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BLOOD FLOW VISUALISATION THROUGH CAROTID BIFURCATION USING ANSYS CFD

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***Abstract: In* the present study, three cases of Blood Flow through Carotid artery is carried out. The Carotid model is built in Catia software and imported to Ansys. Initially normal flow study is carried out for different Reynolds numbers, both Laminar and Turbulent regions are considered for study. Next reduction of area of Internal Carotid Artery (ICA) due to stenotic lesions is considered, the flow pattern is not proper and may create bodily problems due to improper supply of blood. Finally the reduction of cross section of Common Carotid Artery (CCA) is also considered. The results show improper flow towards External Carotid Artery(ECA), which results in problems in supply of blood to the brain region from this part. This study gives proper insight of blood supply in Carotid artery due to changes in cross section formed by lesions which may be created by fatty food or cholesterol deposition..**

***Keywords:* Carotid Artery, Reynolds numbers, CFD, Stenotic lesions and Brain.**

1. INTRODUCTION

Carotid artery is a key artery located in the front of the neck through which blood from the heart goes to the brain. The carotid arteries supply the large amount of blood to the front part of the brain, which is responsible for our personality and our ability to think, speak and move.

Arteries that supply blood to the heart (the coronary arteries), the carotid arteries can also develop atherosclerosis, the build-up of fat and cholesterol deposits called plaque inner side of the vessels. Over time, the plaque narrows the artery, decreases blood flow to the Brain and can lead to a stroke.

The symptoms of the decease are Blurred or loss of vision in one or both eyes, Weakness and/or numbness of your arm, leg or face on one side of your body, Slurring of speech, difficulty in talking or understanding what others are saying, Loss of coordination, dizziness or confusion.

The Treatment for carotid artery disease are Lifestyle Modification, Control of high blood pressure and diabetes, Quit smoking and using tobacco products, have regular check-ups with your doctor, Have your doctor checked your lipid profile and get treatment, if necessary to reach a Lipid goal of LDL less than 100 and HDL greater than 45; Eat foods low in saturated fats and cholesterol, achieve and maintain a desirable weight, Exercise regularly, Take Medications. All people with carotid disease should be on aspirin to decrease the risk of stroke due to blood clots.

In some cases, Coumadin (warfarin) may be prescribed. If so, blood sample will need to be checked regularly to ensure you are on the proper dose.

2 LITERATURE REVIEW

A fluid can be defined as a material that deforms continuously and permanently under the application of a shearing stress. The principal difference in the mechanical behavior of fluids compared to solids is that when a shear stress is applied to a fluid it experiences a continuing and permanent deformation. Fluids offer no permanent resistance to shearing, and they have elastic properties only under direct compression.

Human body systems have different fluids that have properties like viscosity, density, compressibility and surface tension. These fluids are called biofluids. Blood is an excellent fluid that nurtures life, contains many enzymes and hormones, and transports oxygen and carbon dioxide between the lungs and the cells of the tissue [1].

There are basically two types of flows, laminar and turbulent flow. These flows can be differentiated by the viscosity, the fluid inertia. The turbulent flow is very complex flow. This is a fluid motion in which velocity, pressure and other flow quantities fluctuate irregularly [2]. The Reynolds number characterizes weather the flow conditions lead to laminar or turbulent. The Reynolds number is the ratio of inertial to viscous forces and is given by the formula as follows,

$$Re = \rho VD/\mu$$

Where Re is the Reynolds number, ρ is the density in kg/m3, V is the peak instantaneous velocity of the blood (m/sec), D is the diameter of the blood vessel (mm) and μ is the viscosity of the blood in kg/mt-sec. A Reynolds number above about 2300 is turbulent.

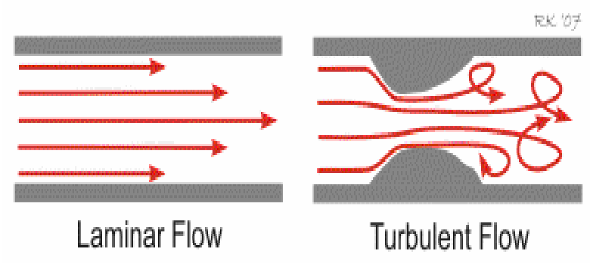

Figure 2(a): Laminar & Turbulent flows

The above figure shows the laminar and turbulent flow [3]. Turbulence generates sound waves (e.g., ejection murmurs, carotid bruits) that can be heard with a stethoscope. Because higher velocities develop turbulence, murmurs increase as flow increases. High cardiac outputs even across anatomically normal aortic valves can cause physiological murmurs because of turbulence.

