# COMPUTER SIMULATION OF BLOOD FLOW IN ARTERIES AFFECTED BY MULTIPLE ANEURYSM

H. GIRIJA BAI[1] and K.B. NAIDU[2]
Department of Mathematics, Sathyabama University,
Chennai-600 119, Tamil Nadu, India
[1] girijanameprakash@gmail.com and[2]kbnaidu999@gmail.com

**Abstract**

The aim of this study is a numerical simulation of hemodynamics in blood vessels with multiple fusiform aneurysms. Dilation of 0.25 is considered. Using computational fluid dynamics, hemodynamic factors such as velocity and pressure are investigated. The problem is solved by finite volume method. Numerical simulation is prescribed using the CFD softwares Fluent and Gambit. High pressure and low velocity is observed in the region of aneurysm. This is an indication to the interruption of blood flow. These techniques based on computer flow study are important for understanding the relationship between hemodynamic parameters and risk of rupture.

***Key words***: computational fluid dynamics; hemodynamics; multiple fusiform aneurysm.

## 1. Introduction

Blood flow over normal physiological situation is a vital field of study, as is blood flow under diseased circumstances. In developed countries majority of deaths are caused from cardiovascular diseases, most of which are connected with some form of irregular blood flow in arteries. Hemodynamics is the study of physical forces involved in blood circulation. It refers to physiological factors governing the flow of blood in circulatory system. Aneurysm is a balloon-like dilation found on the walls of a blood vessel or a sac formed by the localized dilatation of the wall of an artery or a vein, or the heart. Unprocessed aneurysm may rupture under insistent internal pressure, causing fatality or severe disability. Even an unruptured aneurysm can lead to damage by inter-rupting the flow of blood or by impinging on the wall of the vessel, in some cases eroding nearby blood vessel, organs, or bone. Aneurysms are seen most often in large arteries such as the iliac, femoral, popliteal, carotid or renal arteries. Hemodynamic parameters are considered to be responsible for initiating growth and rupture of aneurysms. In arterial walls, if increased blood flow occurs, it leads to enlargement of vessel diameter and reduction of shear forces. To understand aneurysm behavior, the flow dynamics have been studied in multitude experimental models. Multiple aneurysms can grow from the same location of an artery, and the interaction between these aneurysms raises the risk of rupture.

Patients with various aneurysm geometries have been accomplished by several authors in the last decade for,[7,8,9]. Blood flow has been numerically analyzed by Wille[3] in moderately dilated rigid blood vessels to trace stream lines of the flow. Similarly, the pathlines of the flow particles were analyzed by Perktold[1]. Single aneurysm has been analyzed for different dilations by Rathish Kumar & Naidu[2]. Arterial diseases due to hemodynamic factors are not fully understood [1],[2]. Knowledge of flow partition, pressure and shear stress, can give a better understanding of the relationship between the fluid dynamics in pulsatile blood flow and arterial diseases.

The aim of the present study is to find the flow pattern for the multiple aneurysms which has not been thoroughly investigated so far. Axisymmetric pulsatile flow of a viscous fluid in a dilated vessel is considered. Limitations on the amount of the dilation is ignored. Since arterial wall is gently elastic, we neglect the wall dispensability. Change in diameter in arteries is on the order of 10% [4]; so error in fixed diameter is minute.

## 2. Methods

### 2.1. *Formulation of the problem*

- The geometry of the dilated wall with single aneurysm is given by

$$y(x) = \begin{cases} a\left(l + \dfrac{\delta}{2a}\left(l + \cos\left(\dfrac{\pi x}{x_0}\right)\right)\right), & |x| \le x_0 \\ a, & |x| > x_0 \end{cases}$$

where $\delta = a - y(x_0)$ [2]

