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The CUHK Symposium on Blood Flow and Biomedical Engineering

21–22 February 2014

Division of Neurology, Department of Medicine and Therapeutics, The Chinese University of Hong Kong

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Brain Research and Innovative Neuroscience (BRAIN), Institute of Innovative Medicine, The Chinese University of Hong Kong

Department of Imaging and Interventional Radiology, The Chinese University of Hong Kong

Institute of Electrical and Electronics Engineers (IEEE) Engineering in Medicine & Biology Society Hong Kong–Macau Joint Chapter

Otsuka Pharmaceutical (HK) Ltd

Shenzhen Institutes of Advanced Technology (SIAT), Chinese Academy of Sciences

The Government of the Hong Kong Special Administrative Region

Welcome Message

On behalf of The Chinese University of Hong Kong (CUHK), we would like to welcome you to our symposium on blood flow, stroke and biomedical engineering on 21-22 February 2014. As you may be aware, this conference is the first of its kind to be hosted by the Department of Medicine and Therapeutics, CUHK. The aim of this multi-dimensional symposium is to build on the strengths of the research interests of different specialists; to promulgate communication and dialogue among scientists and doctors; and to deliver knowledge transfer of essential clinical applications from doctors to doctors, from doctors to engineers and from engineers to doctors.

The clinical world in which doctors look after their patients may often be different from the research arena in which scientists and engineers work. There exists a knowledge gap, in as much as a service gap, to which efforts must be made to bring together professionals of different disciplines. In this symposium, we welcome and encourage neurologists, radiologists, cardiologists, and neurosurgeons alike to join hands with our engineering specialists. It is through mutual understanding and constant knowledge transfer among the various parties that we may help solve the pressing clinical needs of our patients one day.

Stroke is an important global medical burden and it serves as the best model for biomedical engineering to be applied in clinical medicine. Prince of Wales Hospital is one of the most prestigious teaching hospitals in Hong Kong and South East Asia and we have a multitude of talented scientists and bright clinicians under the auspice of CUHK. The biomedical engineering programme at CUHK has show-cased many cutting-edge engineering concepts for health enhancement and patient care. The Hong Kong University of Science and Technology is one of the leaders of innovation and technology, being the only university in Hong Kong to specialise entirely in science and technology research. The City University of Hong Kong prides itself in the many creative projects with the industry and sectors of the society to which it serves. The three universities have participated in this joint symposium, with sponsorship from The Government of the Hong Kong Special Administrative Region. We hope that this will pave ways for future collaborations in this quintessential aspect of modern medicine.

May I wish you all an enjoyable time with us and we look forward to talking to you and listening to your interests during the conference and workshop.

Yours sincerely,

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The Chinese University of Hong Kong

Professor Lawrence Ka-sing Wong
Mok Hing Yiu Professor in Neurology
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THE CUHK SYMPOSIUM ON BLOOD FLOW AND BIOMEDICAL ENGINEERING

Teaching Concepts of Computational Fluid Dynamics (CFD) and Applied Biomedical Engineering to Medical Professionals: The Hong Kong-Mainland Collaboration

SCIENTIFIC PROGRAMME

21 February 2014, Friday
Venue: Shaw Auditorium, 1/F, Postgraduate Education Centre, Prince of Wales Hospital

LECTURES		
08:30 – 09:00	Registration	
Session 1:	**Boehringer Ingelheim Symposium on Haemodynamics and Stroke**	
Chairpersons: Lawrence KS Wong & Thomas Leung		
09:00 – 09:20	Clinical Aspects of Flow Dynamics in Cerebrovascular Disease: from Atrial Fibrillation to Intracranial Stenosis	Thomas WH Leung
09:20 – 09:45	Computational Fluid Dynamics and Neurovascular Engineering	David S Liebeskind
09:45 – 10:10	Computer Vision Techniques Used for 3D Reconstruction of Blood Vessels	Fabien Scalzo
10:10 – 10:25	Opening Ceremony (Guest of Honour: Prof TF Fok)	Yannie Soo & Lawrence KS Wong
10:25 – 10:40	Coffee Break	
Session 2:	**Forum on Clinical Applications of Flow Dynamics**	
Chairpersons: Vincent Mok & Defeng Wang		
10:40 – 11:05	Treatment of Cerebral Vascular Disease with Flow Diversion and the Recent Trend	John CK Kwok
11:05 – 11:30	Review of New Endoluminal Approaches for Treatment of Stroke	David CC Lam
11:30 – 11:55	An Overview of the Application of Fluid Engineering in Prognosis Estimation of Vascular Diseases	Lin Shi
11:55 – 12:20	Quantitative Analysis for Prediction of Intracranial Aneurysm Rupture Based on Computational Fluid Dynamics Analysis	Defeng Wang
12:20 – 13:30	Buffet Lunch	

