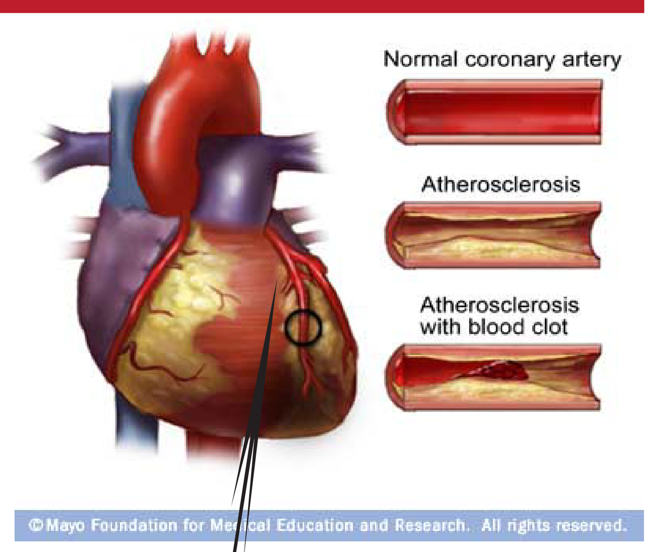
Flow Patterns in coronary artery bifurcation

Guifan Li 257273

Introduction

A artery disease, atherosclerosis, is caused by accumulation of fatty materials such as cholesterol often happen in artery bifurcations.
Some researchers believe that it is localized by Wall Shear Stress [1]. There are also other factors that can determine the location and cause the atherosclerosis.
Local rheological behavior is one of the reasons that localize this disease. Study on local hemodynamics

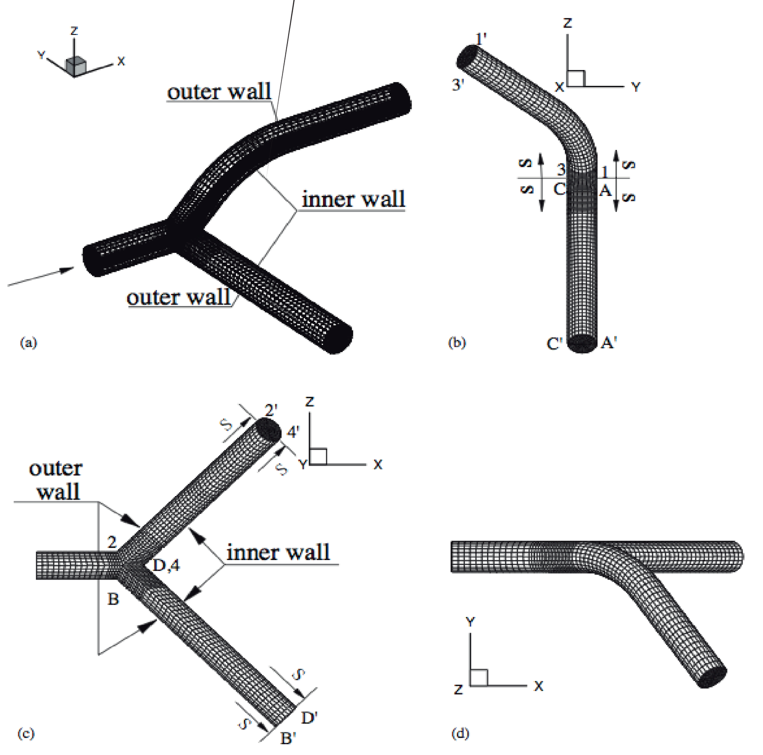


can help us to develop the method to locate the atherosclerosis [8]. According to [8], there are two factors that govern local hemodynamics: the propertied of the arterial wall , bifurcation and the rheological properties of the blood.

Objectives

The first task is to use Gmsh to generate a bifurcation of coronary artery with one straight daughter artery and one bent artery as the right figure.

