THE EFFECT OF STENOSES AND IRREGULAR FLOW RATES IN HUMAN BRAIN VENTRICULAR SYSTEMS

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DEDICATION

To my beloved mother, father, family members and friends

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ABSTRACT

Apart from irregular flow rate, hydrocephalus can also occur due to flow obstructions of cerebral spinal fluid (CSF) flow from the ventricles to the subarachoid space such as stenosis that builds up at the aqueduct. Since the size of the stenosis can affect the seriousness of hydrocephalus, simulation study can be used as cheaper and more detailed method to provide internal flow pattern inside the aqueduct. In this study, three dimensional models of the third ventricle and the aqueduct of Sylvius derived from MRI scans were constructed and the flow patterns were modeled by using MIMICS and CFD software. The constructed region of interest (ROI) was regarded as rigid wall and steady state flows were assumed. Different flow rates were simulated at the Foramen of Monro and several stenosis of various sizes were modeled at the middle of the aqueduct of Sylvius at a fixed location. These were made corresponding to normal patients with variation of CSF flow rates physiologically, and abnormal patients with tumor causing obstruction to or within the aqueduct of Sylvius, respectively. The results shows that the small difference of stenose sizes (1.2 times) is outweighed the difference of the flow rate (2 times) for contributions to abnormal and hydrocephalus. Unlike normal flow rates, there are flow recirculation appeared in the region of interest (ROI) in hydrocephalus cases. The flow recirculation might cause the pressure increase for abnormal flow rates to stay around at 50% - 60% of range for 10% of increment in stenose size. The analysis of the CSF flow patterns can provide a possible potential risk indicator of stenosis severity to the patients.

ABSTRAK

Selain daripada kadar aliran yang tidak teratur, hydrocephalus juga boleh berlaku disebabkan oleh halangan aliran terhadap aliran cecair tulang belakang serebrum (CSF) dari ventrikel ke ruang subarachoid seperti stenosis yang terbina di saluran Slyvius. Disebabkan saiz stenosis memberi kesan kepada tahap hydrocephalus, kajian simulasi boleh digunakan sebagai kaedah yang lebih murah dan terperinci untuk menyediakan corak aliran di dalam saluran Slyvius. Dalam kajian ini, model tiga dimensi ventrikel ketiga dan saluran Slyvius diperolehi daripada imbasan MRI telah dibina dan corak aliran dimodelkan dengan menggunakan perisian MIMICS dan CFD. Kawasan dalam perhatian (ROI) yang dibina dianggap mempunyai dinding tegar dan aliran berkeadaan mantap telah diandaikan. Kadar aliran yang berbeza telah simulasi di Foramen Monro dan beberapa stenosis dalam pelbagai saiz telah dimodelkan di tengah-tengah saluran Sylvius di lokasi yang tetap. Ini dibuat bagi menyerupai pesakit biasa dengan perubahan kadar aliran CSF fisiologi dan pesakit yang tidak normal dengan tumor yang menyebabkan halangan kepada atau dalam saluran Sylvius. Keputusan menunjukkan bahawa perbezaan kecil saiz stenose (1.2 kali) adalah melebihi perbezaan kadar aliran (2 kali) yang menyumbang kepada abnormal dan hydrocephalus. Tidak seperti kes normal, terdapat peredaran aliran semula di dalam kes hydrocephalus. Peredaran aliran semula mungkin menyebabkan peningkatan tekanan bagi kadar aliran yang tidak normal kekal sekitar 50% - 60% daripada julat 10% daripada kenaikan saiz stenose. Analisis corak aliran CSF boleh memberikan petunjuk potensi risiko keseriusan stenosis kepada pesakit

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LIST OF SYMBOLS

A	-	Area
Re	-	Reynold number
Q	-	Volume flow rate
T	-	Temperature
t	-	time
ρ	-	density
P	-	pressure
Po	-	stagnation pressure
μ	-	viscosity
D	-	Diameter
V	-	Velocity
L	-	Length