Session 3:	The Hong Kong-Mainland Collaboration	
Chairpersons: Jia Liu, Xiang-yan Chen & Lin Shi		
13:30 – 13:55	Simulating Blood Flows in Compliant Arteries on Supercomputer	Xiao-chuan Cai
13:55 – 14:20	Blood Flow Simulation in End-to-side Anastomosis Using a Non-Newtonian Model	Eric HJ Hu
14:20 – 14:45	Numerical Simulation–based Study of Shape Optimisation of Artery By-pass	Rongliang Chen
14:45 – 15:00	Coffee Break	
Session 4:	**Research Topics on Blood Flow**	
Chairpersons: Defeng Wang, Yannie Soo & Panel Discussants		
15:00 – 15:25	Haemodynamic Effects of Intracranial Stenosis by Computational Fluid Dynamics	David S Liebeskind
15:25 – 15:50	Cerebrovascular Plaque Imaging and Stroke Risk: Does the Information beyond the Luminal Stenosis Matter?	Xihai Zhao
15:50 – 16:15	Assessment of Collateral Flow for Acute Stroke	Liping Liu
16:15 – 16:40	Towards Patient-specific Continuous Assessment of Cerebral Autoregulation: Mathematical Models of Cerebral Haemodynamics	Jia Liu
16:40 – 17:05	Preliminary Application of the Computational Fluid Dynamics Technique in Clinical Evaluation of Intracranial Atherosclerosis	Xinyi Leng

22 February 2014, Saturday

VENUE: KAI CHONG TONG, G/F, POSTGRADUATE EDUCATION CENTRE, PRINCE OF WALES HOSPITAL

WORKSHOP		
08:30 – 09:00	Registration	
Session 1:	**ANSYS CFX™ Vascular Workshop**	
Chairpersons: Thomas Leung & Xinyi Leng		
09:00 – 09:30	Introduction to Computational Fluid Dynamics	David S Liebeskind
09:30 – 10:30	A Practical Introduction to ANSYS CFX	Fabien Scalzo
10:30 – 11:00	Coffee Break	
Session 2:	**Mathematics of CFD and Clinical Applications**	
Chairpersons: Vincent Ip, Howan Leung & Panel Discussants		
11:00 – 11:25	Navier-Stokes Equations and Inverse Problems in Computational Fluid Dynamics	Jeff CF Wong
11:25 – 11:50	Some Numerical Issues/Methods for Studying Blood Flows in the Human Arterial System	Eric TS Chung
11:50 – 12:15	Clinical Applications of Computational Fluid Dynamics in Ischaemic Stroke	Vincent HL Ip
12:15 – 12:35	Clinical Case Sharing	Florence SY Fan

1

Clinical Aspects of Flow Dynamics in Cerebrovascular Disease: from Atrial Fibrillation to Intracranial Stenosis

Thomas WH Leung
Division of Neurology, Department of Medicine and Therapeutics, The Chinese University of Hong Kong, Hong Kong

Haemodynamics is a term used to describe the flow of blood through the vascular system. The arterial interruption of blood flow in ischaemic stroke may be attributable to thrombosis, embolism, or systemic hypoperfusion and yet the clinical manifestation of ischaemia is quintessentially a product of the complex physiological response to the incident ischaemia. The pressure-flow relationship is generally observed in stenosis situations of abrupt nature such as that of cardioembolism in patients with atrial fibrillation, where the sudden stenosis brings about an acute increase in velocity or even no flow. This may be illustrated by the thrombolysis in brain ischaemia flow grade system. In the more chronic models of intracranial stenosis, a wide variety of mechanisms to compensate for arterial lesions will take place. In case of a distal M1 occlusion, the anterior cerebral artery may serve as flow redistribution to deliver blood to the middle cerebral artery territory via transcortical collaterals. This will also entail maximal vasodilatation in the collateral circulation. The autonomic regulation in these patients is often impaired to such an extent that rapid restoration of blood flow may result in the opposite of ischaemia, namely hyperperfusion. Following endovascular intervention of intracranial or carotid vessels, meticulous attention to blood pressure control is paramount to prevent the manifestation of cerebral hyperperfusion syndrome.

