NUMERICAL ANALYSIS OF ALTERNATE NEWTONIAN-CASSON BLOOD FLOW IN CORONARY ARTERY BYPASS GRAFT ANASTOMOSIS

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Summary Restenosis after coronary artery bypass surgery is simulated by considering blood as Newtonian or non-Newtonian fluid and neglecting the restrictions of blood viscosity model formula. It presented a new alternate Newtonian-Casson blood viscosity model taking into account the changes with shear rate. Results show that viscosity and wall shear stress of alternate Newtonian-Casson model are larger than those of Casson model at low blood flow velocity and have no difference with those of Newtonian model at high velocity.

INTRODUCTION

Coronary artery bypass graft (CABG) is internationally recognized as the most effective treatment of coronary heart disease[1]. Over the past 30 years, more than 1,000,000 bypass grafts have been carried out, with a 40% patency rate after 5 years[2]. Various studies have shown that the primary cause of failure leading to restenosis is the formation of intimal hyperplasia (IH) at the anastomosis[3], which is attributed to local abnormal hemodynamic or more specifically abnormal wall shear stress (WSS) distribution strongly depend on blood viscosity. Newtonian or non-Newtonian blood viscosity models have been carried out in simulating blood flow[4-5]. Whether Newtonian model or non-Newtonian model should be used in numerical simulation, which has not yet been determined. In fact, due to the experimental environment and apparatus, blood viscosity model is based on the shear rate controlled in a certain range, so it is not accurate to consider blood as a Newtonian fluid or completely non-Newtonian fluid. In view of this, it presented a new blood viscosity model of alternate Newtonian-Casson model based on the shear rate changes, which apply Casson model in the shear rate less than $100s^{-1}$ and Newtonian model in addition in this paper. In order to observe if there are differences between the blood viscosity models applied by previous researchers and the alternate Newtonian-Casson model is compared with Newtonian model and Casson model at high and low blood flow velocity respectively, but there are quite few investigations.

MATERIALS AND METHODS

The computed coronary artery bypass surgery tomography (CT) scan images done by helical CT scanner (LightSpeed Plus-U, GE Medical Systems) with multidetector-row capability shown in Fig.1 were provided by Department of Cardiac Surgery of Beijing FuWai Hospital. Fig.2 shows 3D generated geometry profile using threshold and manual segmentation combined in the three-dimensional reconstruction software MIMICS in order to define the region of interest and to extract the vascular surface from the 3D raster gray-scale image obtained at the previous stage. Owing to the needs of computation, in Fig.3 the simplified diameter of blood vessel is regarded as 2mm and that of coronary artery blockage is 1mm.

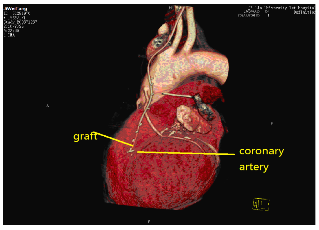

Fig.1. CT angiography of CABG

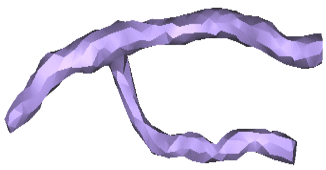
Fig.2. 3D reconstruction geometry of CABG

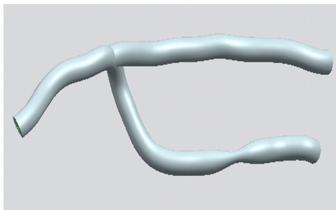
Fig.3. Simplified geometry of CABG

The assumptions are in the following: (a) the coronary artery and graft are impermeable rigid circular tubes; (b) blood is incompressible Newtonian fluid; (c) blood flows are laminar; (d) the gravity of blood is ignored.
The density of blood is $1050kgm^3$. Blood is considered as the Newtonian fluid in the shear rate more than $100s^{-1}$ and Casson fluid in addition, depicted in Tab.1.