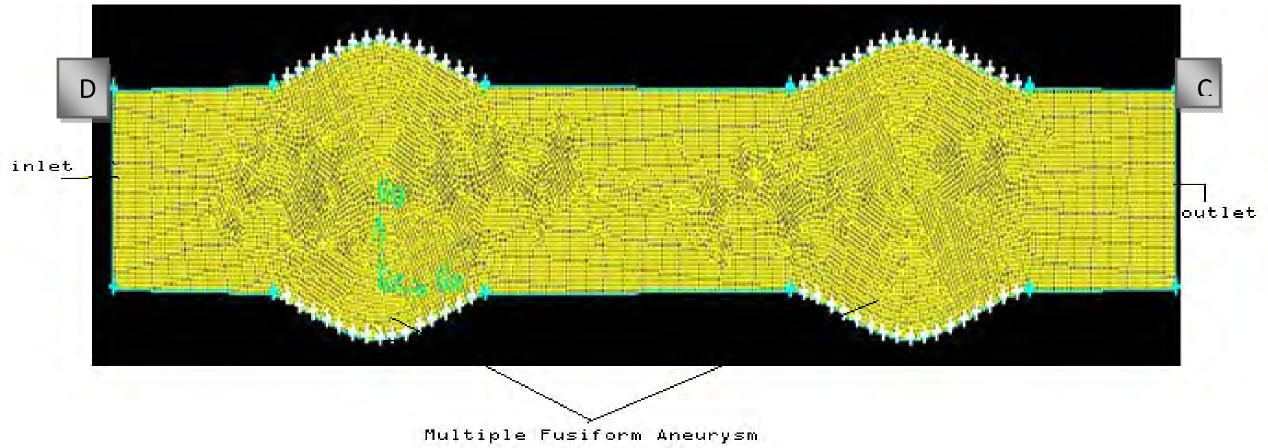



Fig.1. Geometry of dilated vessel with multiple fusiform aneurysm

**ABCD** - Rigid dilated vessel,
***l*** - the length of the vessel,
**δ** - the measure of the degree of dilation of the vessel,
**$2x_0$** - the axial length of the dilation,
**$y(x_0)$** - the minimum vertical height of the vessel
**a** - the maximum vertical height of the vessel [2]

**2.2.** ***Boundary Conditions***

**U = 0,** **V = 0,** on the dilated vessel CD
**U = 0,** **V = 0** on the dilated vessel AB
**U = 0.2, 0.7,** **V = 0** on the inflow segment AD
**$f_x = 0$,** **$f_y = 0$** on the outflow segment BC
$f_x$ and $f_y$ are the components of an arbitrary vector valued function f defined by

$\overline{f} = \overline{n} . \overline{\tau} = -p\,\overline{n} + \mu\,[\overline{n} . (\nabla\overline{u}) + \nabla .(\overline{n} . \overline{u})]$ [2]

**2.3.** ***Governing Differntial Equaions***

Equations of momentum and mass conservation for incompressible fluid can be written as:

$$\nabla . \overline{v} = 0$$

$$\rho\left(\frac{\partial\overline{v}}{\partial t} + \overline{v} . \nabla\overline{v}\right) = -\nabla p + \mu\nabla^2\overline{v}$$

where: **ρ** - density of blood, $\overline{v}$ -velocity field, **p** - pressure, **μ** = co-efficient of viscosity.

**2.4.** ***Methodology***

Computational fluid dynamics is used in many areas, such as engineering and medical

field. This new field provides very detailed information about fluid characteristics. Medical science lent this new technology to study hemodynamics within the body. In aneurysm, CFD helps us to understand their formation, growth, and rupture through study of aneurysm's properties such as geometry, blood flow characteristics; density, viscosity and velocity.

The purpose of our study is to show the possibility of development of computational analyses of velocity, pressure, and patterns of streamlines and pathlines.

Discretization is conducted in Gambit. Governing equations were solved in FLUENT which use finite volume method.

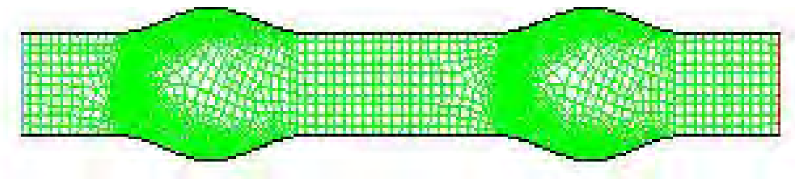


Fig. 2. Grid display for multiple fusiform aneurysm

14963 nodes, 652 mixed wall faces, 40 mixed outflow faces, 40 mixed velocity-inlet faces, 28826 mixed interior faces, 14596 quadrilateral cells

The file obtained in Gambit is imported in software program FLUENT v.6.3.26 (ANSYS. Inc.) and processed in 3 stages, namely preprocessing, processing and post processing.