2

Computational Fluid Dynamics and Neurovascular Engineering

David S Liebeskind
Department of Neurology, University of California, Los Angeles (UCLA), Los Angeles, United States

The concept of time windows or duration of cerebral ischaemia has been ever evolving, as is the traditional approach based on luminal stenosis, particularly in patients with intracranial atherosclerosis. Nowadays we have imaging modalities which may differentiate the pathophysiological states based on neuroimaging criteria and new parameters to gauge ischaemic profiles which may uniquely prognosticate each and every individual patient. The current paradigm for the treatment of intracranial atherosclerosis often assumes the "all or nothing, go or no go" decision for thrombolysis or thrombectomy, often with time since stroke figuring heavily in the decision. It is largely assumed that a complete arterial occlusion is present, without considering flow physiology beyond identification of the perfusion defect in downstream tissue. Revascularisation is often conducted without understanding how such sudden restoration of blood flow may affect downstream neurovascular structures. Current evaluation and treatment strategies for acute ischaemic stroke may have room for incorporating the heterogeneous patterns of infarction and degrees of reperfusion throughout the arterial territory, including hyperperfusion that may lead to haemorrhagic transformation. Other forms of reperfusion injury and infarct growth despite reperfusion may also occur. The pathophysiology of revascularisation may be better understood and ultimately predicted if the haemodynamic status including fractional flow and collateral flow is known before treatment. Fractional flow across the lesion may predict the risk of subsequent ischaemia and the risk of reperfusion injury. This use of fractional flow can hopefully reduce the arbitrary separation of acute ischaemic stroke and intracranial atherosclerosis, focusing solely on haemodynamics and the interaction with other pivotal mechanisms. We have performed computational fluid dynamics studies of many intracranial lesions from the SAMMPRIS trials and we have found computational fluid dynamics a promising field for assessing the haemodynamic effects under varying flow conditions.

3

Computer Vision Techniques Used for 3D Reconstruction of Blood Vessels

Fabien Scalzo
Department of Neurology and Computer Science, University of California, Los Angeles (UCLA), Los Angeles, United States

The quantification of haemodynamics in the brain is essential for an effective treatment of patients admitted for cerebrovascular diseases, such as stroke, stenosis, and aneurysm. A correct understanding of the underlying dynamics of blood flow would have fundamental implications in the management of these cerebrovascular diseases. Because techniques for the automatic non-invasive measurement of the flow dynamics remain challenging in clinical practice for intracerebral vessels, most research groups perform computational fluid dynamics (CFD) simulations to predict the local flow environment. This methodology is very promising and it potentially leads to unique insights into the treatment of cerebrovascular pathophysiologies.

To run CFD simulations, patient-specific models of cerebrovasculature can be reconstructed in three dimensions from current routine imaging techniques; they include digital subtraction angiography, computed tomographic angiography, magnetic resonance angiography, or three-dimensional rotational angiography. These imaging techniques differ in terms of resolution, as well as the features they are sensitive to. Here, we address the reconstruction of the geometry of intracranial vessels from routine imaging. We introduce the recent techniques used to reconstruct the geometries from either bi- (2D) or three-dimensional (3D) images. For 2D images, cerebral arteries can be reconstructed using the following steps: vessel centerline and diameter estimation by automatic evaluation of the intensity profile on each point along the centerline, followed by a 3D geometry estimation using an optimisation algorithm that minimises the error measured using back-projection of the vessels in the original images. A volumetric mesh on which the CFD simulations are performed is generated using the reconstructed geometry. For 3D images, reconstruction of the geometry involves region-of-interest selection, and seed selection to extract the centerlines, followed by image segmentation, denoising, and meshing to obtain the geometry of the vasculature.

4

Treatment of Cerebral Vascular Disease with Flow Diversion and the Recent Trend

John CK Kwok
Department of Neurosurgery, Kwong Wah Hospital, Hong Kong; Division of Biomedical Engineering, The Hong Kong University of Science and Technology, Hong Kong

The convergence of medical imaging and computational modelling technologies has enabled tremendous progress in the development and application of image-based computational fluid dynamics (CFD) modelling of patient-specific blood flows. These technologies have been used for studying the basic mechanisms involved in the initiation and progression of vascular diseases by incorporating CFD information to the anatomical data and for endovascular treatment planning. In recent years, flow diversion devices (FDD) have been demonstrating encouraging results in the treatment of non-ruptured cerebral aneurysm. In this study, more than 100 cases of aneurysms treated by pipeline FDD were pooled and analysed from one single institute. The location, shape, and size of the aneurysms were captured and classified by 3D magnetic resonance imaging, computed tomography or digital subtraction angiography. The flow patterns within the blood vessel lumen and the vessel wall as influenced by the surrounding anatomical structure such as skull bone were examined. The outcomes of the FDD treatment will be presented. As more new FDDs are introduced into the market, the porosity and design of the devices are to be reviewed. Flow diversion has taken over the previous technically demanding stent-assisted coiling method in treating wide neck aneurysms and the present retrospective study has strengthened the current trend of change.