3 METHODOLOGY

- The Carotid is built using Catia software.
- The model has been imported to Ansys for meshing.
- The geometry is split to ease map meshing.
- All necessary boundary conditions are applied.
- For different Reynold's numbers, velocity of flow is considered and applied.
- Ansys Map Mesher is used for meshing purpose. (Fluid141 element is used for meshing).
- Velocity loads are applied on the boundaries.
- Ansys Flotran solver is used for solving the problem.

Carotid Bifurcation of the Patient :

The blood flow field characteristics are studied in a stenosis depositions in the present investigation. The study of the blood flow characteristics is based on the different Reynold's numbers to the carotid bifurcations and instantaneous velocity vector fields.

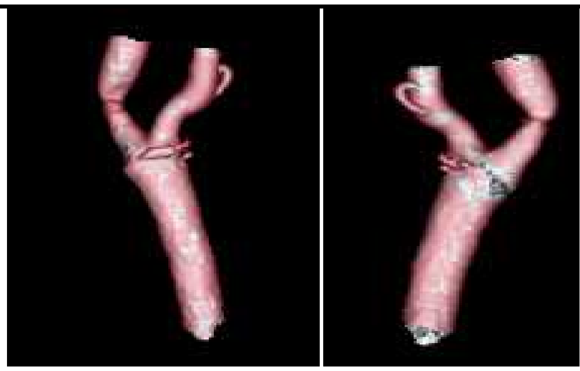

Figure 3(a): Actual Carotid Arteries

The model for carotid bifurcation has been modeled by making use of Catia V5R15 by making use of number of commands like extrude, revolve, blend, fill, multi section solids etc in surfacing and later after carefully joining each and every surface. It has been converted in to solid.

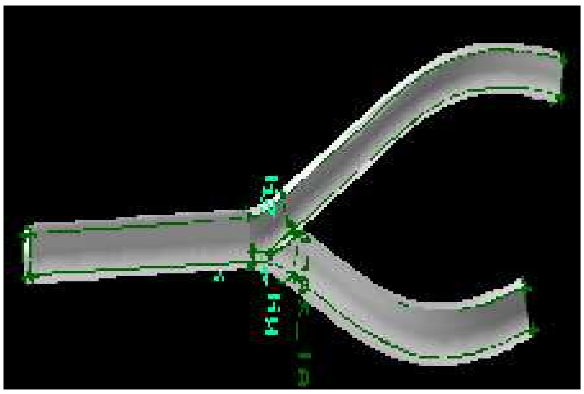

Figure 3(b): Geometric model of Carotid Artrey

ANSYS:

Then the obtained model has been converted into **IGES** format and exported to the **ANSYS.**
Ansys is general purpose finite element programme that can be applied to varied range of engineering problems varying from linear to non linear to transient.

COMPUTATIONAL FLUID DYNAMICS (CFD):

Computational Fluid Dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows.

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CFD Code Working Details:

- CFD codes are structured around the numerical algorithms that can tackle fluid flow problems.
- Hence all codes contain three main elements.
  - Pre – Processor
  - Solver
  - Post - Processor

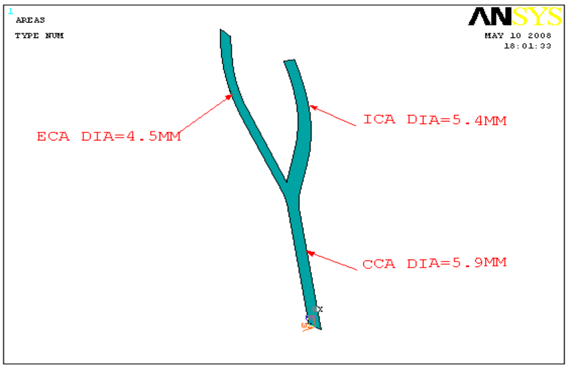

Figure 3(c): Carotid Bifurcation Dimensions

The below picture represents element plot of the Carotid. Member is meshed with Fluid141 element. This element contains 4 nodes and having all the degree of freedom necessary for Fluid analysis.