We take density **ρ** = 1060 [kg/m$^3$] and dynamic viscosity **η** = 0.003 [kg / ms] (Poiseuille). Although blood has actually non- Newtonian behavior, in the simulation it is considered Newtonian because there were no significant differences in the distribution of (wall shear stress) [6].

By Bernoulli's Principle, the qualities of fluid are

- fluid flows smoothly
- fluid flows without any swirls (which are called "eddies")
- fluid flows everywhere through the pipe (which means there is no "flow separation")
- fluid has the same density everywhere (it is "incompressible")

Reynolds number and Womersley number are the only two physical parameters necessary to solve an incompressible fluid flow problem.

Womersley number (α) depends on: flow rate, model geometry and fluid viscosity and varies with vessel diameter.

Womersley number is: $\alpha = r\sqrt{\frac{2\pi\nu\rho}{\mu}}$

where: **r** [m] - entry of the vessel radius, **υ** - flow rate, **ρ** [kg/m$^3$] - blood density, $\mu$ [kg / ms] - blood viscosity.

The Womersley parameter $\alpha$ can be interpreted as the ratio of the unsteady forces to the viscous forces. When the Womersley parameter is low, viscous forces dominate, velocity profiles are parabolic in shape, and the centerline velocity oscillates in phase with the driving pressure gradient (Womersley1955, McDonald1974). For Womersley parameters above 10, the unsteady inertial forces dominate, and the flow is essentially one of piston-like motion with a flat velocity profile.[10]

The dimensionless Reynolds number (Re) gives the flow command. This number varies with the diameter of the vessel for each case. $Re = \frac{\rho v d}{\mu}$

where: **ρ** [kg/m$^3$] - blood density, $v$ [m/s] - maximum speed of blood flow at the entrance, **d** [m] - diameter at the entrance of the vessel, $\mu$ [Kg/ms]-blood viscosity. [5]

Depending on this number, blood flow values in the model can be:

- laminar when Re ≤ 2300,
- transient when 2300 <Re <10000,
- turbulent when Re> 10000.

If flow is laminar, wall shear stress is defined as the velocity gradient at the wall, through the relation: $\tau_{\omega} = \mu\frac{\partial v}{\partial n}$

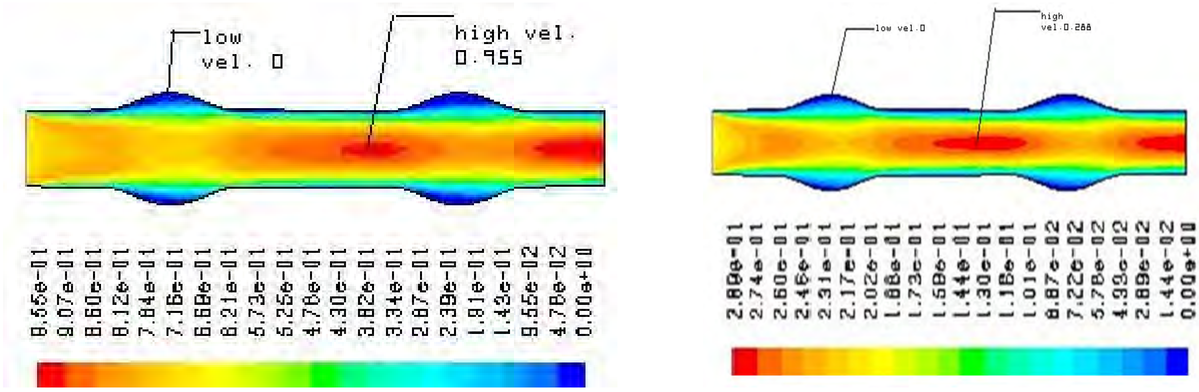
where $\tau_{\omega}$ [Pa] - tension tangential to the wall, **μ**[kg / ms] - blood viscosity, $v$ [m / s] - the speed of blood flow in the vessel, **n** - normal direction to the vessel wall. [5]

## 3. Results

Governing equations were solved in FLUENT which use finite volume method for discretization conducted in Gambit. Detailed study of velocity, pressure and streamlines are made. The velocity and pressure of the fluid vary, through an artery that narrows or widens. The artery is approximately circular, velocity distribution is considered parabolic in the artery entry, with a maximum into the center of the vessel and a minimum close to the vessel wall .