5

Review of New Endoluminal Approaches for Treatment of Stroke

David CC Lam
Department of Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology, Hong Kong

Ischaemic stroke and intracranial aneurysms can be treated endoluminally. Intracranial aneurysms (ICA) are treated with drug-coated metallic coils, but the deployed metallic coils are left dangling inside the ICA preventing the aneurysm from resorption and healing. Endovascular blockages in ischaemic stroke can be dissolved with dissolution agents, or retrieved using mechanical thrombectomy devices. Mechanical thrombectomy retrieves blockage locally, but emerging evidences suggest that the large radial force used in retrieval may scratch the blood vessel wall during blockage retrieval and damage the vessel wall. In contrast, dissolution agents are gentle to the vessel wall, but its ability to dissolve blood clots may cause bleeding in the brain. Symptomatic intracranial haemorrhage (SICH) in areas other than the blockage site may lead to complications and death; SICH can be reduced and eliminated if the dissolution agent is localised. Techniques such as local clot dissolution that can potentially reduce SICH, low force thrombectomy device that can retrieve blockages and with minimal vessel damage, and bioresorbable coils that disappear and allow the aneurysm to heal are first reviewed. More recent results from trials in human placenta are presented to examine the potential benefits and advances offered by these new approaches.

6

An Overview of the Application of Fluid Engineering in Prognosis Estimation of Vascular Diseases

Lin Shi
Division of Neurology, Department of Medicine and Therapeutics, The Chinese University of Hong Kong, Hong Kong

Quantitative and numerical analyses based on computational fluid dynamics is an increasingly important and powerful approach to test different hypotheses and reveal the fundamental biomechanical cause of changes under certain geometric or mechanical assumptions in a virtual environment. In this talk, the speaker will give an introduction of several representative methods for computational modelling of haemodynamics in cerebrovascular diseases. Aside from the introduction of computational geometric and biomechanical modelling methods, experimental validation and clinical applications will also be covered.

7

Quantitative Analysis for Prediction of Intracranial Aneurysm Rupture Based on Computational Fluid Dynamics Analysis

Defeng Wang
Department of Imaging and Interventional Radiology, The Chinese University of Hong Kong, Hong Kong

Blood flow dynamics are thought to play a crucial role in the progression, growth and rupture of intracranial aneurysms. The haemodynamic variations in the aneurysm are often assumed to be related to its continuous growth and eventual rupture. In addition, the assessment of blood flow pattern in the aneurysm is important for the correct placement of intravascular stents or embolisation coils, especially for the effective treatment of large aneurysm. The purpose of this research is to investigate the haemodynamics in a large unruptured intracranial aneurysm using computational fluid dynamics (CFD) technique. In particular, CFD is conducted to analyse the effects of parent artery segmentation on intra-aneurysmal haemodynamics.

8

Simulating Blood Flows in Compliant Arteries on Supercomputer

Xiao-chuan Cai
Department of Computer Science, Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, People's Republic of China; Department of Computer Science, University of Colorado Boulder, Colorado, United States

We discuss a parallel domain decomposition algorithm for the simulation of blood flows in compliant arteries using a fully coupled system of non-linear partial differential equations consisting of a linear elasticity equation and the incompressible Navier-Stokes equations with a resistive outflow boundary condition. The system is discretised with a finite element method on unstructured moving meshes and solved by a Newton-Krylov algorithm preconditioned with an overlapping restricted additive Schwarz method. We also discuss the parallel performance of the implicit domain decomposition method for solving the fully coupled non-linear system on a supercomputer with a large number of processors. This research has been a collaborative work with Y Wu.

9

Blood Flow Simulation in End-to-side Anastomosis Using a Non-Newtonian Mode

Eric HJ Hu
Department of Mathematics, National Central University, Taiwan

Numerical simulation of blood flow in the arteries becomes an invaluable tool to help both surgeons/interventionalists in planning surgical procedures, thus reducing the risk of surgery. Researchers will understand more about the underlying processes of cardiovascular disease. To overcome the difficulties of blood flow simulation in numerical terms, blood itself is often assumed to be Newtonian fluid as the first approximation. However, the shear thinning effect is significant in large arteries due to the dramatic change of the shear stress during a cardiac cycle and the non-homogeneous properties of blood. Moreover, recirculation happens frequently in the low shear-rate region. To compute accurately the wall shear stress that provides more useful information to predict the formation of intimal hyperplasia, it is necessary to take into account the rheological effect of blood flows. In this study, the non-Newtonian blood flows in the end-to-side anastomosis were numerically investigated by using 3D fully parallel incompressible fluid solver. Our fluid solver is developed based on generalised Newtonian fluid model, where the viscosity is the function of rate of strain tensor. More specifically, the more commonly used model for blood flow simulation, namely the Carreau-Yasuda model, is compared with the Newtonian model. We performed investigations on how the wall shear stress distribution, the streamlines, and pressure distributions depend on different physiological conditions and arterial geometries.