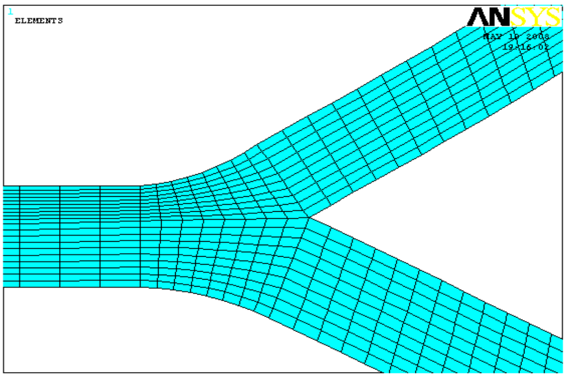

Figure 3(d): Meshed Plot

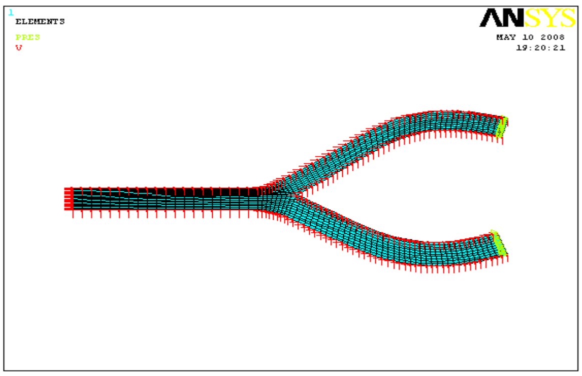

Figure 3(e): Boundary conditions plot

The above picture represents boundary conditions plot of the problem. Left side velocity values are given based on Reynold's number of study. On the outer boundary velocities are made to zero as by the hydrodynamic theory.

4 RESULTS AND DISCUSSIONS:

Flow Analysis using Ansys-Flotran CFD tool for three conditions.

1. Normal Flow conditions.
2. 70% condensed area of ICA.
3. Around 56% reduced area of CCA.

Here the study is carried out for velocities corresponding to different Reynold's numbers.

- Laminar : Re = 500, 1000 and 1500.
- Turbulent : Re = 2500, 3000 and 4000.

4.1 Normal Flow Conditions:

- **Studies of Reynold's Number equal to 500, 1000, 1500, 2500 and 3000.**

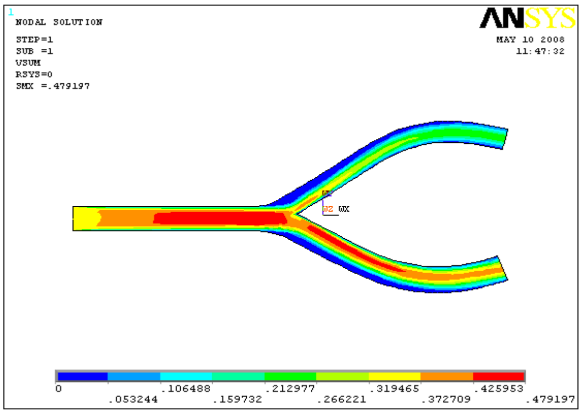

Figure 4.1(a): Velocity Flow of Blood Corresponding to Reynold's Number Equal to 500

Above Picture shows velocity of the blood particles for Reynold's number equal to 500. Maximum velocity is around 0.479197 m/sec velocity can be observed by the red color. Different colors represent flow velocity of the blood.

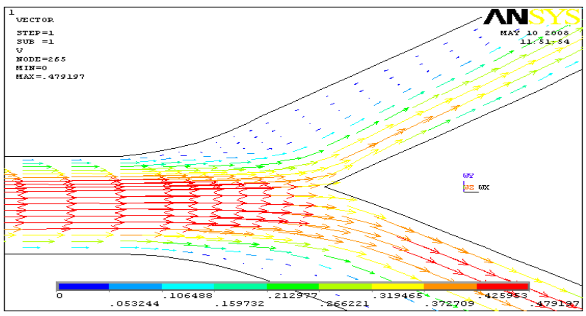

Figure 4.1(b): Vector Plot at Bifurcation Point, Re=500

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Flow can be observed by vector plot of the system which represents magnitude and direction of flow. Arrow size indicates the magnitude of velocity at that point. Smaller arrow size represents smaller flows. The flow division can be observed at the bifurcation point.

