HEMODYNAMICS ANALYSIS FOR COSINE SHAPED STENOSES TO BLOOD FLOW BEHAVIOR

SOH KIAN JIN

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JUNE 2014

To my beloved parents

ACKNOWLEDGEMENT

In preparing this project dissertation, I was in contact with supervisors, researchers, academicians, practitioners, employer and colleague. They have contributed to my learning and progresses of the project, as well as physical & financial aid.

I would like to express my sincere appreciation to my project supervisor, Assoc. Prof. Dr. Kahar Osman, for his guidance, consultation and precious sharing of knowledge.

I would also like to express my utmost gratitude to my partner Ms.Madelyn Lim for her constant support, patience, love and care.

Besides that, I wish to show my thankfulness to my fellow postgraduate university colleague, Goh Zhen Hwee, Fam Kok Yeh & Ng Chee Chung for their companion, encouragement & relentless aid in all aspect.

I am forever thankful to my parents for their endless giving of love, food, shelter & education to bring me up to where I am now.

Last but not least, I would like to thank my employer, Ir.Sang Fat Chon, Ir.Lim Ah Bah & Ir.James Wong, whom are directors of Perunding Mektrik Sdn Bhd for the financial support.

Thank you very much.

ABSTRACT

The Study of flow over stenoses have been investigated by many researchers. In these cases, the more realistic the models are, the higher the acceptability of the results. For this study, a very common shape of stenosis, that is modified cosine, are modeled. Newtonian and non-Newtonian blood flow along with the pulsatile flow conditions was used. The results show that tendency for recirculation to occur reduces as the stenosis expands in the longitudinal direction. On the other hand, higher tendency for recirculation of blood is observed if the stenosis expands in the transverse direction. The wall shear stress is observed to decrease as the stenosis expands in the longitudinal direction but no significant changes is observed if the stenosis expands in the other direction. Similar patterns of flow are observed for both Newtonian & non-Newtonian flow condition but the non-Newtonian flow tends to produce higher WSS.

ABSTRAK

Kajian aliran keatas *stenoses* telah disiasat oleh ramai penyelidik. Dalam kes ini, model yang lebih realistik, akan menghasil penerimaan keputusan yang lebih baik. Untuk kajian ini, bentuk yang sangat biasa *stenosis*, bentuk kosinus yang telah diubahsuai telah dimodelkan. Aliran darah *Newton* dan *Non-Newtonian* bersama-sama dengan keadaan aliran yg berdebar-debar telah digunakan. Keputusan menunjukkan bahawa kecenderungan untuk edaran semula berlaku mengurangkan sebagai *stenosis* mengembang dalam arah membujur. Sebaliknya, kecenderungan lebih tinggi untuk edaran semula darah diperhatikan jika *stenosis* mengembang dalam arah melintang. Tegasan ricih permukaan dapat diperhatikan untuk berkurangan *stenosis* mengembang dalam arah membujur tetapi tiada perubahan ketara diperhatikan jika *stenosis* mengembang ke arah yang lain. Corak yang sama aliran dipatuhi bagi kedua-dua keadaan aliran *Newtonian* & *non-Newtonian* tetapi aliran *non-Newtonian* cenderung untuk menghasilkan WSS yang lebih tinggi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Nomenclature

γ	Constant pressure gradient component for dynamic fluid flow
$\dot{\gamma}$	Strain rate
μ	Fluid viscosity
v	Kinematic viscosity
ρ	Fluid density
W_0	Womersley number
h	distance between the plates
f	flow frequency
ω	$2\pi f$ = angular frequency or n
u	velocity field
Re	Reynolds Number
2D	Two-dimensional model
3D	Three-dimensional model
WSS	Wall Shear Stress
CFD	Computational Fluid Dynamics

Unit

kg	-	Mass
kg/ m^3	-	Density
m/s	-	Velocity
m^3	-	Volume
m^3/s	-	Mass Flow Rate
Pa	-	Pressure/ Wall Shear Stress/ Stress
Pa.s	-	Viscosity
s	-	Time in Second
W	-	Wattage

CHAPTER 1

INTRODUCTION

1.1 Research Background

Stroke is defined as the interruption of blood supply to the brain. The type of stroke concerned here is Ischemic stroke which consist of 87% of all strokes. There are also two type of ischemic stroke which is (i) Thrombotic Ischemic stroke - a clot formed at stenosis site, (ii) Embolic Ischemic strokes. – caused by clot breaking off. The broken plaque is then carried to the blood vessel in brain which inflicts stroke [4].

