Computational Analysis to Study Peripheral Arterial Diseases

Ramunigari Naveen, Corral Raul, Roy Debarshi , Rodriguez Paul

***Abstract* - The computational analysis for biological functions has gained significant importance in development of molecular medicinal research. The presented work is trying to explain the Peripheral Arterial Diseases (PAD) with a mathematical approach using the study of fluid dynamics in deep arteries with the FLUENT software. PAD includes arterial thrombosis, atherosclerosis etc. PAD is slowly increasing in the United States of America due to increased fat consumption in the daily diet. Statistics have shown that PAD affects 8-12 million people in USA [1]. We proposed a geometrical model which resembles the arterial blood flow containing the unidirectional arterial valves and will be representing the flow circumstances which depict the flow in the arteries. We measured the flow patterns in the arteries and were able to find the areas of concentration; that helps in estimating if there is a chance for plaque formation in some specific areas. A better understanding of such complicated flow is very helpful in developing artificial valves effectively in vitro. The aid from the computational study helps in improving the prophylaxis given to the person suffering from PAD, by better understanding the physics involved in the clot formation. The model of the artery was designed and analyzed using commercial software's. The results of the pressure and velocity data help in understanding the cause of the disease and helps in diagnosing of the problem.**

Keywords-Computational Analysis, Claudication, Peripheral Arterial Disease, Artery, Fluid Dynamics.

I. INTRODUCTION

Peripheral Artery Diseases (PAD) is primarily caused by narrowing of the artery due to partial or complete blockage. PAD in the leg leads to the difficulty in walking.
People with high blood pressure, diabetes mellitus,

Manuscript received July 19, 2010.
Ramunigari Naveen, Graduate Student, Department of Civil Engineering. University of Texas El Paso, El Paso, TX 79902
(Corresponding author e-mail : r.naveengoud@gmail.com)
Roy Debarshi, Graduate Student, Department of Biological Science, University of Texas El Paso, El Paso, TX 79902.
Corral Raul & Rodriguez Paul, Undergraduate Student, Department of Mechanical Engineering, University of Texas El Paso, El Paso, TX 79902

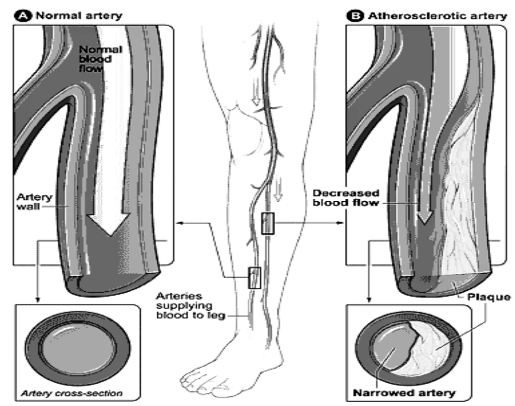

Figure 1 : Peripheral Artery

Hyperlipidemia, hyperhomocystinemia, hypercholestero laemia, advan-ced age, excessive cigarette smokers, are prone to develop peripheral arterial diseases [2]. Claudication is such a condition where there is a circulatory problem in the arteries in the different parts of the body [1]. Fat deposition is a predisposing factor for such conditions (Figure 1) [9]. The person develops a tendency to walk with pain and eventually it might lead to critical limb ischemia, where the tissues get very little oxygen supply [1]. In the case of claudication, a person develops painful skin ulceration on the toes or feet. It can create intermittent pain in the leg while walking and may lead to limping [3]. This is a very painful condition which might develop due to obstacle or inhibition of blood flow in the artery. The condition develops over the time and may become chronic.

Medical history of the patient and the physical examination are the first things to be done in any kind of pathological condition. Swelling in the leg, ankle or feet might suggest a blockage in the artery. Pain, numbness or muscular cramps in the leg might indicate PAD. Among the diagnostic proc-edures, ECG, Doppler ultrasonography, electro-physiological testing, MRI, PET, angiography of the peripheral arteries are a few of the techniques used commonly in any diagnostic labs [3].