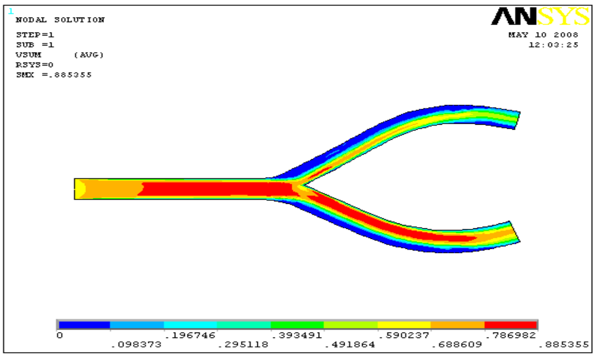

Figure 4.1(c): Velocity Flow of Blood Corresponding to Reynold's Number Equal to 1000

The above picture shows velocity flow across the Carotid. Maximum velocity is around 0.885355 m/sec. Maximum flow velocity is observed in the ICA and CCA parts. The color bar shows flow velocities at different regions.

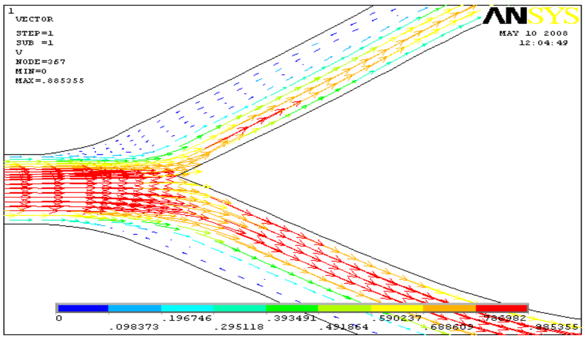

Figure 4.1(d): Velocity Vector Plot, Re=1000

The above picture shows velocity plot of blood through Carotid. Velocity is maximum in the center portion compared to the members near to the wall of Carotid.

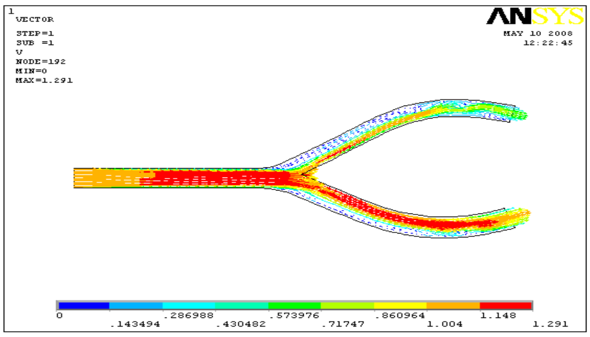

Figure 4.1(e): Velocity Flow of Blood Corresponding to Re= 1500

The above picture shows velocity plot. Maximum velocity is around 1.291 m/sec. Again maximum velocities can be observed in the CCA and ICA parts.

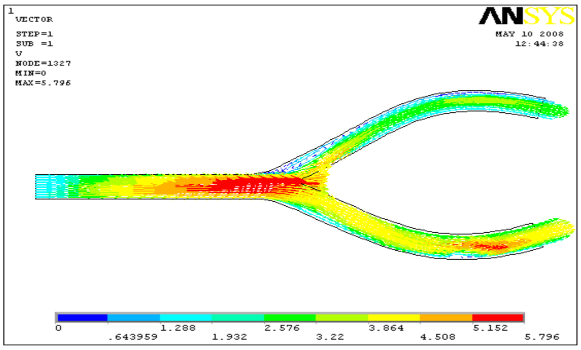

Figure 4.1(f): Velocity Flow of Blood Corresponding to Re= 2500

The above picture shows turbulent flow of fluid (blood) corresponding to Reynold's number equal to 2500. Maximum flow velocity is around 5.796 m/sec.

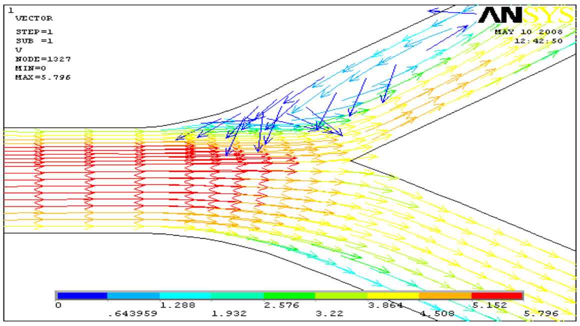

Figure 4.1(g) : Vector Plot of the Velocity Plot, Re=2500 (Turbulent Flow)

The above picture shows turbulent flow in the members. Maximum flow velocity is around 5.796 m/sec. Due to turbulence, back flow of blood can be observed in the Carotid in ECA. This backflow creates lot of stress on the Carotid walls. Clearly the turbulence in the flow is shown above.