This project is to employ the same geometry of bifurcation artery as used in [1] and by using the same boundary condition for the bifurcation of artery to simulate the blood flow and to plot the flow patterns which include:
1) Axial Velocity profile for Newtonian and non-Newtonian fluids.
2) Contour Plots for Newtonian and non-Newtonian fluids.
3) Secondary Flows for the non-Newtonian fluids.
4) Wall Shear Stress for the Newtonian fluids.
Furthermore, based on the above boudnary condition, we change the pure straight daughter artery to a stenosis of 0.75 and 0.5 area contration and plot the axial velocity profiles, secondary flow plots for the non-Newtonain fluids and Wall Shear Stress for the Newtonian fluids. Low WSS located the atherosclerosis.



This is from Fig 1 in [1]

Methods

OpenFOAM is a C++ library contains solver that can solve the 3-D Navier-Stock differential equation (1).

$$\rho\left(\frac{\partial u}{\partial t}+u\cdot\nabla u\right)=-\nabla p+\nabla\cdot T \quad (1)$$

where $T=2\eta(\dot\gamma)D$ and $D=\frac{1}{2}(\nabla u+\nabla u^T)$

η is constant for Newtonian

$$\frac{\eta-\eta_\infty}{\eta_0-\eta_\infty}=[1+(\lambda\dot\gamma)^a]^{\frac{(n-1)}{a}} \quad (2)$$

η change with $\dot\gamma$ in non-Newtonian flow

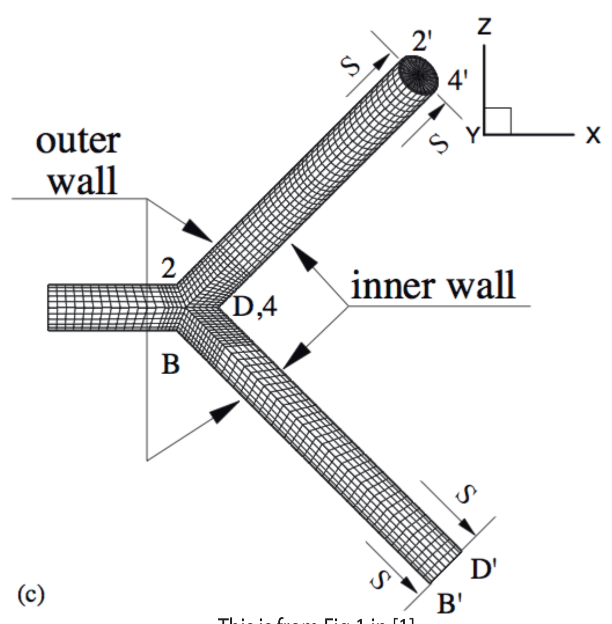
Geometry of the artery is:
mother artery: 3 S (S is normalized to the diameter D of mother artery).
Straight artery: 8 S from origin
Bent artery: 1.5 S then undergoes 45 degree bending before it further extend 4 S

Carreau Yasuda model (2) is employed to solve the non-Newtonain fluid and this model is used and equation (2) demonstrate relationship between shear shinning and shear rate .

