Computers in Biology and Medicine 43 (2013) 1134–1141

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Blood flow vectoring control in aortic arch using full and partial clamps

Seyed Roholah Ghodsi [a,*], Vahid Esfahanian [b], Rahim Shamsodini [c], Seyed Mohammad Ghodsi [d], Goodarz Ahmadi [e]

[a] VFE Research Institute, University of Tehran, Tehran, Iran
[b] School of Mechanical Engineering, University of Tehran, Tehran, Iran
[c] Yazd University, Yazd, Iran
[d] Sina Trauma Research Center, Tehran University of Medical Science, Tehran, Iran
[e] Department of Mechanical and Aeronautical Engineering, Clarkson University, Potsdam, NY, USA

ARTICLE INFO

Article history:
Received 13 February 2013
Accepted 22 May 2013

Keywords:
Aorta
Aneurysm
Computers
Blood flow
Stress

ABSTRACT

Background: Early diagnosis and treatment of aneurysm plays an important role in reducing the mortality risk of rupture. The aneurysm is a complex phenomenon and caused by different reasons, such as arteriosclerosis and heredity. In addition, pressure and Wall Shear Stress are two known factors influencing the establishment of an aneurysm. The aim of this study is to investigate the effect of using a full or partial clamp to control the blood flow streamlines and hence the location of stress concentration in a clean configuration of aorta. The main question is how to control the stresses distribution in order to reduce the possibility of aneurysm growth with less negative effects on the other sides.
Methods and results: A simple form of aortic arch with three branches is considered to simulate the effect of changing blood flow streamlines directions. A parameter study has been performed on the main characteristics of clamp, i.e. size, location, and the percentage of coverage. The Shear Stress Transport model is employed to simulate steady-state Newtonian blood flow when the Reynolds number is about 6500. Simulations are conducted using the commercial CFD solver ANSYS Fluent. The obtained results show that the location of clamp is more effective than the size. It is also found that increasing the depth of clamp has a negative impact on mean velocity field and hence on stress concentration.
Conclusion: The present results demonstrate that the Blood Flow Vectoring Control (BFVC) can change the main form of flow streamlines and consequently the distributions of pressure and Wall Shear Stress. A partial clamp leads to better results.

1. Introduction

Early diagnosis and treatment of aneurysm play an important role in reducing the mortality risk of rupture. Unfortunately, the incidence of thoracic aortic aneurysm is increasing over time, continuously [1]. The prevalence of aneurysms of thoracic aorta according to the anatomic classification are [2] 60% in ascending aortic, 10% in aortic arch, 40% in descending aortic, and 10% in thoraco-abdominal.

There are different causes of thoracic aortic aneurysms, such as aortic dissection, genetic, congenital, and autoimmune [2]. Therefore, this problem has been studied from different aspects, i.e. medical and mechanical. The proposed treatments based on mechanical equipment are clipping and coiling. Because of sensitivity and complexity of aneurysms, each method has its own advantages and disadvantages. As a result, a way to reduce the negative impact with a new look is still being investigated.

The stresses are known influential factors on aneurysm establishment. The Wall Shear Stress (WSS) on the vessel walls are generated by normal stresses due to blood pressure and shear stress due to blood flow. Therefore, the pressure and flow characteristics, i.e. velocity and direction, have crucial effects on vessel wall tensions and deformations. Normal stresses due to the blood pressure are transferred to all vessel wall layers (intima, media and adventitia). But, just the inner layer of arterial wall, i.e. the vascular endothelium, is exposed to the shear stress [3].

The study on aneurysms in the thoracic aorta is more difficult than in the abdominal portion [2]. Because of the abilities of computational fluid dynamics to investigate the complex flow field, different studies are performed to simulate flow field of the thoracic aorta and investigate the effective parameters on the establishment and growth of aneurysms. Filipovic et al. studied hemodynamic parameters of velocity fields and shear stress in the thoracic aorta with and without aneurysms using a finite element method. They predicted the effect of aneurysm on changing the

* Correspondence to: VFE Research Institute, University of Tehran (Campus 2), College of Engineering, 4th Floor of Institute of Petroleum Engineering Building, North Kargar Avenue, P.O. Box: 14395-1335, Tehran, Iran. Tel./fax: +98 21 88020741.
E-mail addresses: dr.sr.ghodsi@ut.ac.ir, roholahghodsi@gmail.com (S.R. Ghodsi).

0010-4825/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compbiomed.2013.05.016

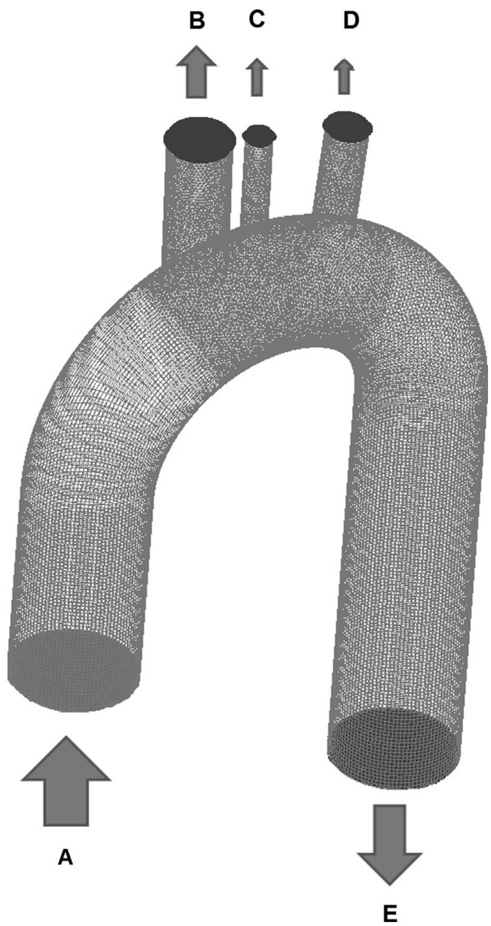

Fig. 1. A 3D view of computational domain and generated grid.

