Simulation of the Effect of Tachycardia on Atherosclerotic Plaque Development Based on the LDL Transport in Coronary Arteries

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The formation of the atherosclerotic plaque is associated with the accumulation of lipids, monocytes and macromolecules into the arterial wall, which loses its elasticity and is gradually fattened. The process is influenced by the local hemodynamic environment. Furthermore, it is reported that tachycardia or high heart rate affects the physiology of the arterial wall enhancing the pro-atherosclerotic conditions. Especially, the endothelium is exposed to extended low shear stress of the systolic phase. In this work, the effect of high heart rate on the LDL transport and the development of atherosclerosis are examined using the finite element method. The simulation is performed on two case studies i.e. 3D reconstructed right coronary artery with and without atherosclerotic plaque. The velocity profile is pulsatile, while the tachycardia case is assumed to have 40% increased flow rate and 25% increased velocity than the normal case. The Navier-Stokes equations are used to model the blood flow and LDL transfer is modeled using convection-diffusion equation. The accumulation of the LDL is based on the Kedem-Katchalsky equations and is considered to be shear stress dependent. The results indicate the role of hemodynamics on the accumulation of LDL. Moreover, high heart rate enhances the influence of blood flow lengthening the exposure to low shear stress during systole. It is found that the area of low wall shear stress (0-2 Pa) which is critical for the formation of plaque is about 8% greater in the tachycardia case than the normal case. That means that the penetration of LDL on the arterial endothelium is increased at the systolic phase. In addition, comparing the two arterial models, the results depict that atherosclerotic plaque is formed not locally at the lowest values of shear stress, but at regions where low shear stress dominates. Lowering the heart rate, the pro-atherosclerotic environment is reduced.