Shape of plaque formed is irregular for every case and it grows over time. Many authors has cross-referenced from other journal for the most commonly assumed elementary morphology of plaque despite acknowledgement of the realistic complex plaque. It is consist of various 2D models such as triangle, round sphere, semi-elliptic and cosine shaped. There's not a definite shape that would accurately represent the shape of plaque. Nonetheless, it is the post-stenotic flow and pressure through the narrow artery based on these shapes is more interesting since it shows significant differences in distribution between these models [9]. In figure 1.1 shows that the shape of stenoses often grow to a lump of cosine shaped plaque and rectangular shape plaque [14].

The blood is non-newtonian in nature. However assumptions have been made to treat blood as Newtonian flow and treated for a constant density. A three-phase computational fluid dynamics approach including plasma, RBCs, and

leukocytes was even used to numerically simulate the local hemodynamics in such a flow regime [13].

Although the advent technology of the Doppler ultrasound scanner have conveniently replaced the conventional method (angiograph or x-ray) of diagnosing stenosis, the scanner is unable to determine the changes of blood flow across the constricted blood flow. Many studies have been done to provide a solution or reference to understand the mechanism across this phenomenon of plaque build up and flow. Where the velocity profile across the stenotic artery and the wall shear stress can be estimated as an prediction to the condition of each of the atherosclerotic area. The medical practitioner will then be able to then make decision upon the severity of the stenosis and to suggest types of treatment such as stenting, endarterectomy or just oral medicine prescription [5, 10, 11, 12].

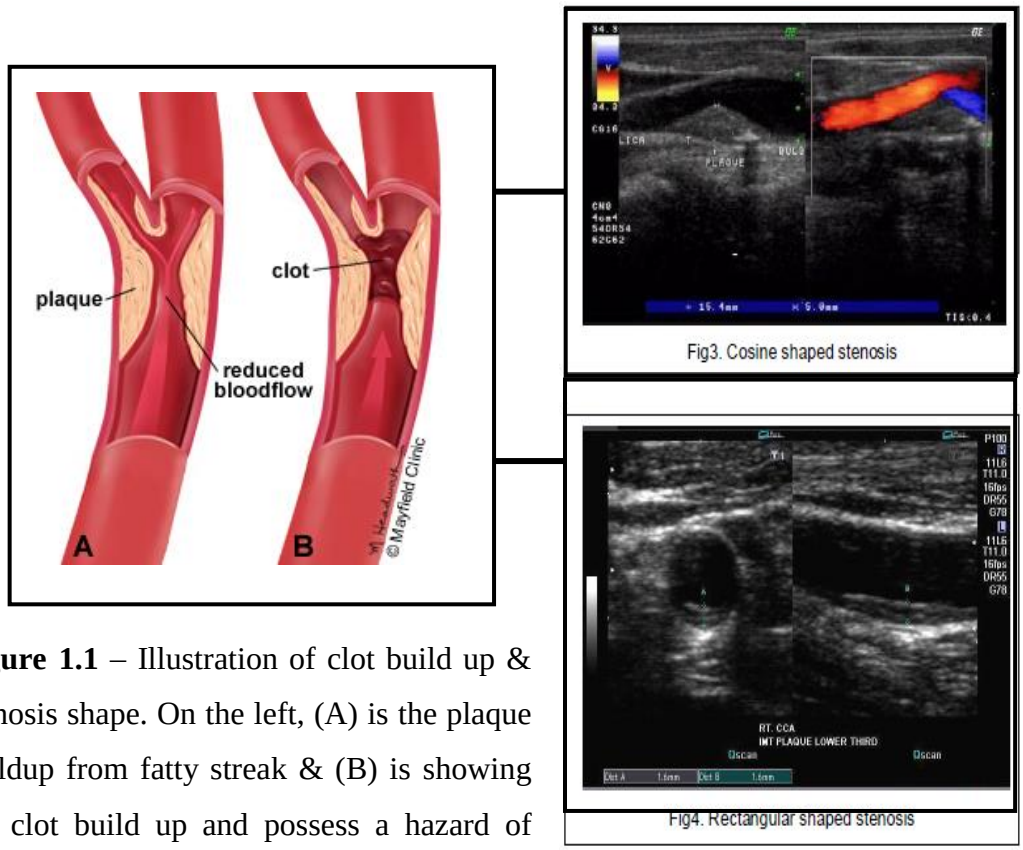

Figure 1.1 – Illustration of clot build up & stenosis shape. On the left, (A) is the plaque buildup from fatty streak & (B) is showing the clot build up and possess a hazard of breaking off [11]. On the right is a diagram captured by Dasgupta, K. & Choudhury, A.R. on the statistical study of common trend of lipid deposition into lumen and the shape of stenoses of cosine shape (top) & rectangular shape (bottom) [14].