Taking bed rest and restricting the movement of the affected limb has been suggested by most of the physicians. Raising the affected leg above the heart level when being

ISBN: 978-988-18210-0-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

seated or lying down enhances the venous blood, which in return would be beneficial to counteract the situation [2]. The commonly prescribed medicines for PAD are aspirin, nicotine replacement products, anti-diabetic drugs, Simvastatin, Vitamin –B complex, etc [2].

II. FLUID FLOW

Fluid flows are mostly laminar o(r turbulent. In laminar flow the fluid particles flow in lamina which varies in its flow velocity from zero velocity near to the wall to maximum velocity in the axial stream [4]. This pattern of flow of the velocities forms a parabolic shape when we try to get the flow profile. With such a type of flow there is a very minute chance of mixture possible across the lumen of the artery [5]. In experimental work the estimation of flow velocity from the injection of dye materials is dependent on the clear visualization of the parabolic profile such dyes assume in laminar flow [6]. The presence of laminar or turbulent flow may also alter the calibration of flow meters. The present study reports the results of observations of laminar flow and disturbances of laminar flow in a wide range of arteries. The estimates of the Reynolds' number have been made for each artery, so that it is possible to make some predictions of the nature of flow in species.

There might be a possibility of eddies formation when there is an obstacle in flow or if there is any change in the velocity. A collapsed flow behavior is exhibited in the artery s when a differential pressure is applied to the fluid flow.

III. GOVERNING EQUATIONS

Fluid mechanics uses some basic equations that must be satisfied if the assumptions are to be true. Fluid mechanics assumes that every fluid obeys these governing equations

1) Conservation of mass
2) Conservation of energy
3) Conservation of momentum

With continuum and incompressible fluid approximations, these principles help in partial differential equations (PDEs), popularly known as Navier-Stokes equations. The derivation of the Navier–Stokes equations begins with an application of conservation of momentum for a fluid flow. The general form of the equations of fluid motion is

$$\rho\left(\frac{\partial v}{\partial t}+v\cdot\nabla v\right)=-\rho+\nabla\cdot\mathbb{T}+f \qquad (1)$$

Where $\mathbf{V}$ is the flow velocity, ρ is the fluid density, *p* is the pressure, $\mathbb{T}$ is the stress, and $\mathbf{f}$ is the force acting on the fluid and ∇ is the del operator.

$$\nabla\cdot\mathbf{v}=\mathbf{0} \qquad (2)$$

the stress tensor is related to the pressure (p) and shear stress tensor (τ) by

$$\sigma(p,v)=-p\,\mathrm{I}+\tau \qquad (3)$$

With **I** as the identity matrix.
The shear stress (τ) for fluids is given by

$$\tau=\begin{cases}2\mu\dot{\varepsilon}, & Newtonian\ fluids\\ 2\mu(\dot{\varepsilon})\,\dot{\varepsilon} & Non\ Newtonian\ fluids\end{cases} \qquad (4)$$

Where strain rate tensor ($\dot{\varepsilon}$) of fluid is given by

$$\varepsilon^{\cdot}(u)=\mathbf{1/2}\ \left((\nabla v)+(\nabla v)^{\dagger}T\right) \qquad (5)$$

Various relationships for the viscosity approximation have been reported in other research articles for the non-Newtonian fluids. The most commonly used one is the Casson model [7]. This is suitable for simulating blood flow. In order to solve the equations, we use the Dirichlet conditions at the surface of arteries where velocities are prescribed by the deformation of the artery and Neumann condition at the inlet and outlet where stress free conditions are good approximations of boundary conditions (BCs) along with initial conditions [7].