distribution of WSS [4]. Furthermore, the study of small scales of fluid motion needs more accurate approaches, such as Large-Eddy Simulation. Lantz et al. studied the effect of WSS on the aortic wall using Large-Eddy Simulation (LES) approach [5].

However, the effects of changing the streamlines on the pressure and WSS distribution have not been studied comprehensively. Wang et al. developed an in vitro flow system to change flow direction to any angle by pre-aligning cells in laminar shear and then rotating 90°. As a result, the endothelial cells are aligned and then flow is changed in any direction [6].

The wall deformation can change the flow streamlines and thereby the stresses distribution. The wall deformation, e.g. stenosis, generates vortices. If the velocity in a healthy artery is considered as 0.78 m/s, the peak velocity at the throat varies from 1.47 m/s in the 30% stenosis to 3.2 m/s in the 70% stenosis [7]. Keshavarz-Motamed et al. investigated the size of generated vortices and also displaced streamlines as a function of the size of stenosis in a simple U-tube [8]. It seems that, except the size, the other effective parameters of wall deformation should be studied, such as location and shape.

The main aim of the current study is to investigate the effects of changing flow streamlines on pressure and WSS distribution in aortic arch using a clamp. The clamp can change the velocity and also generate considerable vortices, proportional to the size of the clamp. A parametric study is performed on the main characteristics of clamp, i.e. size, location, and the percentage of coverage. It seems that a clamp with optimum features can change the stress concentration efficiently with fewer side effects.

2. Modeling specifications

In the present study, the simulation is performed in a three-dimensional domain (Fig. 1). The boundary conditions are implemented in systolic situation, i.e. steady-state developed flow.

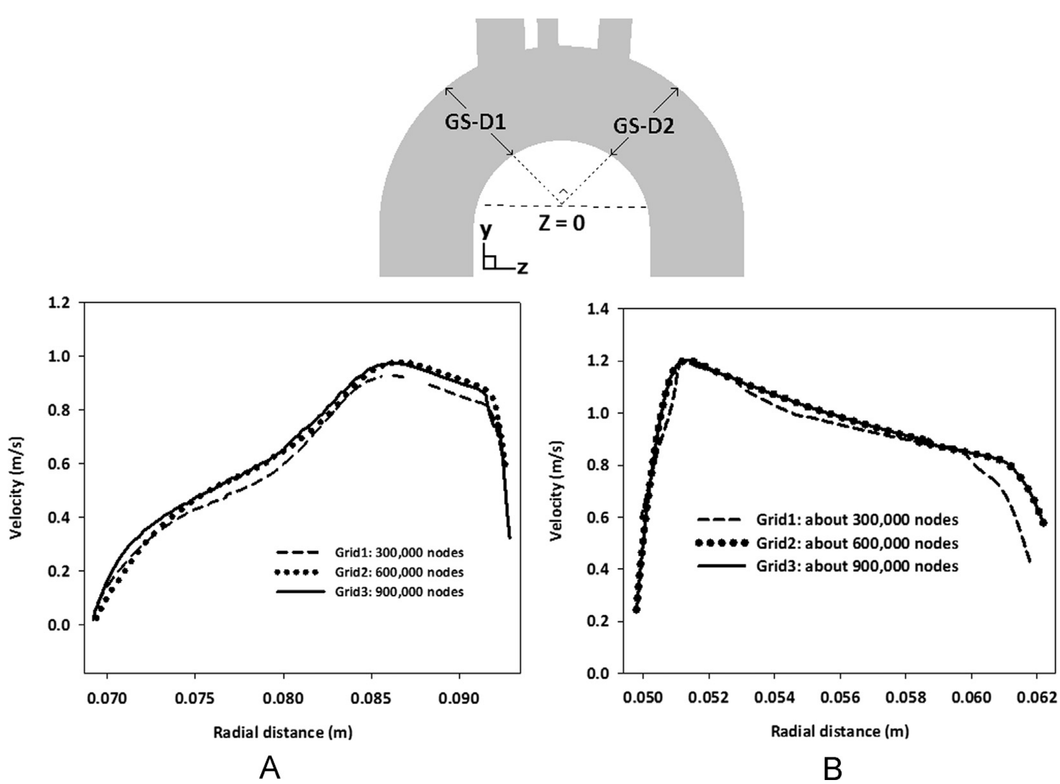

Fig. 2. Two selected radial sections in plane $z=0$ to retrieve data, i.e. (A) GS-D1 and (B) GS-D2. Comparison of velocity profile of three grid resolutions in two radial sections.