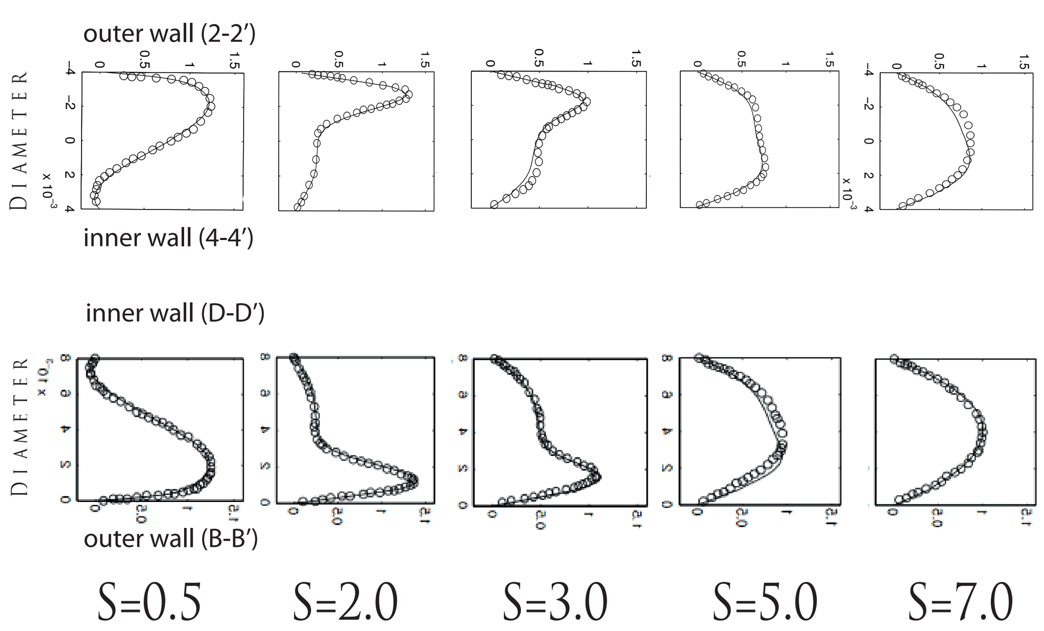
The reasons that we need to explore Newtonian and non-Newtonian fluids is because that Newtonian is for the Blood Flow in large arteries(above 5mm) and the non-Newtonian is for the Blood flow for the small arteries(5mm downto invisible).

Results

Velocity Profile for Newtonian Flow:



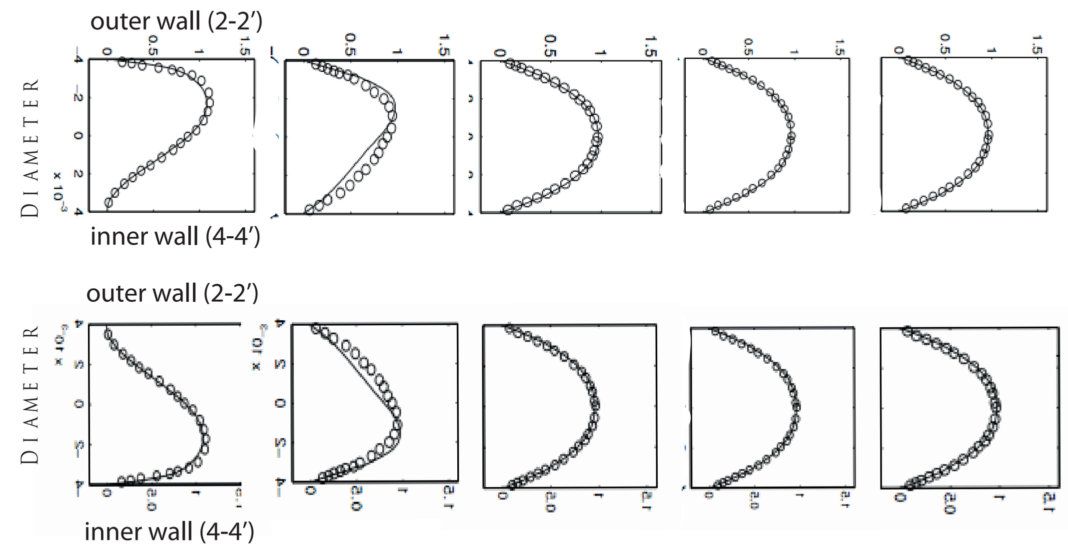
This is from Fig 1 in [1]