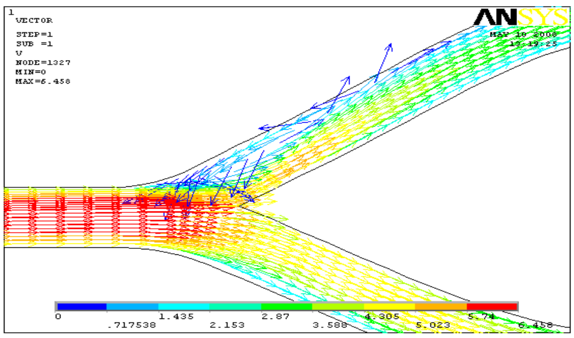

Figure 4.1(h): Vector Plot of the Velocity Plot, Re=3000 (Turbulant Flow)

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The above picture shows maximum flow velocity of 6.458 m/sec. More turbulence can be observed in the flow pattern.

The following table gives maximum outlet velocity for normal condition of CCA corresponding different Reynolds number.

Table 4.1: Reynolds number Vs Oulet Velocity

Reynolds Number	Max. Outlet Velocity
500	0.4791
1000	0.8853
1500	1.291
2500	5.796
3000	6.458

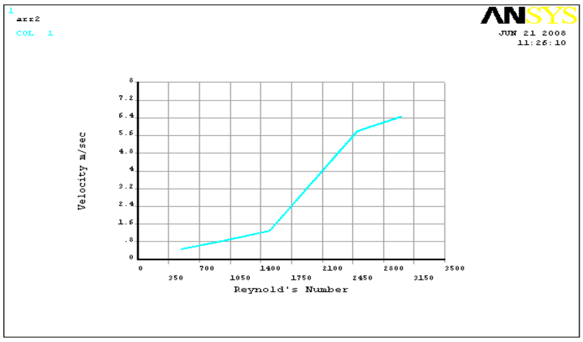

Figure 4.1(i): Reynolds Number Vs Maximum Velocity Output

The above graph shows velocity output variation with Reynolds numbers. Velocity increases with Reynold's number. Small difference can be observed
in the plot i.e. velocity is steeply increasing in the transition region between Laminar to Turbulent.

4.2 Blood flow during geometrical change in ICA:

The following figure 4.2(a) shows, geometry change in the Carotid. The geometry change is taking place in the ICA part.

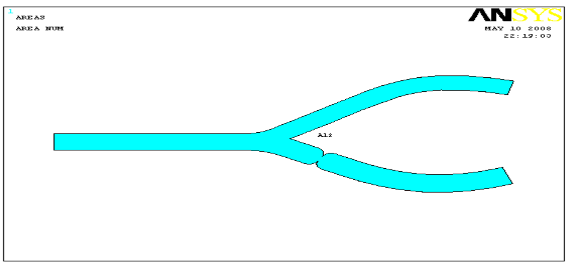

Figure 4.2(a): 70% Reduction of flow area in ICA

Figure 4.2(b): Reynold's Number Equal to 500

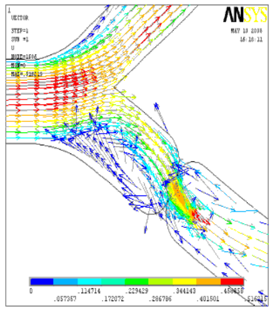

Figure 4.2(c): Vector Plot of the Velocity

Back flow is taking place due to this geometry change. This recirculation can be observed by arrows in blue color. The red color shows maximum flow path. The above picture is taken for Reynold's number equal to 500. Maximum velocity observed is 0.516214m/sec.

The following table gives maximum outlet velocity of geometry change in ICA corresponding different Reynolds number.

Table 4.2: Reynolds number Vs Velocity for ICA

Reynolds Number	Max. Outlet Velocity
500	0.5162
1000	0.9193
1500	1.363
2500	3.525
3000	4.181
3500	4.834

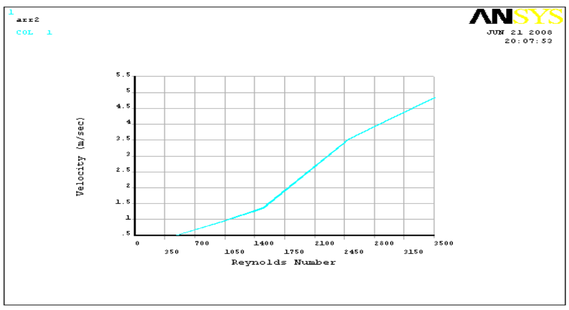

Figure 4.2(d): Reynold's Number Vs. Velocity (70% Reduction ICA)

The above picture shows output velocity variation with reference to Reynolds number. Constant increase of velocity can be observed in the graph from the begining except in the lower range of Laminar flow.