CHAPTER 1

INTRODUCTION

1.1 Project Background

The cerebrospinal fluid (CSF) is contained within and surrounds the brain and spinal cord [7]. It suspends the brain through its buoyancy force and protects it from impact on the cranial vault walls in cases of sudden head motion. The CSF further serves as an intermediary between blood and nervous tissue, providing the latter with nutrients and removing waste products. Within the skull, the cerebrospinal fluid is enclosed in the ventricles and the subarachnoid space. The ventricles are four cavities interconnected by pathways. The two lateral ventricles are situated within the cerebral hemispheres. They communicate by way of the foramen of Monro with the third ventricle located in the median sagittal plane of the cerebrum. The fourth ventricle is connected to the third through the aqueduct of Sylvius .CSF is secreted from the bloodstream mainly in the choroid plexi of the brain ventricles at a rate of approximately 0.7 ml/min [13]. A pulsatile motion, governed primarily by the cardiac cycle, is superimposed upon the steady flow caused by the CSF production; the interaction between the cardiovascular and the CSF systems is not fully understood. Traditionally, it was accepted that the CSF is drained mainly through the arachnoid villus system in the superior sagittal sinus.

CSF is similar in composition to water and is mainly produced within the VS: it is secreted into the VS via branched structures known as the choroid plexus. Locations of choroids plexus within the brain are along the underside of the two lateral ventricles and over the top of the third ventricle as well as at the bottom of the fourth ventricle. CSF flow is pulsatile (Jacobson 1996).The relationship between how CSF moves through the entire central nervous system (CNS) and the effect of brain movement, arterial blood flow ,cardiac cycle and breathing on it has been the source of much medical discussion [14], [24], [26]. Pulsatile CSF motion is thought to occur due to contraction entering and leaving the brain [11], however other theories include the expansion of the third ventricle, causing a pulsatile downward motion of CSF [15] and the displacement of CSF via expansion of the choroids plexus of the lateral ventricles [9].The CSF pulse wave itself has been shown to be a combination of sine waves [16].

When there is an imbalance between the formation and absorption of CSF, an excess of CSF will accumulate within the ventricles resulting in hydrocephalus. This will cause increased intracranial pressure, which leads to increase pressure onto the brain substance. This pressure increase depends on the degree of the hydrocephalus, which in turn is affected by the cause of the hydrocephalus. The causes of hydrocephalus can be due to excessive CSF production eg by a choroid plexus papilloma or from impairment or obstruction of CSF absorption. Most common obstruction is caused by stenose that formed at the aqueduct of Sylvius. Hydrocephalus can cause death if not treated in a timely manner. The treatment of hydrocephalus include placement of a shunt catheter that can drain CSF from the ventricular spaces. Currently employed shunts contained valves that open when a given preset pressure threshold is reached. This is a very crude approach; a more sophisticated shunt that actively regulates the flow or pressure could potentially lead to much better results for the patients well-being. This justifies the need for a better understanding of the human ventricular system, an integral part of which is the CSF flow and pressure dynamics within the ventricles.

In children, a phenomenon where the ventricular systems is large or prominent but the children are asymptomatic can occur in which no surgical intervention is necessary and the ventricular size will attain the normal appearance as they grow older. This condition is termed benign enlargement of the subarachnoid spaces. However this condition can be confusing and of concerned particularly to a non-Pediatric Radiologists as to whether it is a hydrocephalus or otherwise.

Computational fluid dynamics (CFD) has previously been used to attempt to model CSF flow. A thorough analysis of CSF fluid dynamics through CFD numerical simulations will allow comparisons of CSF flow in normal and abnormal cases, which cloud lead to advances in treatment without the need for extensive human trials. Also , understanding how CSF moves through the CNS and creating a numerical simulation that accurately represents its flow dynamics could allow CFD to be used to model the distribution of a drug injected into the CNS. This will allow complex trials of a variety of drugs in vitro (out of the body),again reducing the amount of human testing that is necessary.