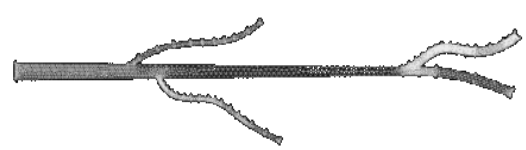

Figure 2: Geometry & Mesh of the Artery

IV. ANALYSIS PROCEDURE

The blood circulatory system in the human body is complex. It consists of arteries, veins, and capillaries making a circulatory network throughout the body. Any abnormality formed anywhere in this system will result in different pathophysiological events in human body. In our study we are concerned with the peripheral arterial diseases. Hence we tried to model a blood vesicular flow pattern

ISBN: 978-988-18210-0-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

using a computational approach. To get the dimensions of a human artery, one peripheral artery is longitudinally demonstrated (Figure 2) for analyzing the pressure gradients for its measurements.

A. Steps involved in modeling

Geometrical model of the artery.
Geometry meshing (Figure 2)
Specifying material properties
Applying boundary conditions
Solving for Fluid results (blood flow)

B. Properties of blood:

Element type chosen in Fluent: triad mesh
Density: 1025 kg/m^3
Reference temperature= 37 C
Minimum viscosity limit= .0027 N-s / m^2
Maximum viscosity limit=.0027
Pressure = 15998.6 – 10665.7 Pa
Inlet velocity = 13.87 mm/s

C. Modeling

The blood is desired to enter the model from the bottom boundary, so the inlet velocity of 13.87mm/s is used to create the blood inflow condition in the model. This is a no slip condition [8]. The incoming blood leaves the model from the top outlet. The problem to solve is to find out the relevant effects of pressure with respect to time of fluid flow at that particular region, and the velocity contours are plotted using the software.

D. Analysis

The analysis has been done using the FLUENT software. The results at various points have been measured, and helped us to find the formation of abnormal arterial pressure. When the blood is flowing through this portion of the artery, we have absorbed that the max values of the pressure is found to be 9.61 Pa, and it might be one of the causes for plaque formation. The other possible effects such as depleted blood pressure or even rupture in the artery walls are also possible. By using the computational approach, it will help us to measure the possible location of the problem, which could enrich the present diagnostic methodology of PAD.

V. RESULTS

The pressure contours (Figure 3) represent the blood flow pattern through the artery with due concentration at the point of maximum magnitude. The velocity contours (Figure 4, 5) over the velocity vectors show the magnitude (Figure 6) and directional location at each point in the flow.