1.2 Problem Statement

Various method of simulation and analysis were done in the topic of stenoses based on numerous theory. To date, analysis of the growth of thrombosis in a more realistic approach & systematic method is yet to be standardized [16]. There are still many areas of unknown that can be simulated and investigate to bring a thorough understanding of vortex induced stenotic flow.

Critical studies were also done to generalize & compile loads of analysis across many different disciplinary background & principle for example clinical, medical, mathematical, mechanical, biomedical association/university [29]. It is arguably abundant to where all the analysis done that is deem meaningless and low in relativity to the contribution of actually practices in medical house. Some of the analysis have even extensively reorganize the result and represented the stress with respect to all possible terms such as wall shear stress gradient, Reynold's number, and even stream wise velocity.

On the other hand, accuracy of these results is often debatable against experimental result as the boundary condition applied on models varies between the researcher and geometry of the unpredictable thrombosis. Most of the mechanical department paper computes the result internally between the self-generated CFD models to study the mechanical behavior without much verification of the experimental data, due to difficulty of time constraint and facilities available.

In this shape model study, the area of interest is focused on the reaction stresses & velocity profile through a three dimensional model with similar representation of result with previous 2D model.

1.3 Research Objectives

Significance of study :

This study will provide the mechanical characteristic of the pulsatile flow across constricted stenotic blood stream and identify the significance of shape variation to assist surgical decision making such as coronary artery bypass graft, stenting.

Objective :

1. To review the highly affected area of human blood vessel – Carotid artery stenosis and the velocity profile & wall shear stress in 2D & 3D Model.

2. To identify the properties of the blood flow for density, viscosity, Reynolds number, and mean velocity of blood stream.

3. To analyze the effect of cosine shaped stenoses to human blood flow behavior.

1.4 Expected Outcome Of the Simulation Analysis

1. Higher % of blockage causes larger recirculation length of flow. It will cause high tendency of thrombosis.

2. Blockage above 50% is deemed critical and total pressure would show 300 Pa, the threshold to tendency of rupture.

3. The recirculation length decrease proportionally with the decreasing gradient of the cosine shape plaque.

4. A significant type of shape or series of shape variation would deter the velocity current and promote recirculation by negative flow rate.

5. Flow through constricted stenoses will generate high magnitude of pressure, wall shear stress & velocity.

REFERENCES

[1] Marshalla. I., Zhaob. S., et al, (2004): "*MRI And CFD Studies Of Pulsatile Flow In Healthy And Stenosed Carotid Bifurcation Models*", Journal of Biomechanics 37 (2004) 679–687.

[2] Botnar. R., Rappitsch. G., et al., (2000): "*Hemodynamics In The Carotid Artery Bifurcation: A Comparison Between Numerical Simulations And In Vitro MRI Measurements*", Journal of Biomechanics 33 (2000) 137}144.

[3] Lorenzini. G., Casalena. E., (2008): "*CFD Analysis Of Pulsatile Blood Flow In An Atherosclerotic Human Artery With Eccentric Plaques*", Journal of Biomechanics 41 (2008) 1862–1870

[4] Page. A., Mokhtarb. W., (2012): "*CFD Simulation Of Carotid Artery Stenosis – Simplified Model*", Grand Valley State University, Grand Rapids, Proceedings of the 2012 ASEE North-Central Section Conference.

[5] Vergaraa. C., Ponzinib. R., et al, (2010): "*Womersley Number-Based Estimation Of Flow Rate With Doppler Ultrasound: Sensitivity Analysis And First Clinical Application*", Computer Methods And Programs In Biomedicine 98 (2010) 151–160.

[6] Hodis S., Zamir M., (2011): *Mechanical Events Within The Arterial Wall Under The Forces Of Pulsatile Flow: A Review*, Journal Of The Mechanical Behaviour Of Biomedical Materials 4(2011)1595-1602.

[7] Bacabac R.G., Smit T.H., Cowin S.C., et al. (2005): *Dynamic Shear Stress In Parallel-Plate Flow Chambers,* Journal of Biomechanics 38 (2005) 159-167.

[8] Moayeri M.S., Zendehbudi G.R., (2003): *Effects Of Elastic Property Of The Wall On flow Characteristics*, Journal Of Biomechanics 36 (2003) 525-535.