There are basically three approaches to obtain the ventricular flow pattern. They are in-vivo measurements using, e.g., Magnetic Resonance Image (MRI) velocimetry, computational fluid dynamics (CFD) simulations and experimental methods using a physical model of the ventricular system. While anatomical MRI scans can achieve excellent spatial and temporal resolution (e.g. the geometry reconstruction of the ventricular system), velocimetric MRI scans do not reach the same level of detail. Typical resolution (voxel size) of the latter is of the order of 0.5 mm; which is insufficient to accurately capture the CSF flow pattern in the human ventricles, where important feature sizes are in the range of 1.5 mm (thickness of the third ventricle, connection between ventricle chambers). While the resolution can be theoretically enhanced by increasing measurement time, this is not viable for in vivo measurement as the required resolution would lead to prohibitively long scan times. The construction of physical model of the ventricular system would be eventually consume a great period of time and high cost. Although the outcome result can be used to verify the gathered data, it is still considered unnecessary for early stage of this research. Thus, to the best of our knowledge, CFD remains as the best methods. Extensive CFD simulations have been carried out by Kurtcuoglu [28] where anatomical MRI scans were used to obtain the ventricle geometry. In this study, CFD was used to perform the same simulation that utilized local patients MRI scans.

The model presented in this research only consist of several parts in human ventricular system which are Foramino of Monro, the third ventricle, aqueduct of Syvlius and the fourth ventricle. The generated model only covered several parts due to the limited resources of workstation power that is available in the local laboratory. Several sizes of stenoses has also been modeled at the middle of the aqueduct of Slyvius fixed location to resemble real blockage that occur in the channel.

1.2 Problem statement

As the Hydrocephalus patients growing in worrying number, preventive measures and treatment should be available to all level of society. The early and important step to realize these is to enable Cerebrospinal Fluid (CSF) flow of the patient to get analyzed as fast as possible at affordable cost.

However, common analysis for CSF flow by using velocimetric Magnetic Resonance Image (MRI) and experimental methods using a physical model of the ventricular system have several disadvantages. While anatomical MRI scans can achieve excellent spatial and temporal resolution (e.g. the geometry reconstruction of the ventricular system), the expensive velocimetric MRI scans do not reach the same level of detail. Typical resolution (voxel size) of the latter is of the order of 0.5 mm; which is insufficient to accurately capture the CSF flow pattern in the human ventricles, where important feature sizes are in the range of 1.5 mm (thickness of the third ventricle, connection between ventricle chambers While the resolution can be theoretically enhanced by increasing measurement time, this is not viable for in vivo measurement as the required resolution would lead to prohibitively long scan times. The construction of physical model of the ventricular system would be eventually consume a great period of time and high in cost. Although the outcome result can be used to verify the gathered data, it is still considered unnecessary for early stage of this research.

In response to this problem, our study proposes alternative option for making the CSF flow analysis. Simulation by Computational Fluid Dynamics (CFD) software package can provide cheaper, safer and less time consuming analysis. The simulation also can reach further details on small region (etc. aqueduct of Slyvius) up to 0.1mm. By using AMIRA to extract data from MRI scans, we can build Human Ventricular System (HVS) geometry and simulate CSF flow in Engineering Fluid Dynamics (EFD) software. The analysis of the CSF flow pattern can provide a possible potential risk indicator of HVS abnormality to the patient.

1.3 Objectives

By using CFD software and computational hardware, the goal of this research is to provide reference or platform for the clinician to oversee/predict subjects with possible risk of getting hydrocephalus. Below are the objectives in order to achieve the goal.

1) To determine the effects of irregular flow rate on human ventricular.

2) To determine the effects of stenoses in aqueduct of Slyvius on human ventricular.

3) To establish the correlation between the sizes of stenose and various flow rate in human ventricular system.

1.4 Scope of study

The scope of this work is as follows;

1. The analysis is focused at the Third Ventricle, Aqueduct of Slyvius and Fourth Ventricle due to the limited computer hardware capability.

2. The model wall is assumed as rigid due to the limited CFD software and computer hardware capability.

3. Cerebrospinal fluid will be regarded as 99% of water based on the most previous researchers` findings.

4. Solutions will be based on numerical solution due to small and complex geometry.

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