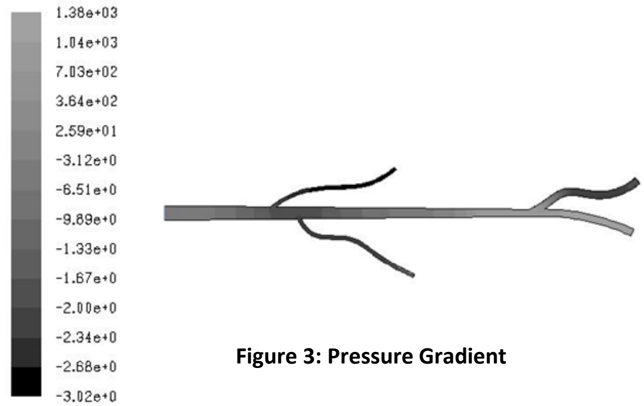

Figure 3: Pressure Gradient

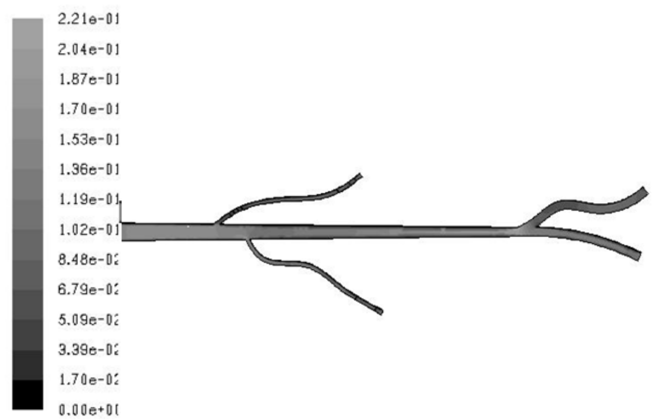

Figure 4: Velocity Gradient

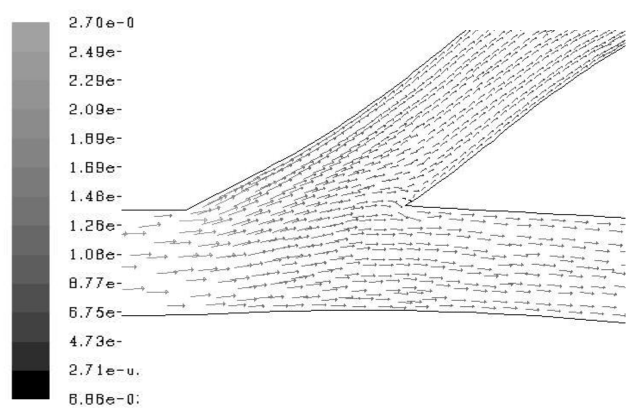

Figure 5: Velocity Vectors

ISBN: 978-988-18210-0-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

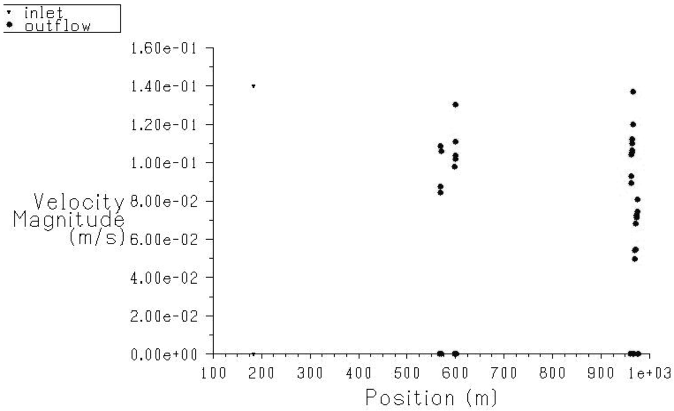

Figure 6: Velocity Magnitude

VI. CONCLUSIONS

We observe that, as the velocity is increasing it manages the flow to squeeze in between the boundaries. This is even evident from the velocity magnitude graphs. Due to the presence of any blockage in the blood vessels the pressure is being formed in the walls of the artery which resulted in an altered blood flow.

REFERENCES

[1]. Hirsch AT, Criqui MH, Treat-Jacobson D, Regensteiner JG, Creager MA, Olin JW, et al.(2001) Peripheral arterial disease detection, awareness, and treatment in primary care. JAMA ;286:1317–24.

[2]. Gey DC, Lesho EP, Manngold J (2004) Management of peripheral arterial disease, Am Fam Physician, 3: 525-532

[3]. Wilt TJ (1992). Current strategies in the diagnosis and management of lower extremity peripheral vascular disease. J Gen Intern Med. ;7:87–101

[4]. E.P.W.Helps, D.A.McDonald (1954, January) Observations On Laminar Flow In Veins. J. Physiol [online].I24, 63I-639. Available:www.ncbi.nlm.nih.gov/pmc/articles/PMC1366298/pdf/jphysiol01412-0224.pdf

[5]. EDWARD J. BALDES,, J. F. Herrick, HIRAM E. ESSEX, FRANK C. Mann, ROCHESTER, MINN. (1940, July) , The American Heart Journal, Pg 743 -755

[6]. J. Prothero and A. C. Burton (1961). The Physics Of Blood Flow In Capillaries. Biophysical Journal Vol-1 1961, 565-579.

[7]. C.-H. Hsu, H.H.Vu, Y.H.Kang (2009, December). The Rheology of Blood Flow In A Branched Arterial System With Three Dimensional Models: A Numerical Study. Journal of Mechanics, Vol. 25, No. 4 N21-N24.

[8]. Dulal Pal, N. Rudraiah, Rathna Devanathan (1988) . The effects of slip velocity at a membrane surface on blood flow in the microcirculation J. Math. Biol. (1988) 26:705-712.

[9]. www.nhlbi.nih.gov/health/dci/Diseases/pad/pad_what.htm