5579 Tu, 14:45-15:00 (P22)

The influence of a convergent nozzle on the flow field of a mild stenosis located in a T-junction

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This work examines the influence of a stent, having the shape of a convergent nozzle, on the flow field of a mild stenosis (50%), located in the 90° branch of a T tube junction. The proposed shape of stent aims at reducing the stenosis recirculation zones, so that the probability of arterial occlusion is reduced. Previous work of the same group on a straight tube concluded that the nozzle helps in reducing the length of the stenosis recirculation zone by a small amount and also it increases the level of the wall shear stresses. In the present work, the nozzle inlet diameter is twice that of the tube branch, and the parent tube diameter is twice that of the branch tube. The flow field is examined both numerically and experimentally. The commercial code FLUENT is used for the flow prediction, considering the flow incompressible, isothermal and the fluid Newtonian. The experimental investigation is based on flow visualization of a Plexiglas tube junction, including a 50% stenosis in the 90° branch. Using a Laser sheet and flow tracers, the regions next to the tube inner walls are detected, examining the recirculation zones extent. Under both steady and unsteady inlet flow conditions, the nozzle is found to reduce the extent of the recirculation zones in all the examined cases.

7682 Tu, 15:00-15:15 (P22)

Computer-controlled physiological blood flow simulator

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The present project was set up in the response to a need for mimicking the pulsatile flow conditions in laboratory specially, the beating heart flow conditions in arteries and different organs. The ability to reproduce realistic arterial flow waveforms in vitro is essential in the study of vascular haemodynamics and also calibration of some clinical techniques in blood flow measurement. Different mechanisms were proposed for satisfying these flow conditions. Consideration weakness and advantages for each individual mechanisms, one suitable design was selected.

For this mechanism procedure of design, the parts and needed materials were studied. The main requirement was to provide the suitable precision of the mechanism to produce a predetermined periodic flow wave form. Following this design the parts were constructed and tested. The system is capable to produce a flow waveform with a maximum of flow rate 400 ml/s accurately. This system based on the maximum amount outflow and the driving system is considered a novel system.

5089 Tu, 16:00-16:15 (P24)

Experimental validation of a wave propagation model of blood flow in vessels with viscoelastic wall properties

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In cardiovascular surgery patient specific data such as local pressure, flow and wall shear stress are helpful for pre-operative decision-making. Computational methods such as the Finite Element Method may be used to obtain these local haemodynamical data. Because of the high computational cost involved with 3D Fluid Structure Interaction models of the total arterial tree, 1D wave-propagation models may be more suited to provide clinically relevant information. Crucial in these models is the choice of a constitutive law to describe the arterial wall behaviour. Most commonly used wall models are based on linear elastic material properties or polynomial approximations through experimental data. However, since the arterial wall with its complex morphology is known to behave viscoelastic, these approaches may not be sufficient.

In this work a differential equation describing the behaviour of a standard linear solid model (viscoelastic) is introduced into the 1D wave equations to couple the intraluminal pressure to the arterial wall distension. The resulting set of equations (mass conservation, momentum balance and constitutive law) is solved in the time domain using the spectral element method.

To evaluate this numerical model, wave propagation in several viscoelastic tubes was simulated and the resulting pressure, flow and wall distension are compared to experimental data from Giannopapa [1]. Both a straight vessel and a tapered tube are investigated and the influence of the viscoelastic wall model with respect to a linear elastic approach is illustrated. High resemblance between numerical and experimental data is obtained, showing that the numerical wave propagation model is well suited to describe wave propagation in vessels such as arteries where geometrical and fluid dynamical non-linearities as well as viscoelastic wall behaviour play an important role.

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6256 Tu, 16:15-16:30 (P24)

Numerical simulation of the asymmetric redirection of blood flow in the left ventricle

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The KAHMO (Karlsruhe Heart Model) has been developed as a framework for the patient specific numerical simulation of the intraventricular flow. The framework combines different methods from several disciplines.

Based on MRI records of the patients heart, a 4 dimensional geometry of the endocardium is created. The movement of the inner ventricular wall is imposed onto the numerical model as a moving wall boundary condition in a moving grid. The heart valves are modelled using a two dimensional planar pressure drop over the mean valve location, which is varied temporarily and spatially to create the physiological velocity profiles at the mitral and aortic orifice. At the boundaries of the three dimensional simulation model a time dependent pressure boundary from a one dimensional circulation model [1] is used. The model includes a generic atrium and aortic tract, since these features could not be extracted from the original data set. The method has been validated by comparison with results of in vitro experiments and in vivo MRI flux measurements [2].

