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Numerical Comparative Studies of Wall Shear Stress in Coronary Artery Bypass Grafting

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Abstract:
In this paper, numerical simulation of Coronary Artery Bypass Grafting with complete bypass graft and end to side bypass graft are presented. The numerical model is validated with published model in the Design Modeler and developed for 70 % occlusion and 30^{o} anastomosis angle. The numerical performance for a k-Ω turbulence model with SST is used to analyze wall shear stress. The wall shear stress plays a pivoting role for the development of stenosis in the artery. The wall shear stress is calculated in the key areas of the flow domain such as area near the stenosis and the toe region of anastomosis. The comparative studies for both bypass grafting methods shows that at the critical regions wall shear stress with End to Side bypass grafting has higher value compared with the complete bypass grafting. This presented study may be helpful to understand the real mechanism of Intimal Hyperplasia.

Keywords —**Coronary Artery Bypass Grafting,Wall Shear Stress, Anastomoses Methods, Intimal Hyperplasia, ANSYS Fluent.**

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I. INTRODUCTION

The Coronary Artery Bypass Grafting (CABG) is a surgical procedure operated on a patient having Coronary Artery Disease (CAD). The CAD is primarily arises due to accumulation of fats inside the artery. This affects blood flow in the arterial system by creating blockage into the artery [1]. In CABG a bypass graft made up of natural veins or from other part of body or sometimes artificial material like poly tetra fluro ethylene (PTFE) is placed in such a way that the normal blood flow will takes place namely bypassing the blockage[2]. Further the problem of Intimal Hyperplasia (the problem which occurs due to restenosis) in the graft would arise over the time due to haemodynamic parameters.

The techniques used for the CABG depends upon the surgeon and their past experience [3]. In this paper comparative analysis of twobypass techniques i.e. complete bypass grafting and the end to side anastomosis bypass grafting are done in ANSYS Fluent [4][5]. The published research studies showed that damage between the graft and host artery is occurred due to improper haemodynamic parameters [6][7], and Intimal Hyperplasia (IH) [8][9] which ultimately lead to failure of the graft. The present study showed that key haemodynamic factor for CAD is wall shear stress (WSS) as reported in published research [10]. The results obtained with the both methods shows the superiority of the ETS model over complete bypass graft as far as wall shear stress (WSS) is concerned.

II. METHODOLOGY

Generalised ray diagram based on the previous studies [11] for the complete bypass grafting and End to Side (ETS) bypass grafting are asshown in Fig.1 and Fig.2. On the basis of these diagrams the geometries under consideration are prepared. α is an anastomosis angle which defines the angle at which the bypass graft is connected to the host artery. The leading edge of the bypass graft connected to the host artery and the trailing edge connected to the same is referred as toe. D is the diameter of the host artery with respect to which the other dimensions are considered.

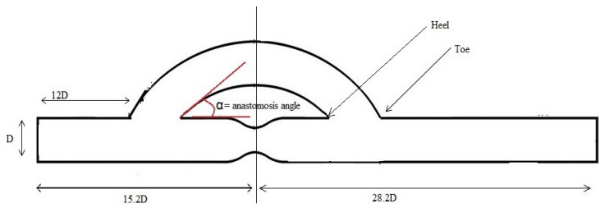

Fig. 1 Complete bypass grafting Ray diagram

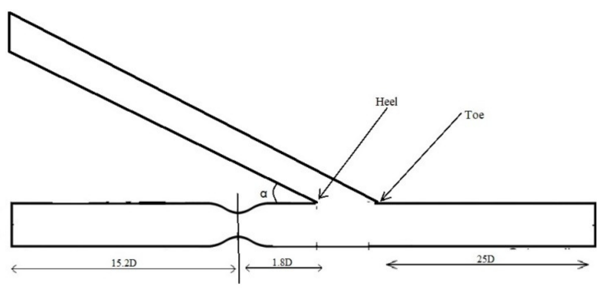

Fig. 2 End to Side anastomosis (ETS) Ray diagram

A. Physical Model

Fig.3 and Fig.4 shows the physical models and the corresponding meshing done in ANSYS meshing software for complete bypass grafting and end to side bypass grafting technique with meshing respectively. The geometries are on the previously published data and drawn in the ANSYS Design Modeler with 70% occlusion area and 30^{o} junction angle. For both the cases used for study, the diameter (D) of host artery and bypass graft is same. Fig.5 shows velocity profile considered depending upon the averagevelocity for steady state as per the type of anastomosis technique.