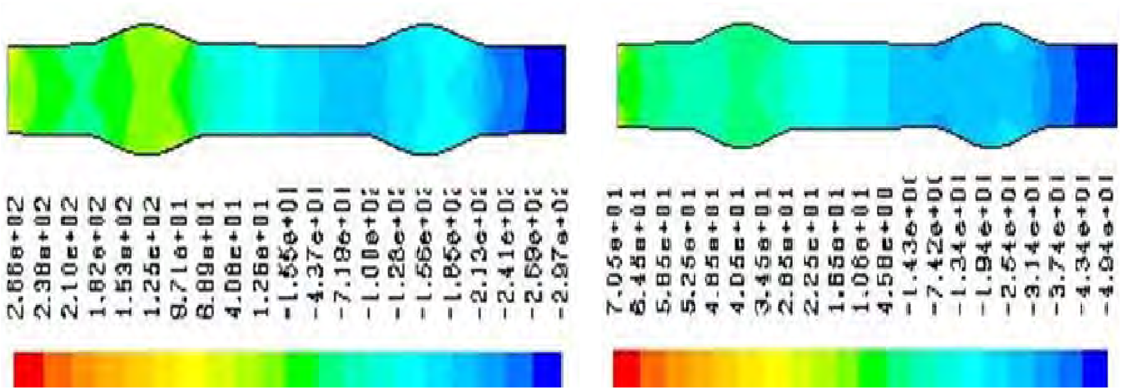
Each aneurysm has its unique hemodynamic profile, but many aneurysms have the same characteristics. The most common jet inflow had maximum collision in the aneurysm neck. After impact on the wall of the aneurysms, the inflow jet disintegrates into one or more "whirlpools", depending on the aneurysm geometry.

In this comparative study with different velocities, it is observed that the velocity is low near the boundary and high in the centre of the vessel for both cases which agrees with the reality. The pressure magnitude is high in the region of aneurysm, which is reverse to velocity profile.




(a) (b)

Fig.3. Velocity Magnitude for a multiple fusiform aneurysm –(a) inlet velocity 0.7 m/s (b) inlet velocity 0.2 m/s



(a) (b)

Fig.4. Static pressure for a multiple fusiform aneurysm (a) inlet velocity 0.7m/s (b) velocity 0.2m/s

Streamlines are a family of curves that are instantaneously tangent to the velocity vector of the flow. These show the direction of fluid element which travel at any point at any time. These stream lines are representative of the speed in a given time.

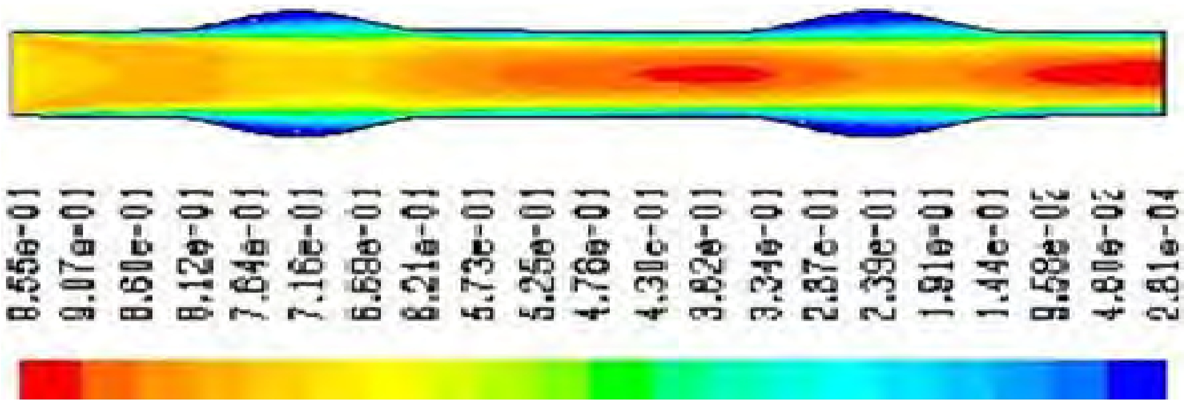
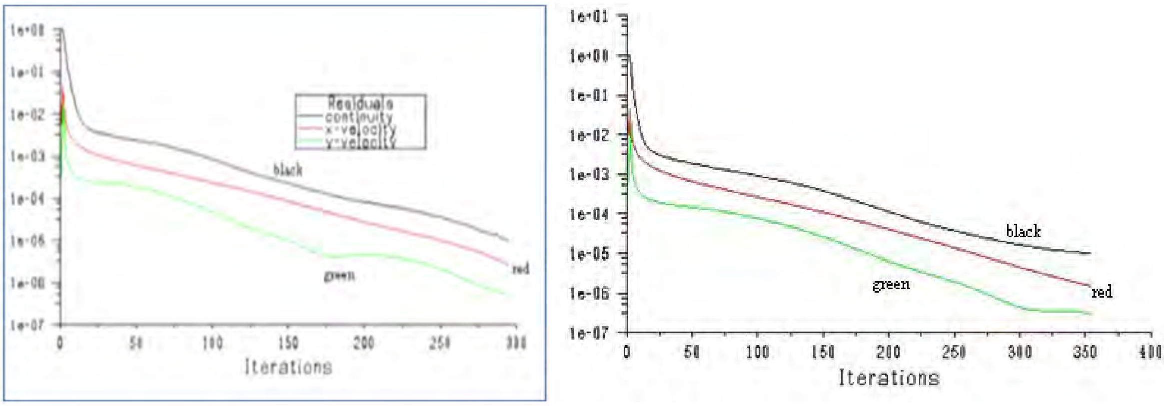


