HEMODYNAMIC EFFECT OF PATENT DUCTUS ARTERIOSUS (PDA)

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To my beloved parents, siblings and friends

Thank you for all the support, sacrifice and encouragement throughout this journey

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ABSTRACT

Patent ductus arteriosus (PDA) is a condition in which the patent ductus arteriosus remain patent after birth, causing the blood to shunt through the ductus arteriosus. Thus it is very crucial to determine the flow conditions while the shunting process is outgoing. The objective of this research is to identify the abnormality of hemodynamic which includes the flow rate percentage in different PDA morphologies. Three patient-specific PDA morphologies have been identified and modelled using MIMICS and Solidworks. The blood flow inside the PDA morphologies are investigated numerically using ANSYS CFX 14.0. Four criteria have been identified which are the flow characteristic, time-averaged wall shear stress (TAWSS), oscillatory shear index and mass flow rate. Flow recirculation with low velocity and low TAWSS has been identified at the proximal wall of the aortic branches and PDA, and the region of the insertion of PDA at pulmonary artery. High velocity blood flow and high TAWSS mainly focused on the distal wall of the aortic branches and PDA, and the distal of pulmonary artery, after the insertion of PDA to the pulmonary artery. High OSI value is identified at outer wall of the ascending aorta, at the PDA wall and at the pulmonary artery, especially at the region of the insertion of PDA at the artery and the distal of the left pulmonary artery. DS LPA has the highest percentage of wall area covered by OSI larger than 0.2, approximately around 50%. Lastly the PDA morphologies simulated exhibit a left-to-right shunt, which diverts approximately 10% of blood flow from the aorta to the pulmonary artery. The highest shunted blood flow is found in TR LPA morphology.

ABSTRAK

Ductus arteriosus terbuka (PDA) adalah keadaan di mana ductus arteriosus kekal terbuka apabila bayi sudah lahir, menyebabkan aliran darah dipintas dari aorta ke arteri pulmonari melalui ductus arteriosus. Oleh sebab itu, keaadan aliran darah perlu dikenalpasti sementara proses pintasan aliran darah ini berlaku. Objektif kajian ini adalah untuk mengenalpasti kesan aliran darah, termasuklah jumlah darah per unit masa yang melalui PDA bagi setiap geometri. Tiga geometri PDA dari pesakit telah dikenalpasti dan geometri tersebut dimodel menggunakan MIMICS dan Solidworks. Analisis kesan aliran darah ini menggunakan kaedah berangka melalui "*Computational Fluid Dynamics*" dengan menggunakan perisian ANSYS CFX 14.0. Empat kriteria telah dikenalpasti iaitu ciri aliran, purata masa tegasan ricih dinding (TAWSS), indeks ayunan ricih (OSI) dan kadar aliran darah. Aliran darah balik semula yang mempunyai nilai TAWSS rendah dikenalpasti di bahagian dinding proksimal cabang aorta dan PDA, dan kawasan di mana PDA dan arteri pulmonari bercantum. Aliran darah dengan halaju tinggi dan TAWSS yang tinggi tertumpu di bahagian dinding distal cabang aorta dan PDA, dan distal arteri pulmonari, selepas kawasan di mana PDA dan arteri pulmonari bercantum. Bacaan OSI yang tinggi tertumpu di dinding luar aorta menaik, dinding PDA dan di arteri pulmonari. Kawasan di arteri pulmonari tertumpu pada kawasan PDA dan arteri pulmonari bercantum, dan pada distal arteri pulmonari kiri. Peratusan luas kawasan pada dinding yang tertinggi untuk OSI lebih daripada 0.2 adalah pada DS LPA iaitu dalam lingkungan 50%. Semua geometri PDA dikenalpasti mempunyai pintasan dari kiri ke kanan, di mana aliran darah dipintas dari aorta ke arteri pulmonari adalah dalam lingkungan 10%. Aliran darah yang paling banyak dipintas adalah pada TR LPA.

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AS	-	Ascending aorta
CFD	-	Computational Fluid Dynamics
CHD	-	Congenital heart disease
CT	-	Computer tomography
CVO	-	Combined ventricular output
DS	-	Descending aorta
IJN	-	Institut Jantung Negara (National Heart Institute)
LAC	-	Left aortic arch
LES	-	Large eddy simulation
LPA	-	Left pulmonary artery
$\dot{m}$	-	Mass flow rate
m/s	-	meter per second
MPA	-	Main pulmonary artery
OSI	-	Oscillatory shear index
p	-	Pressure
PDA	-	Patent Ductus Arteriosus
RPA	-	Right pulmonary artery
τ_w	-	Wall shear stress
TAWSS	-	Time-averaged wall shear stress
TR	-	Transverse aorta
$\boldsymbol{u}$	-	Velocity vector
μ	-	Viscosity
ρ	-	Density

CHAPTER 1

INTRODUCTION

Ductus arteriosus is a normal fetal blood vessel which connecting the aorta to the pulmonary artery. Before birth, ductus arteriosus acts as a shunt to redirect blood from the fetal blood circulation, obtained from the umbilical cord, to the aorta in order to supply oxygenated blood to the fetal body, as the lungs is not functioning at this stage. Upon birth, the vessel is no longer needed, as the lungs are already functioning. Thus the ductus arteriosus will close by itself within the first few days.