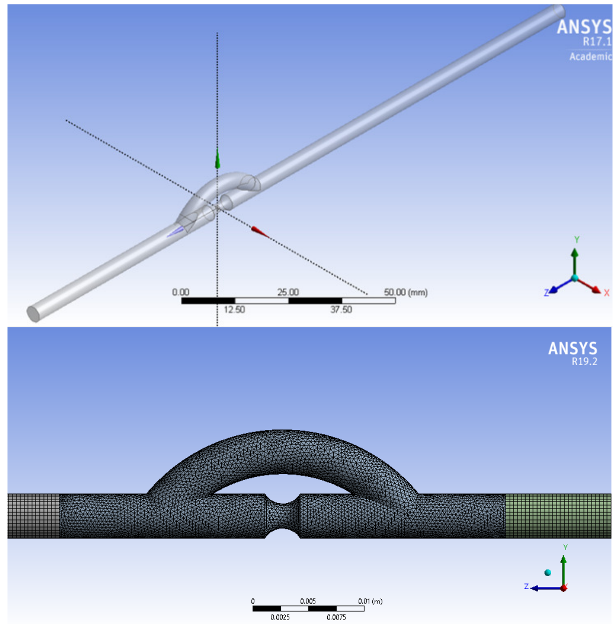

Fig. 3. Three dimensional model for complete bypass grafting with meshing

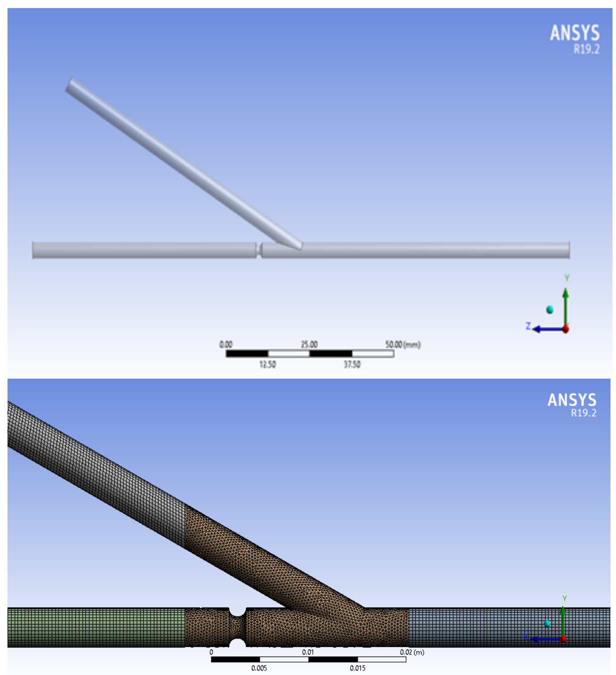

Fig. 3. Three dimensional model for End to Side (ETS) bypass grafting with meshing

Following are the assumptions made in the simulation model

- The model is three dimensional.
- The flow is laminar, incompressible and steady.

- The working fluid i.e. blood follows Newton's law of viscosity.
- The density ρ and dynamic viscosity μ are 1015 kg/m^3 and 0.0035 Pa respectively.

B. Numerical Model

The governing continuity and Navier Stokes equations [12][13] alongwith the boundary conditions are as given below [14]

$$\nabla . q = 0 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\rho\left(\left(\frac{\delta q}{\delta t}\right) + q.\nabla q\right) = \left((-\nabla P)\right) + (\mu \nabla^2 q)) \;\ldots\ldots..(2)$$

Where,

q Represent the velocity in all three directions, P represents the pressure and μ is the dynamic viscosity.