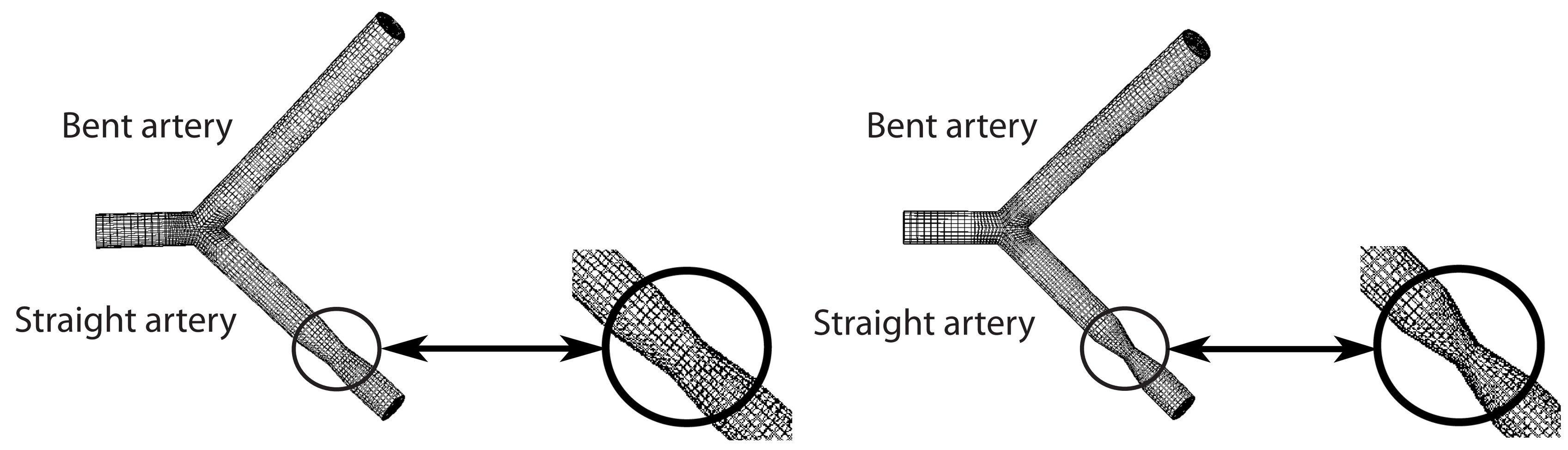
Flow separation on the outer wall is found from velocity profile at S=0.5, then the axial velocity profiles are shifted towards the inner wall for straight artery and bent artery, after S=5.0, the velocity profile approaches asymptotically to symmetric when the separation effect is negligible.
For the bent artery, the velocity profiles are firstly skew towards the outer wall and then shifted to the inner wall at around S=4.0 when the curvature effect is less dominant.

Velocity Profile for non-Newtonian Flow:

Comparing to Newtonian fluids, the non-Newtonian axial velocity profiles are flattened because of shear shinning effect.