By applying this method on a healthy subject it is for the first time possible to simulate the asymmetric redirection in the left atrium and ventricle as observed in MRI flux measurements by Kilner [3] and others with a numerical model using a specific human heart geometry.

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4377 Tu, 16:30-16:45 (P24)

Shear-thinning viscosity effects in bifurcating blood vessels

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We investigate the shear-thinning viscosity blood flow behaviour in three bifurcating vessels reconstructed from medical imaging, under different physiological conditions: a small angle planar bifurcation of a carotid artery, a larger angle planar bifurcation from the circle of Willis and a non-planar aortic bifurcation. The roles of Womersely and Reynolds numbers are discussed by specifying typical hemodynamic values. The shear-rate dependent Carreau-Yasuda model is used to capture the non-Newtonian behaviour of blood. The main objective of this study is to asses the influence of shear-thinning non-Newtonian effects in these reconstructed geometries.

Two numerical methods are used to validate the study: a lattice Boltzmann hemodynamic solver and a finite element package. We have observed significant deviations from the Newtonian behaviour in both the velocity field and the wall shear stress.

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7100 Tu, 16:45-17:00 (P24)

Numerical simulation of the blood flow in the curved blood vessel with and without stent

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Nowadays stent therapy is widely adopted to treat atherosclerotic vessel disease. But experimental researches have shown that the flow in the blood vessel with endovascular stent may have strong influences on the cruor and restenosis. Numerical simulations of curved vessel model and direct blood flow velocity measurement by Laser-Doppler-Anemometer are two approaches for the study of the blood flow patterns. In this paper, a three-dimension numerical simulation was done on the flow fields in the vessel before and after stenting to compare with the experimental results. In this simulation, blood was assumed to be incompressible coherent Newtonian fluid, the curved blood vessel was modeled to be U tube and the vessel wall was non-flexible. Boundary, initial and calculation conditions were same with experimental conditions. Inflow velocity was unsteady and outflow pressure was 101325 Pa. The simulation calculation data and experimental results are compared and showed good agreement. Because of the embedded endovascular stent, drag incremented and the flux reduced. The entrance and the elbow piece as well as the exit speed have the changes. From the study, the influence on the inlet is smaller than the influence on the blood vessel curving part after embedding the stent. Regarding the curved vessel, this kind of stent has the smaller influence on the flow. It has small influence on the flux, but it has the certain influence on the flow velocity in the stent edge. The simulation calculation can reflect the real flow situation. Numerical simulation with finite element method could be a better method in the study of the blood flow in the blood vessel and provided a new technique for the more complex flow situation in the future.

5312 Tu, 17:00-17:15 (P25)

Analysis of pulsatile blood flow in stented human coronary arteries

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Alteration of arterial wall shear stress (WSS) may cause endothelial damage which is believed to be a major cause of plaque and thrombus formation. Stent implantation affects WSS values which might lead to in-stent restenosis. It has been shown that WSS values change particularly between stent struts and in post-stent region. This study presents computational fluid dynamics models to analyze blood flow in stented human coronary arteries and investigate effects of a flow divider on hemodynamic parameters.

Methods: Computational fluid dynamics was used to investigate the pulsatile flow field in models of stented human coronary arteries with blood flow assumed as incompressible and Newtonian. Rigid boundary conditions were assumed for all models. Blood pulsatile velocity profiles and pulsatile shear stress values were computed, and time dependent flow disturbances were studied in stented arterial segment, pre-stent and post-stent regions.

Results: Results indicated that for the stent strut spacing equal to three times of strut height, the maximum WSS value between stent struts decreases to almost 20% of WSS value in pre-stent region and becomes 90% for the stent strut spacing equal to eight times of strut height. Results show that flow disturbances in the form of large flow reversal areas periodically appear during the course of the pulsatile cycle in post-stent region depending on the stent geometrical factors and hemodynamic parameters. By application of a flow divider, the maximum value of WSS in stented segment increases markedly and the size and location of flow recirculation areas alters in post-stent region. Results might be used for optimization of intravascular stent design.