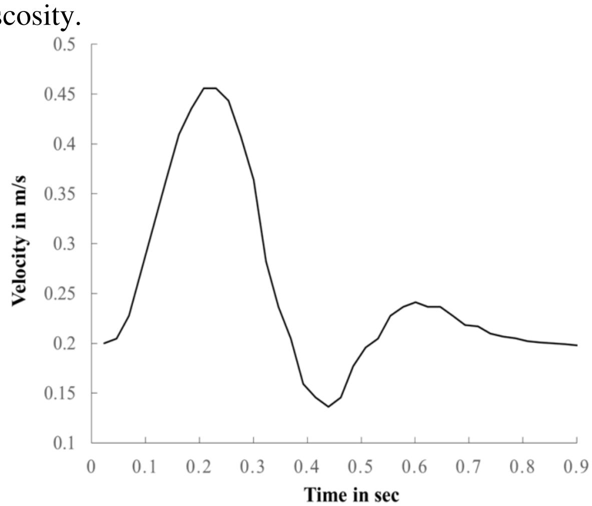

Fig. 5. Pulsatile inlet velocity profile for the blood flow [12]

The boundary conditions used for analysis are as follows

(1) The arterial wall has No-slip conditions because these are assumed as rigid walls.
(2) At inlet velocity distributions is uniform and fully developed flow.

The host artery is long enough from the toe to achieve fully developed flow at exit as that of inlet.

C. Solution Methodology

The physical model developed is meshed with both structured and unstructured grid and Y+ value of the first layer height and corresponding inflation layers are chosen. A grid independence test has been carried out for the pressure at the midway of the bypass graft and mesh element count of 248000 was selected in both the cases and the same is shown in Fig.6. Y axis of the graph defines the pressure in mm of Hg and X axis defines time in seconds. The turbulence model with k-Ω SST has been selected to avoid eddies effect if any [15]. The convergence criterion for the solver is set to 1e-6. A pressure based solver was used with a pressure-velocity coupling SIMPLE solution method. Prior to performing numericalsimulation a validation of outlet velocity profile with the velocity profile given at the inlet as boundary condition is done to ensure the outlet flow as fully developed and the same is shown in Fig.7