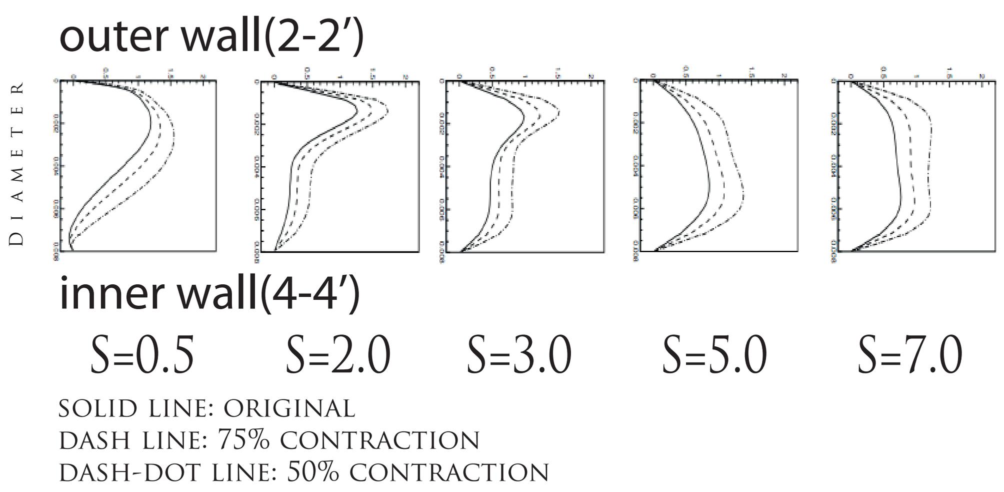


Development



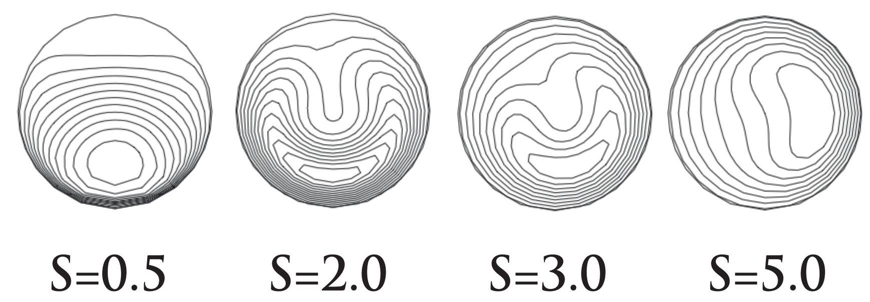
Velocity Profiles:

The effect of the artery stenosis on the velocity profiles make the magnitude of the velocity higher and the shape of axial velocity profile hard to recovery its original shape (parabolic fully developed flow as the velocity profile at inlet).



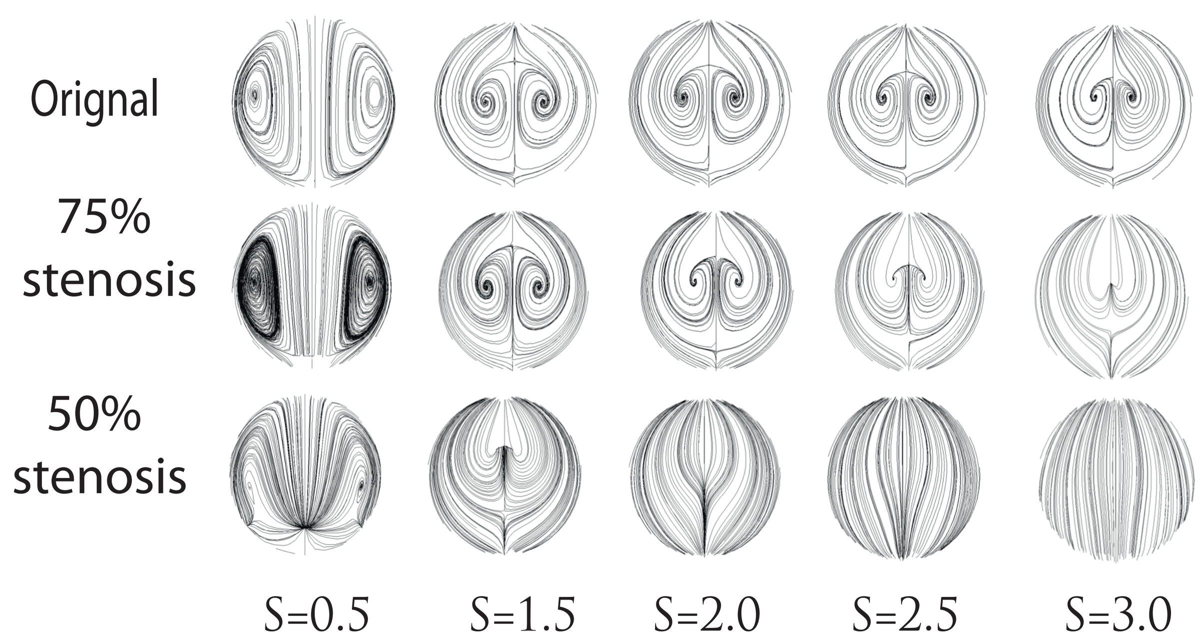
Contour Plots:

For the bent artery, the "C" shape rotates anti-clockwisely viewing from end of bent artery under the effect of curvature.