[9] Moloy Kumar Banerjee,1 Ranjan Ganguly,2 and Amitava Datta2 (2012): *Effect of Pulsatile Flow Waveform and Womersley Number on the Flow in Stenosed Arterial Geometry*, International Scholarly Research Network ISRN Biomathematics Volume 2012, Article ID 853056, 17 pages doi:10.5402/2012/853056

[10] "*What Is Carotid Artery Disease*?",http://www.nhlbi.nih.gov/health//dci/Diseases/catd/catd_all.html, As Accessed on 23rd December 2013, National Heart, Lung and Blood Institute.

[11] "*Managing risk condition"* , http://www.uhnj.org/stroke/risky.htm, As accessed on 23rd December 2013, University Hospital, Newark, New York.

[12] "*Carotid Stenosis (Carotid Artery Disease)*" - http://www.mayfieldclinic.com/PE-CarotidStenosis.htm#.UsfA-MQW1MEAs Accessed on 23rd December 2013, Mayfield Clinic / University of Cincinnati Department of Neurosurgery, Ohio.

[13] Jung. J., Ahmed. H., (2008): *Three-Phase CFD Analytical Modeling Of Blood Flow*, Medical Engineering & Physics 30 (2008) 91–103.

[14] Dasgupta, K., Choudhury, A.R., Chanda, A., Nag, D., "*Clinical and Computational Study of Geometry &Heamodynamics of Arterial Stenosis"*, International Journal of Scientific & Engineering Research Volume 2, Issue 4, April-2011.

[15] Currie, I.G., (1993) "*Fundamental Mechanics of Fluids"*, 3rded, New York, Basel.

[16] Fang, B.T., Zhu, L.D., et al, (2013), "*Simulation Of A Pulsatile Non-Newtonian Flow Past A Stenosed 2D Artery With Atherosclerosis*", Computers in Biology and Medicine 43 (2013) 1098-1113.

[17] Olgac, U., Kurtcuoglu, V., Poulikakos, D., (2008), "*Computational modeling of coupled blood-wall mass transport of LDL: effects of local wall shear stress*" American Journal of Physiology - Heart and Circulatory PhysiologyPublished 1 February 2008Vol. 294no. H909-H919DOI: 10.1152/ajpheart.01082.2007

[18] Huang, H., Virmani, R., et al, (2001),"*The Impact of Calcification on the Biomechanical Stability of Atherosclerotic Plaques*", American Heart Association, Circulation. 2001;103:1051-1056.

[19] "*Hemorheology*" – http://en.wikipedia.org/wiki/Hemorheology. (as accessed on 7th March 2014).

[20] Riley, W.A., Barnes, R.W., et al, (1992), "*Ultrasonic Measurement Of The elastic Modulus Of The Common Carotid Artery*,*The Atherosclerosis Risk in Communities (ARIC) Study*", American Heart Association, Stroke. 1992;23:952-956.

[21] Rabby. M.G., Abdur. R., et al, (2013), "*Pulsatile non-Newtonian Blood Flow Through A Model Of Arterial Stenosis*", Procedia Engineering 56 (2013) 225 – 231.

[22] Johnston, B.M., et al, (2006), "*Non-Newtonian Blood Flow In Human Right Coronary Arteries: Transient Simulations*", Journal of Biomechanics 39 (2006) 1116-1128.

[23] Ding, Z., Wang, K., et al, (2001), *"Flow Field And Oscillatory Shear Stress In A Tuning-Fork-Shaped Model Of The Average Human Carotid Bifurcation*", Journal of Biomechanics 34 (2001) 1555-1562, Elsevier.

[24] Joel M.E., Anburajan M., (2013), "*3D Modeling Of Stenotic Internal Carotid Artery Treated With Stent A CFD Analysis Of Blood*", International Conference on Computer, Networks and Communication Engineering (ICCNCE 2013).

[25] Li, Z.Y., Taviani, N., et al, (2009), "*The Mechanical Triggers Of Plaque Rupture: Shear Stress Vs Pressure Gradient*", The British Journal of Radiology, 82 (2009), S39-S45.

[26] "*First Order vs. Second Order"* - http://jullio.pe.kr/fluent6.1/help/html/ug/node841.htm (as accessed on 8th April 2014).

[27] "*Choosing a Turbulence Model* " - http://jullio.pe.kr/fluent6.1/help/html/ug/node402.htm (as accessed on 8th April 2014).

[28] Li, Z.Y., Simon P.S., (2006), "*How Critical Is Fibrous Cap Thickness To Carotid Plaque Stability?: A Flow-Plaque Interation Model*", Stroke. 2006;37:1195-1199, American Heart Association.