Table 1 viscosities versus shear rate

$\dot{\gamma} > 100s^{-1}$	$\dot{\gamma} \le 100s^{-1}$
$\mu = 0.00345\text{Pa}\cdot\text{s}$	$\mu = \frac{\tau_y}{\dot{\gamma}} + \eta + 2\sqrt{\frac{\tau_y \eta}{\dot{\gamma}}}$

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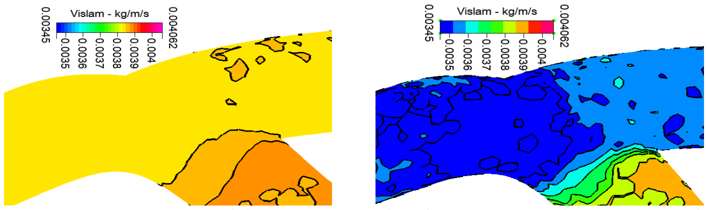
Boundary conditions for the computation are as follows (a) on all rigid vessel walls, all velocity components are constant zero according to the no-slip condition; (b) A steady flow of 0.03ms^{-1} and 0.01ms^{-1} are applied to the inlet of graft and host artery at the low blood flow velocity, while 0.25ms^{-1} and 0.15ms^{-1} are exerted at the high blood flow velocity; (c) The value of 0Pa is specified for the coronary artery outlet pressure.

RESULTS AND DISCUSSION

Influences of blood viscosity models on viscosity at low/high blood flow velocity

The region of the anastomosis is a dangerous area promoting the IH confirmed by clinical observation[6]. The development and progression of IH close to the hemodynamic conditions are highly influenced by molecular viscosity of the blood[7].The viscosity values of Casson model are obviously greater than that of the alternate Newtonian-Casson model at the anastomosis of coronary artery in Fig.4.



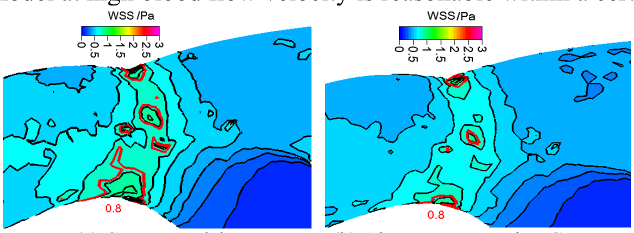
(a) Casson model (b) Alternate Newtonian-Casson model

Fig.4. viscosity contours at the anastomosis of CABG at low blood flow velocity

Influences of blood viscosity models on WSS at low/high blood flow velocity

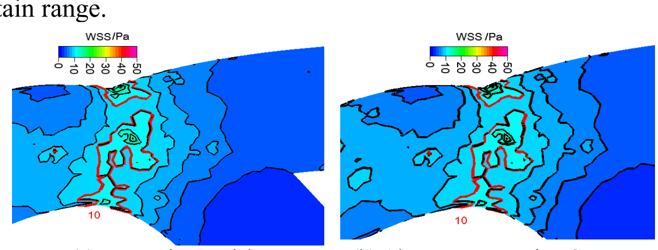
The formation of IH at the anastomosis is attributed to local abnormal hemodynamic more specifically abnormal WSS distribution, which is proportional to the blood viscosity model at the coronary artery wall. The WSS contours of 0.8Pa for Casson model and alternate Newtonian-Casson model presented to quantify the difference are shown in Fig.5. It can be seen that the WSS values of Casson model are evidently larger than those of alternate Newtonian-Casson model at low blood flow velocity. So results from being directly simplified non-Newtonian fluid are larger than those of the real situations at low blood flow velocity.

The WSS contours of Newtonian model and alternate Newtonian-Casson model are presented in Fig.6. The WSS distributions of two models are similar to the WSS value of 10Pa selected. That blood simplified as the Newtonian model at high blood flow velocity is reasonable within a certain range.



(a) Casson model (b) Alternate Newtonian-Casson model

Fig.5. WSS contours at the anastomosis of CABG at low blood flow velocity



(a) Newtonian model (b) Alternate Newtonian-Casson model

Fig.6. WSS contours at the anastomosis of CABG at high blood flow velocity

CONCLUSIONS

In fact, there is some limitation with the non-Newtonian blood models. The blood viscosity models based on the experimental data are applicable in a certain range, so blood should not be treated as a Newtonian or non-Newtonian fluid in general under all circumstances in numerical simulations. To simulate the hemodynamic of CABG exactly using a new blood viscosity model could compensate defects of application range for blood viscosity model. It is more reasonable to determine the choice of blood viscosity model based on the shear rate.

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