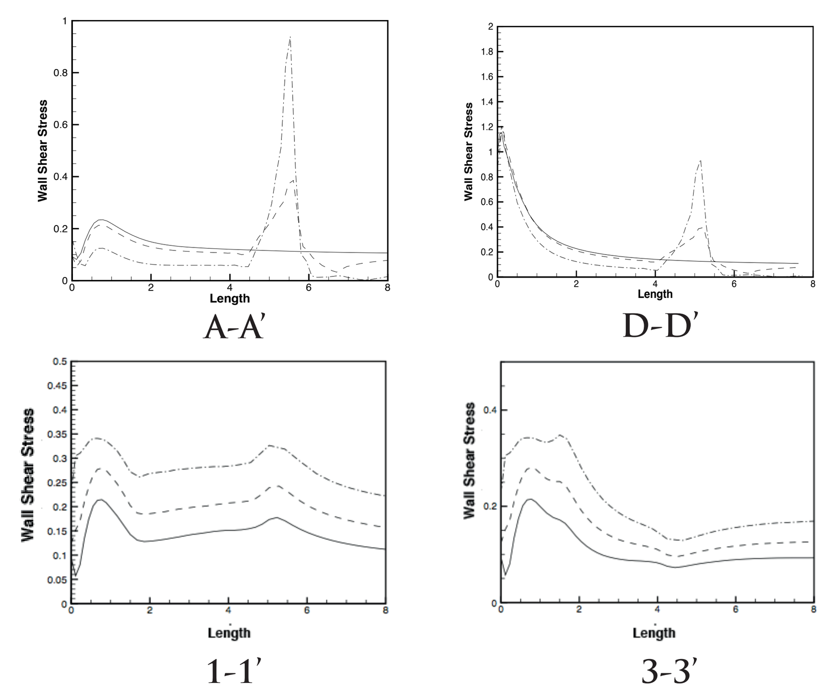
Secondary flow plots for non-Newtonain:

The counter rotation is diminishing as the blood flow through the straight artery. As the artery contract, the effect of rotation is less apparent as we can see that for 75% contraction, the counter rotation disappears at S=3.0. For 50% case, the counter rotation does not even form at the bifurcation.



Wall shear stress:

The wall shear stress is significant high near the stenosis, reaching its maximum at the smallest section. This is due to the axial velocity gradient is increase dramatically near the stenosis(the velocity at the wall is zero and velocity at artery center is high) as the diamter of artery decrease



Conclusion

In this study, the influence of the Newtonian and non-Newtonian properties of blood and non-planarity(bent) of the bent artery on Wall Shear Stress, velocity distribution and flow field in the straight and bent daughter artery is analyzed. In the curvature pipe of the bent daughter artery, the velocity profile is skew toward the outer wall, creating a relatively low Wall Shear Stress on the inner wall. The low Wall Shear Stress distribution are found at the inner walls of the curvature and the lateral walls of the bifurcation. The effect of stenosis on the Wall Shear Stress is studied as well. It is found that the low Wall Shear Stress region is the plain section lying between the bifurcation and stenosis. Stenosis can relatively lower Wall Shear Stress in straight artery while increase Wall Shear Stress in the bent artery. The counter rotation is weaken in the straight artery as the the stenosis is smaller.

Reference

[1] Chen, J and Lu, X.y. Numerical investigation of the non-Newtonian blood flow in a bifurcation model with a non-planar branch. Jounral of Biomechanics. Vol 37 (2004) 1899-1911

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