However, there is condition which the ductus arteriosus does not close and remain patent after few days. This condition is called patent ductus arteriosus (PDA). If the ductus remain patent, the flow of blood reversed. Some of the blood flow is shunted from the aorta to the pulmonary artery and recirculated to the lungs. This condition may cause the heart to work harder in order to supply the blood to the whole body and may congested the lungs with blood. In the case of patient with complex cyanotic congenital heart disease (CHD) with duct-dependent pulmonary circulation, patenting the ductus arteriosus acts as a palliative measure before conduit cavopulmonary angioplasty takes place after 6 to 12 months after birth. Maintaining the patency of the ductus arteriosus using stent have been introduced and proven to be lifesaving.

1.1 Problem Statement

Since the morphology of PDA is different for each patient, the characteristic of flow inside the morphology and the effect of various geometry of PDA morphologies to the flow characteristic inside the PDA is not fully understood. Due to the complicated nature of the arterial geometry, researchers chose to use simplified model of the aorta, PDA and pulmonary arteries geometries in computational fluid dynamics (CFD) simulations.

Since the PDA acts as a shunt which diverts the blood flow, there will be changes of blood flow rate inside the aorta and the pulmonary artery, thus changing the distribution of blood to the body and lungs. The changes of the flow distribution compared to normal may cause complications to the patient, such as cyanosis or lung congestion and the flow distribution is different with different type of morphology.

1.2 Research Objectives

1. To identify the hemodynamic effect due to the abnormality of flow in PDA for different morphologies
2. To determine the percentages of blood flow rate in PDA for different morphologies.

1.3 Significant of study

The behavior of arterial hemodynamic on PDA is analyzed as a comparative study among all morphologies. This study will become a basis of designing a suitable medical devices that can be used for PDA applications. The study of flow rate inside the PDA morphologies will help medical practitioner to decide the suitable treatment of cyanotic congenital heart disease, which may reduce the morbidity and mortality to the patient.

1.4 Scope of research

1. Only three morphologies of PDA are investigated
2. Normal-structured PDA morphologies with no tortuosity are considered
3. Transient flow is considered.

1.5 Theoretical Framework

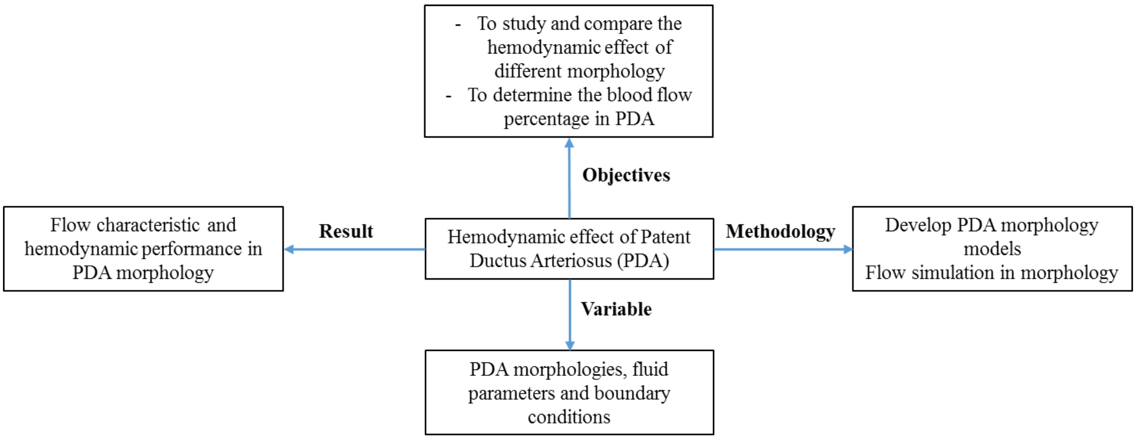

Figure 1.1: Theoretical framework of the study

1.6 Organization of thesis

Chapter one consists of the introduction and the background of the study, followed by chapter two which discusses on the relevant literature review. Chapter three details on the research methodology that will be used for this study, followed by chapter four presents the result obtained from the completed simulation runs and several discussions related to the results are made. Chapter five concludes the study and recommendation for future improvements are identified.

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