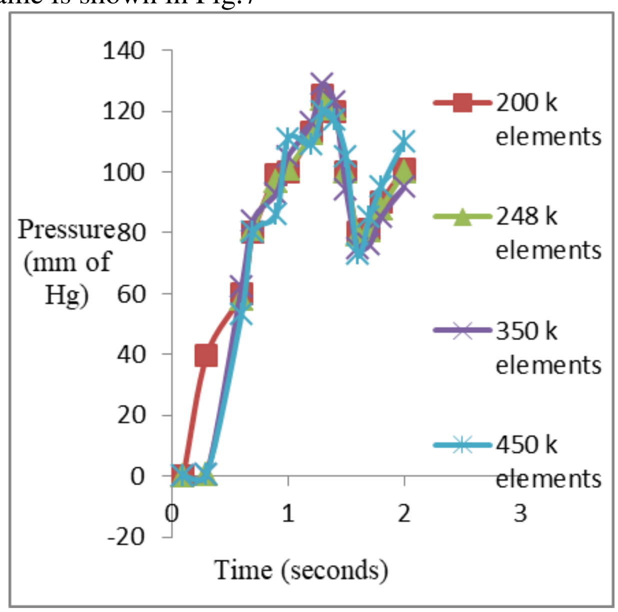

Fig. 6. Grid independence test for velocity profile at the outlet

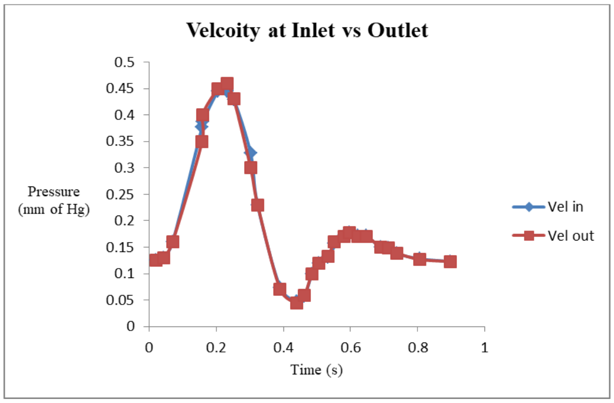

Fig. 7. Validation of velocity profile at inlet verses at the outlet

III. RESULTS AND DISCUSSION

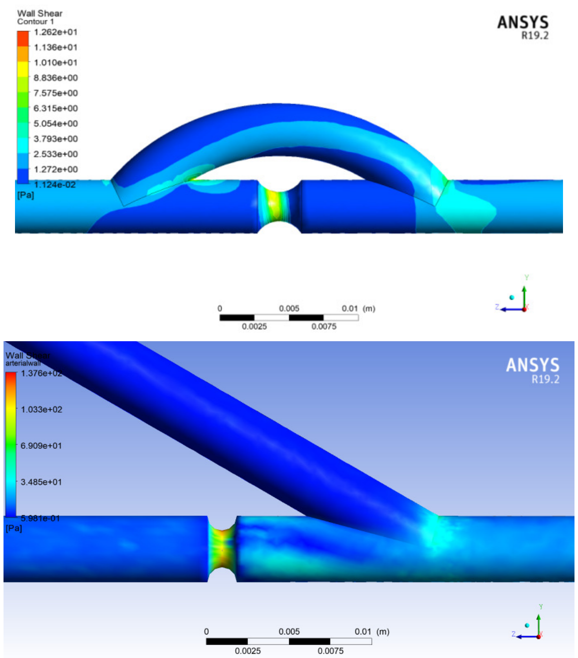

Fig. 8. Contours of wall shear stress near the stenosisin both complete bypass grafting and ETS bypass grafting

From Fig.8 and Fig.9 which shows wall shear contours and velocity contours respectively obtained for 70%-30^{o} combination for both complete bypass grafting and ETS bypass grafting configurations. The following are the observations

1. Wall shear stress near the stenosis as well as near the anastomosis decides the growth of the stenosis or the failure of the graft due to Intimal Hyperplasia (IH).
2. The wall shear stress at the critical points is observed to be enhanced in the End to Side anastomosis technique than those in complete bypass grafting, as reversal of flow due to stenosis is less compared with the complete bypass grafting.

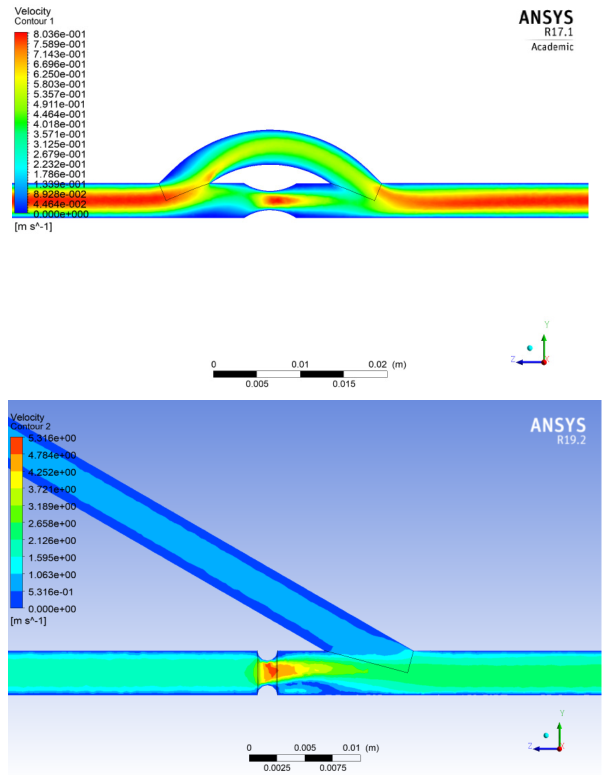

Fig. 9 Velocity contours for both bypass grafting at time step 0.25 sec

The maximum value of wall shear stress near the toe is about 3 Pa and 34 Pa for complete bypass grafting and End to Side bypass grafting respectively. The value of wall shear stress near the stenosis drops to an average value of 0.6 Pa and 20Pa for complete bypass grafting and End to side bypass grafting respectively.

IV. CONCLUSIONS

The paper presents numerical studies of coronary artery bypass grafting model with anastomosis angle 30^{o} and occlusion of stenosis 70% for complete bypass grafting as well as End to Side (ETS) anastomosis bypass grafting method. The k-ΩSST turbulence model in ANSYS FLUENT is used to analyse the growth of stenosis in the artery with respect to wall shear stress. The results showed that the wall shear stress depicts the superiority of ETS over complete bypass grafting method. The average wall shear stress obtained with ETS near thestenosis were lies around 20 Pa compared to the 0.6 Pa with the complete bypass grafting and the maximum is 11 times higher in ETS configuration compared to the complete bypass grafting. The result also shows that the chances of failure of the graft due to Intimal Hyperplasia (IH) and restenosis are higher in complete bypass grafting as the wall shear stress is lower.

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