Hemodynamic Effects on Atherosclerosis-Prone Coronary Artery : Wall Shear Stress / Rate Distribution and Impedance Phase Angle in Coronary and Aortic Circulation.

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Background and purpose

Atherosclerosis and its clinical manifestations are major causes of morbidity and mortality. Although many systemic risk factors predispose to atherogenesis, atherosclerosis preferentially affected certain regions of the circulation. Intraluminal hemodynamics, such as flow velocity, pressure changes, and wall shear stress (WSS) have been suggested to be additional risk factors for the development of coronary atherosclerosis. There is presently little information about the spatial three-dimensional distribution of hemodynamics in the coronary microcirculation and rheologic characteristics. We visualized and quantified the geometrical patterns of WSS in the human artery models, and compared the rheologic properties of the coronary with the aortic circulation in order to delineate the influence of the phasic difference (phase angle) of the coronary and aortic circulation on the WSS by computed numerical simulation.

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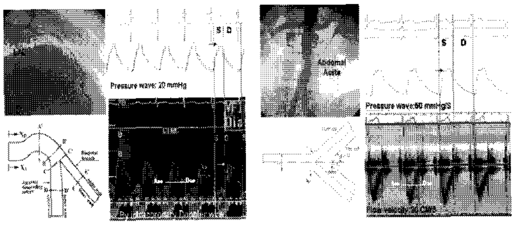
Method

Coronary artery and abdominal aorta model ;

To evaluate the hemodynamic variables in human coronary and aortic models, the basic models were deduced from their measurements of *in vivo* left coronary artery and abdominal aorta at iliac bifurcation level using angiography, pressure wire, and Doppler catheter.

Coronary model(a, left lower) and aortic model(b, left lower)



(a) Left coronary artery (b) Abdominal aorta

Based on the images of human left anterior descending(LAD)artery and abdominal aorta with pressure tracing and Doppler flow-velocity study.
(Acc: acceleation phase, Dec:deceleration phase)

Rheological properties of blood and Numerical analysis

To define the geometrical shear distribution in the vascular models, a non-Newtonian fluid model was adopted as being a constitutive equation. The following continuity equation and the Navier-Stokes equation was used as the governing equations, where ρ, u, p, η and i, j were the density, velocity vector, pressure, apparent viscosity, and tensor indexes, respectively.

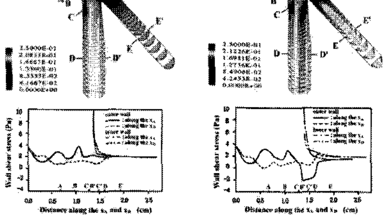
$$\frac{\partial u_j}{\partial x_j}=0,\quad \rho\left(\frac{\partial u_i}{\partial t}+u_j\frac{\partial u_i}{\partial x_j}\right)=-\frac{\partial p}{\partial x_i}+\eta\frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$

Arterial and Fluid model for calculating Wall Shear according to phase angle

The impedance phase angle may be expected to influence the local fluid mechanics near the pulsating wall. In order to delineate the influence of the phasic difference (phase angle) of the coronary and aortic circulation on the WSS, elastic straight artery models for the coronary artery as well as the aorta were simulated under typical flow conditions of the two arteries. The phase angle between the blood flow and wall motion at typical flow conditions for coronary arteries was calculated by phase difference between each first harmonic of the Fourier series by analyzing the wall motion. The axisymmetric artery was modeled using a 260×40 grid. Blood viscosity was modeled using a modified Powell-Erying non-Newtonian model. A numerical analysis was performed for five periods (0.0-4.5 sec) to eliminate transient effects and a 0.005 sec time increment was employed.

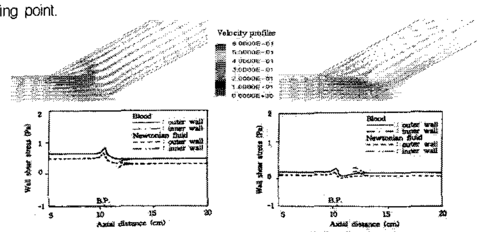
Results

Result 1. The velocity vectors (upper) and distribution of wall shear stress(lower) of the coronary model. Prominent abrupt changes of velocity and wall shear stress at outer wall around the branched site are noted in deceleration phase.



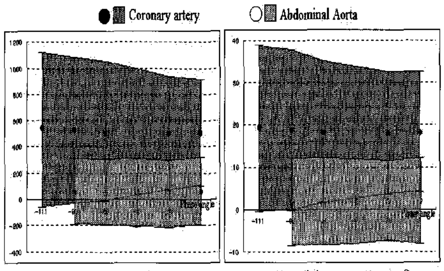
(a) acceleration phase (b) deceleration phase

Result 2. The velocity vectors (upper) and distribution of wall shear stress(lower) of the aortic model. Prominent changes of velocity and separation of wall shear stress at outer wall around the branched site are noted in deceleration phase. B.P ; branching point.



(a) acceleration phase (b) deceleration phase

Result 3. Influence of phase angle on the wall shear stresses for the coronary artery and abdominal aorta. The mean wall shear rate(WSR) and wall shear stress (WSS) of the coronary artery was more than 10 times higher than that of the abdominal aorta while the amplitude of WSR and WSS was double of the abdominal aorta.



(a) Wall shear rate(1/sec) (b) Wall shear stress(dyne/cm²)

Result 4. Hemodynamic variables under the condition of pulsatile/non-Neutonian fluid

	Abdominal Aorta	LAD
Diameter(cm)	1.5	0.3
Qmean(cm^3/sec)	15.55	1.413
Qamp(cm^3/sec)	2.0 Qmean	1.0 Qmean
T (sec)	0.75	0.75
Re(Reynolds number)	400	182
α(Womersley parameter)	12	2.39
Diff. Diameter/ diameter	±3%	±5%
U (viscosity, CP)	3.45	3.45
Density(g/cm^3)	1.045	1.045
Phase angle	**-45°**	**-111°**
mean WSS(dyne/ cm^2)	**1.806±10.72**	**19.42±20.53**
mean WSR(1/sec)	**49.86±281.4**	**542.8±587.3**

Conclusion

This study suggests that local rheologic properties may contribute to the atherogenesis in bifurcated and curved areas. The local rheologic properties were distinct, especially in the coronary artery under the physiologic situation. These insights may provide a basis for a rational design of promising new therapeutic strategies for managing cardiovascular diseases.