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4.3 Blood flow during geometrical change in CCA:

The picture shows geometry change in the Carotid. The geometry change is taking place in the ICA part.

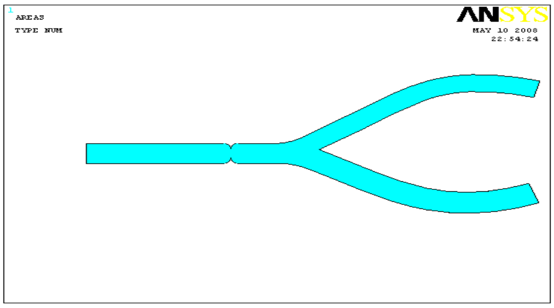
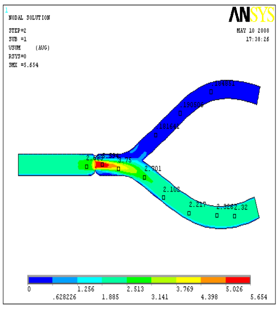


Figure 4.3(a): 50% Reduction of flow area in CCA



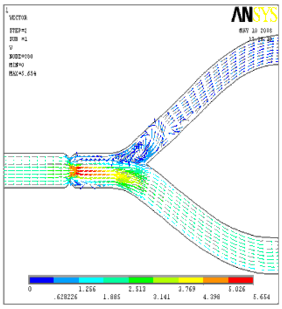


Figure 4.3(b): Reynold's Number Equal to 3000

Figure 4.3(c): Vector Plot of the Velocity

The above pictures represents flow corresponding to Reynold's number equal to 3000. From the figure it can be observed that backflow occurs from both ICA and ECA parts. Also it can be observed again maximum flow is taking place towards ICA.

The following table gives maximum outlet velocity of geometry change in CCA corresponding to different Reynolds number.

Table 4.3: Reynolds number Vs Velocity for CCA

Reynolds Number	Max. Outlet Velocity
500	0.8225
1000	1.584
1500	2.465
2500	5.292
3000	5.654
3500	6.130

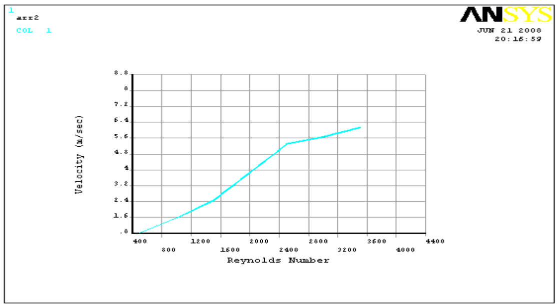


Figure 4.3(d): Reynold's Number Vs. Velocity (50% Reduction CCA)

The above graph shows variation of output velocity with reference to Reynolds numbers. A gradual increasing of velocity can be observed along with Reynolds number. But in the higher range i.e. Turbulent range, the flow slope is dropping.

5 CONCLUSIONS:

- The Carotid model is built using Catia software and imported to Ansys and the geometry is split in to number of areas to ease map meshing. A 4 noded Fluid 141 element is used for map meshing of the Carotid.
- All the necessary boundary conditions and material (Blood) properties are applied for the problem.
- Initially structure is analysed without any geometric change (i.e., normal carotid bifurcation). The results are presented for Reynold's number equal to 500, 1000, 1500, 2500, 3000 and 3500. The results shows complete regular flow pattern (Laminar). But later study has been extended to turbulent region. The results shows, some back flow is taking place. Also flow is becoming turbulent in this region. Velocities are maximum and main flow is diverting towards ICA.
- Geometrical change (created by stenotic lesions) is incorporated in the model by Boolean operations. Again the structure is meshed and boundary conditions are studied. The results shows, even in laminar region, back flow is taking near the obstruction and creates some negative pressure on the boundary. Reynold's number more then 2500, flow is more turbulent, main flow is confined to minimum areas. This shows improper supply of blood to the veins and other important parts of the body which will impair the working of bodily parts.

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- In the 3rd case, the geometry is changed in Common Carotid Artery (CCA). The flow pattern is studied for the same boundary conditions. Maximum flows are diverting towards ICA compared to ECA. Very minimum flows are taking place in the ECA which will create possible problems in circulation of blood in the Carotid.

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