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Editorial

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Fluid Dynamics Aspects in the Vascular Biomedical Engineering

SS Yoo, Professor Emeritus ¶

School of Aerospace and Mechanical Engineering, Hankuk Aviation University

More than 150 years ago J. P. Poiseuille, a French physician, who was interested in the blood flow rate in the arteries, discovered experimentally that the flow rate in the circular tube was proportional to the fourth power of tube diameter. The finding was very unusual to scientists and engineers at that time. G. H. L. Hagen, a German engineer, solved the governing equations for the flow in the circular tube and obtained the exact form of the flow rate showing the same result as the Poiseuille finding.

Analytical approach to the flow phenomena had been established by the Navier-Stokes equations, which are considered as the starting point of modern fluid mechanics. Computational fluid dynamics has been developed to such a high level as to solve most of recent engineering problems based on the Navier-Stokes equations. Analogy to the piping system of the industries is found in the arterial system where blood plus its cells and nutrients flow in the vessel and in the pulmonary system where air plus aerosols flow in the airways. It is tempting to use the Navier-Stokes equations directly for the numerical solution of blood and air flows, but the model is most of the times based on the Newtonian fluids such as air and water. To have an insight into the physics of blood flows in the real blood vessels the fundamental nature of blood and blood vessels itself should be examined. Any deviation of blood property from Newtonian behavior and any variation of blood vessels from the circular tube shape with flexible compliance might result in erroneous outcome.

Blood with cells and nutrients may be classified as a homogeneous fluid in continuum sense when it flows in large arteries. Blood does not follow the Newtonian viscosity law but exhibits the non-Newtonian behavior. Red blood cells play dominant role in the rheological characteristics of blood that shows pseudoplastic behavior. Blood shows high viscosity in the low shear rate range, shear-rate-depending viscosity in the medium shear rate range , and low viscosity in the high shear rate range. A constitutive equation suitable to depict the rheological behavior of blood is required to describe the flow phenomena analytically. In the field of non-Newtonian fluid mechanics many models for pseudoplastic behavior like blood have been reported in the literature. Results of biochemical analysis for the hematocrits and rigidity of RBC may be useful for the rheological modeling of blood. Most of the experimental data for the blood viscosity available in the literature are in vitro data. Measurement techniques for in vivo blood viscosity should be developed as accurate as possible. Finding an analogous fluid to the real blood may facilitate the rheological study of blood. For the time being aqueous solutions of high molecular weight synthetic polymers are used as in vitro experimental fluids among engineers. Interdisciplinary works among hemo-rheologist, medical researchers, and engineering researchers are imperative.

A blood vessel may be treated as a simple circular

¶ Koyang-shi, Kyonggi-do, Korea, 412-791
E-mail : sangsyoo@naver.com

tube with rigid wall in first approximation. To have meaningful computational results for hemodynamics we have to understand the structural nature and physical properties of the blood vessels. Most of the computational works in the field of hemodynamics have been based on the rigid circular tube but in recent years research is moving toward the elastic tube. It is expected that viscoelastic properties of the wall will be more understood in the near future. It may take time to step forward to the flow phenomena in the real blood vessels. In classical mechanics, the viscoelastic theories have been developed mostly for those materials the property of which deviates from the elastic slightly. Arterial vessels behave similar to the collapsible rubber-like tubes, showing distortion of flow passage shapes subject to the intramural pressure difference. The computational analyses and in vitro experimental studies will have to employ these collapsible wall boundary conditions for better and realistic simulations. Wall boundary conditions that are depending on the vessel properties are very crucial for accuracy of the numerical analysis: rigid wall implies fixed boundary condition, elastic wall deforms instantaneously depending on the pressures applied, and viscoelastic wall responds with some time-lag to the applied pressures. Studies on the mechanical properties of the blood vessels and analytical bases for viscoelasticity will surely contribute to the hemodynamic research.

In the conservative mechanics, fluid dynamics is based on the conservative laws: conservation of mass, conservation of momentum, and conservation of energy. Industrial systems and natural environment we are living comfortably are the results of transfer process of momentum, heat and mass. Physiological process in human body can be explained by similar transfer mechanism. Blood flow in the arteries and veins is a process of momentum transfer. Heat is generated through oxidation of nutrients and transferred to a uniformity by circulating blood streams. Exchange of oxygen and carbon dioxide in the airway-lung system is the typical mass transfer process. The well established fluid dynamic principles will undoubtedly support the biomedical research for circulatory disorders. However, some hypotheses, approximation and artificial factors introduced due to complexity of the circulation system make it mandatory to validate computational results using in vivo and in vitro experimental results. Laser Doppler anemometry and particle imaging velocimetry are the recent in vitro measurement techniques.

Atherosclerosis is a form of arteriosclerosis characterized by variable degree of damages in the intima of arteries. Causes of the atherosclerotic plaques are not known yet. However, some risk factors such as hypertension, increased blood lipid levels, diabetes, and inability of endothelial cells to cope with excessively low shear stress have been suggested in the medical literature. Sites prone to atherosclerotic plaques are the neighborhood of arterial bifurcations where flow is disturbed in a complicated manner. It has been speculated that formation of the plaques is related to the biochemical reaction of endothelial cells to the blood flow stresses such as pressure and shear stress. A thorough investigation on the mechanism of cellular proliferation under the flow stresses is imperative in order to detect causes of atherosclerotic plaques. An angioplasty operation, either by a surgical procedure or by dilating the vessel using a balloon inside the lumen, is one of the most interesting topics to the biomedical engineering researchers. For a surgical procedure an autogenous graft or an artificial graft is used at the site of plaque in practice. Patency rate may be enhanced by proper geometric design of the end-to-side anastomosis and by proper matching of the end-to-end anastomosis. Geometrical studies for the anastomosis can be done by computer simulation in advance for design and evaluation of vascular intervention.

Since the flow field is strongly affected by the boundaries, slight variation of a portion of bounary might cause quite different results: realistic geometry of an artery in the site is crucial to have meaningful experimental and computational results. Researchers in the biomedical engineering field are required to access to the in situ medical environment for significant progress. Modern medical apparatus in angiography such as MRI CT and X-ray CT are products of cooperative work among physicists, medical and engineering researchers.

In spite of strenuous efforts by the two teams, some medical terminologies are foreign to the engineering research workers and engineering terminologies plus mathematical equations are unfamiliar to the medical side researchers. Cooperative works among medical doctors and engineering specialists will surely enhance production of meaningful results in the vascular biomedical engineering. Publication of the International Journal of Vascular Biomedical Engineering is an effort of the Biomedical Engineering Society for Circulatory Disorders to promote the cooperative research works from both sides. Interesting articles on vascular intervention of biomedical engineering are included in the present volume. Submission of original papers to this Journal is encouraged in such fields as respiration, flows in a series of bifurcated airways, heart and circulatory dynamics, blood flows in the arteries and veins, microcirculation, lymphatic flows, blood cells, hemorheology, experiments and computer simulations on blood flows, flow visualization and angiography.

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