Fig.5.Streamlines- velocity vectors for multiple fusiform aneurysm- filled arrows

Pathlines are the trajectories that individual fluid particles follow

Fig.6. Pathlines of an multiple fusiform aneurysm Particles ID

Iterations were calculated and solution converges correct to 5 decimals with equation of continuity (black), and momemtum equation x - velocity ( red ), y – velocity ( green )




(a) (b)

Fig 7. Solution converges at (a) $295^{th}$ iteration for inlet velocity 0.7m/s (b) $354^{th}$ iteration for inlet velocity 0.2m/s.

## 4. Conclusion

Flow analysis shows that flow model is not similar for all aneurysms. Flow characteristics are highly dependent on the geometry of the vessels and aneurysms.

High pressure and low velocity is obtained in the region of aneurysm. These techniques based on computer flow study are important for understanding the relationship between hemodynamic parameters and risk of rupture, and will be very useful since it can be done by routine clinical environment.

## REFERENCES:

[1] Perktold .K. On the paths of fluid particles in an axisymmetrical aneurysm. J. Biomech. 20(3), 311- 317 (1987)

[2] B.V. Rathish kumar and K.B. Naidu. Hemodynamics in Aneurysm. Computers and Biomedical Research 29,119 – 139(1996)

[3] Wille.S.O. Finite element simulations of the pulsatile blood flow patterns in arterial abnormalities. In “Finite Elements In Biomechanics” (R.H. Gallagher et al. Eds.) pp. 39 – 60. 1982.

[4] Mcdonald,D.A. ”Blood Flow in Arteries” Camelot, Baldwin Park, CA, 1974.

[5] Computational hemodynamics in a patient - specific cerebral aneurysms models S. Gaivas[1],P. Cârlescu[2], Ion Poeată[3]

[6] Malek A.M. and Izumo S. Mechanism of endothelial cell shape change and cytoskeletal remodeling in response to fluid shear stress. Journal of Cell Science 109, 713-726 (1996)

[7] Cebral, J.R., Castro, M.A., Soto, O., Lohner, R., and Alperin, N., (2003), “Blood-flow models of the circle of Willis from magnetic resonance data”, J. Eng. Math., 47, 369-386

[8] Hassan T et al (2004) Computational replicas: anatomic reconstructions of cerebral vessels as volume numerical grids at three-dimensional angiography. AJNR Am J Neuroradiol 25(8):1356–1365.

[9] Hassan T et al (2005) A proposed parent vessel geometry-based categorization of saccular intracranial aneurysms: computational flow dynamics analysis of the risk factors for lesion rupture. J Neurosurg 103(4):662–680

[10] Bloof flow in arteries, David N. Ku , Annu.Rev. Fluid Mech.1997.29:399–434
Copyright c ! 1997 by Annual Reviews Inc. All rights reserved