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4462 Tu, 17:15-17:30 (P25)

A laser guiding and tweezers platform for cardiovascular endothelia assembly

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In spite of the prolonged human life, organs age with time. Cardiovascular disease such as atherosclerosis is one of the most serious chronic diseases in our society. In this research, a novel technique to assemble a section of micro vessel in vitro is demonstrated with the feasibility of application to an artificial arteriole. The use of a low-NA direct laser guidance associated with the high-NA laser tweezers to construct an assembly platform is proposed in this work. The system is composed of three modules: optical tweezers, laser guidance and the microfluidic channels. The endothelial cells in a syringe are pumped into main channel. The computation of fluid dynamics assists the design of the geometry of micro channels to allow sufficient nutrition entering the building site so as to keep the cell of good vitality but not disturb the process. The micro channels are fabricated by MEMS technology. The cells are then Laser-guided in line through the secondary channel. The optical tweezers trap cells at the end of the secondary channel and move them to the proper place to form a piece of blood capillary. The optical tweezers are manipulated by tilting the mirrors. The optical design is based on the thin-lens principle and optics simulation software. In the optical optimization, the working range of optical tweezers covers 80% of field view of the microscope objective. For a N.A. = 1.25 oil-immersion microscope objective, the working area lies in a range of diameter of 70–80 μm.

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14.11. Mechanobiology of Vascular Walls and Cells

7374 We, 08:15-08:30 (P28)

Multiscale analysis of shear-induced stresses at endothelial cell focal adhesions

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Endothelial cells (ECs) regulate vascular health by transducing hemodynamic shear stress (Tau) into intracellular biochemical signals responsible for the production of new proteins and small vasoactive molecules. In order to determine the role of focal adhesion (FA) proteins in EC mechanotransduction of Tau, finite element analysis (FEA) of extracellular fluid dynamics and intracellular stresses was performed on 3-D, cell-specific, multicomponent solid models developed from multimodal microscopy. Surface topography and cell shape were derived from 3-D deconvolution image reconstruction of calcein-, Hoestch, and DiI-stained ECs in confluent monolayers while FA location and size was obtained from quantitative analysis of total internal reflection fluorescence (TIRF) images of the same cells. FA-scale and single integrin stresses were computed from the cell-scale stress analysis using novel FEA coupling variables which enable linear spatial scaling of mesh parameters and computations. Analysis of the effects of single molecule stresses on the physics of integrin activation state, bonding kinetics, and protein conformation suggests that, although surface Tau is amplified at least 20 fold in FAs, integrin stress magnitudes appear below the threshold needed to affect single integrin-extracellular matrix (ECM) binding kinetics and of insufficient magnitude to appreciably affect protein conformations. Further analysis of single FA deformation using experimentally-determined basal membrane topography, supports a new model for integrin-facilitated mechanotransduction in which Tau initiates an unidentified signaling pathway which leads to integrin activation and, simultaneously, bends the membrane downstream of the FA to facilitate formation of new Integrin-ECM bonds resulting in downstream signaling pathways such as Rho and MAPK activation.

5510 We, 08:30-08:45 (P28)

Differentiation of two types of mechanosensors in endothelial cells

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Mechanosensitive (MS) ion channels are the only established mechanosensor with molecular entity in cells. However, turning to slowly going mechanotransduction, we can see another type of mechanosensor. Endothelial cells *in situ* exhibit a spindle like shape aligning their long axis along the vessel running, while they will lose this characteristic shape when cultured in dish. Notwithstanding, they can recover their original shape and alignment when subjected to uniaxial cyclic stretch that mimics circumferential cyclic stretch in the vessel. In other words, cells can detect the direction of applied forces and covert this information into their morphology. We found that Ca^{2+} influx *via* MS channels was indispensable for this phenomenon but the Ca^{2+} signal itself could not tell the direction of the force to the cell. As the stress fibers in the stretch axis were preferentially disrupted by cyclic stretch and then reorganized perpendicular to the stretch axis, we suspected that the stress fiber, particularly its major component actin fiber, might be a force direction sensor. To test this hypothesis in a direct way, we examined dynamics of single actin fibers in response to mechanical stretch. Surprisingly relaxing but not stretching an actin fiber caused its rapid depolymerization with an aid of cofilin, a soluble actin-depolymelrizing factor. In living cells disruption of stress fibers caused by actin fiber depolymerization activates several downstream signal molecules around the focal adhesion, which eventually led to a cell shape change. In this sense, the stress fiber (actin fiber) is eligible for a mechanosensor capable of detecting force-direction. In conclusion, stress fibers act as a slow force-vector sensor, while the MS channel a fast force-scalar sensor.