocytes in flow through tubes and the existence of a cell-depleted zone at the wall has been debated among physiologists and rheologists for some time. Among recent techniques used to study the distribution and orientation of corpuscles is one in which the vessels are quick-frozen in low-temperature liquids ($< -100°C$) and subsequently prepared for sectioning. Results obtained with this method were given by R. H. Phibbs

(United States) who tested rabbit femoral arteries (1 mm inside diameter) and C. A. Wiederhielm (United States) who tested frog mesenteric vessels (0.1 to 0.2 mm inside diameter). A preferred orientation of red cells parallel to the tube axis was found. The degree of orientation in the frog mesentery was more pronounced in the tube center, but in the rabbit artery it was more evident at the periphery and there was also a significant decrease in erythrocyte concentration within 50 microns of the wall. Wiederhielm's results also indicated that the higher light transmission through the vessel center, often observed as a relatively light streak, could be explained by specular transmission of the incident light beam through the erythrocytes which in the center are oriented perpendicular to the beam. In the peripheral laminae, however, the angle between the cells and light beam is on the average less than the critical angle leading to reflection and scattering of the light.

Several papers dealt with the effects of dextrans (plasma expanders) on the flow properties of blood, with particular reference to the aggregation of the red cells. R. E. Wells and H. J. Meiselman (United States) showed that over a range of molecular weights of 40,000 to 100,000 dextran did not protect against the aggregating effects of fibrinogen. In fact, increased aggregation was found even with the low-molecular-weight dextran and the therapeutic effect of this substance is probably due to hemodilution, that is, the influx of extracellular water into the intravascular compartment. The changes brought about in the animal by the addition of high-molecular-weight dextran were discussed by L. E. Gelin (Sweden), a pioneer in the clinical use of dextrans. The intravascular aggregation leads to stasis in the post-capillary flow, and the decreased venous return leads to a decreased cardiac output. Such changes, however, may be reversed by the addition of a low-molecular-weight dextran.

A number of novel techniques for measuring pressure-flow relations in circulating blood within animals were described. In one case, presented by W. G. Frasher (United States), a chronic exterior artificial shunt consisting of Teflon and Sialastic tubing was inserted between one carotid artery and the opposite jugular vein of a dog. Blood viscometry in outflow tubes, of various diameters, attached to the shunt was then carried out under various conditions. S. Charm and G. S. Kurland (United States) measured the flow and pressure gradient in the long artery of the rat's tail and found the measured energy loss along the vessel the same as, or somewhat less, than that predicted from experiments in glass tubes.

Quantitative in vivo observations may also be made in the microcirculation as demonstrated by H. Wayland (United States) who described the measurement of red cell velocities in the mesenteric capillary bed of the cat using a double-slit photometric device. Two distinctly different types of flow were observed: steady flow in which the flow velocity appeared to be linear with pressure difference, and an oscillatory flow with a period of from 6 to 10 seconds. The oscillatory character appeared to be related to activity of precapillary sphincters. The results are being correlated with blood flow in artificial tubes of the same diameter.

A number of authors spoke on the properties of the red cell membrane and the erythrocyte deformation. The viscoelastic properties of the membrane were described by J. A. Kochen (United States) who showed that, when adhering to a glass surface by a single point on its membrane, red cells could be pulled out to the shape of a tear drop by deforming stresses. The tail of the drop steadily lengthened into a filament while the rest of the cell became spherical. Eventually rupture occurred with the release of hemoglobin and the deposition of the remainder of the membrane from the tail on the glass surface. The spherical parts resembled intact red cell ghosts in size, appearance, and osmotic behavior, thus suggesting that reconstitution of the membrane had occurred after the release of hemoglobin. Such a demonstration of filament formation and elastic recovery in the membrane was similar to the viscoelastic properties and spinnability of polymer solutions and protoplasm, and suggested similarities in molecular organization.

To account for the shape of the red cell and apparent uniform mechanical properties of its membrane, A. C. Burton (Canada) proposed the existence of a force between opposite membranes of a single cell analogous to that which acts between membranes of two red cells that form rouleaux. For such forces to be transmitted across a distance of a few microns, the presence of long molecules that form chains between the membranes was necessary. Accordingly, an experiment was devised in which the force between the charged plates of a condenser was measured with a balance. The presence of long, nylon fibers (1 mm in length), which were oriented by the electric field and formed chains, increased the attractive force at a given plate charge.

The role of electrical charge in the suspension stability of red cells was discussed by G. V. F. Seaman (England). Using values of the measured electrophoretic mobility of dog cells, the application of the Derjaguin-Verwey-Overbeek theory for the electrostatic repulsive and long-range London–Van der Waals attractive forces between spherical particles showed that a force of about 10^{-7} dyne would be required to separate the cells. This was in reasonable agreement with the value calculated from the minimum shear rate required to give complete dispersion of the erythrocytes in suspensions without fibrinogen.

The special optical and microanalytical methods necessary to study the living cell and its organelle structures were described by J. J. Wolken. He used a microspectrophotometer to measure not only the spectrum of hemoglobin but the variation in its concentration from place to place within a single cell.

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It is proposed to hold the next conference of the Society in France in 1969. Details are available from G. Bugliarello, Carnegie Institute of Technology, Pittsburgh, Pennsylvania, or from M. Joly, Institut Pasteur, Paris, France.

The president of the Society is A. L. Copley (Veterans Administration Hospital, East Organe, New Jersey and the New York Medical College, New York City); the vice presidents are: H. Hartert (Pfalz und Medizinische Universitatsklinik, Heidelberg, Germany), S. G. Mason (McGill University, Montreal, Canada), and S. Oka (Tokyo Metropolitan University, Japan).

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