10

Numerical Simulation–based Study of Shape Optimisation of Artery By-pass

Rongliang Chen
Laboratory for Engineering and Scientific Computing, Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, People's Republic of China

A domain decomposition–based parallel method is introduced for numerical design of an optimal by-pass for a blocked artery. The optimal by-pass is described as the solution of a shape optimisation problem governed by the steady-state incompressible Navier-Stokes equations that are used to model the blood flow. The problem is discretised with a Q2-Q1 finite element method on unstructured moving meshes and then solved by a parallel one-shot Lagrange-Newton-Krylov-Schwarz algorithm. In order to accelerate the convergence of the inexact Newton method, we introduce a two-level inexact Newton method which solves a coarse grid problem to generate a good initial guess for the fine grid inexact Newton method. Numerical experiments show that our algorithms perform well on a supercomputer with over one thousand processors for problems with millions of unknowns.

Haemodynamic Effects of Intracranial Stenosis by Computational Fluid Dynamics

11

David S Liebeskind
Department of Neurology, University of California, Los Angeles (UCLA), Los Angeles, United States

There is an urgent need for stroke experts to advance the care of their patients, yet current approaches are outmoded and have not been successful. The traditional emphasis on anatomical identification of disease, using percent luminal stenosis, results in suboptimal identification of lesions likely to produce recurrent ischaemia and, consequently, results in poor patient selection and hampers the development of new aggressive treatments. The traditional emphasis on time since symptom onset and alleged need to achieve complete revascularisation in patients with acute ischaemic stroke ignores the very nature and degree of the underlying culprit lesion and hampers our understanding of the relationships between the patient's original ischaemic state, revascularisation, reperfusion, reperfusion injury, and haemorrhagic transformation. The trajectory for the study and care of cerebrovascular patients needs to adapt, as it has in cardiology, employing haemodynamics and pathophysiology as the new guideposts for advancement. We introduce fractional flow as one haemodynamic parameter to be utilised to set a course on this new path for the care of stroke patients.

Cerebrovascular Plaque Imaging and Stroke Risk: Does the Information beyond the Luminal Stenosis Matter?

12

Xihai Zhao
Department of Biomedical Engineering and Center for Biomedical Imaging Research, School of Medicine, Tsinghua University, Beijing, People's Republic of China

Cerebrovascular vulnerable plaque disruption is the major cause of ischaemic stroke. Early detection of these high-risk lesions will be important for stroke prevention. Currently, measuring luminal stenosis of carotid and intracranial arteries is still the key determinator for disease severity and making treatment strategy in clinical practice. However, positive remodelling occurs in most of atherosclerotic plaques when lipid core occupies less than 40% of area of intima. As such, measuring lumen narrowing will underestimate the plaque severity. Previous studies demonstrated that a substantial number of vulnerable plaques appear in lower-grade stenosis. Directly viewing arterial wall is strongly suggested for characterisation of cerebrovascular plaques. High-resolution, black-blood magnetic resonance (MR) imaging has been proposed for evaluation of plaque burden and compositional features. In this lecture, I shall explain why we need to view the arterial wall differently and I shall discuss the clinical meaning of atherosclerotic plaque MR characteristics.

13

Assessment of Collateral Flow for Acute Stroke

Liping Liu
Department of Neurology and Stroke Center, Beijing Tiantan Hospital, Capital Medical University, Beijing, People's Republic of China

Collateral circulation plays a more and more significant function in acute or subacute stroke. Collateral circulation is developed through secondary channels after obstruction of the principal channels supplying the ischaemic region. Better collateral indicates less infarction size, less haemorrhagic transformation, and good clinical outcome. A pathophysiologic phenomenon related to more than one artery can supply the same territory and collaterals are always present to some extent. The question is how to evaluate the collateral flow and whether it is adequate. In this presentation, I will briefly summarise the definition of collateral circulation, the assessment of collateral circulation by neuroimaging and the role of collateral circulation.

14

Towards Patient-specific Continuous Assessment of Cerebral Autoregulation: Mathematical Models of Cerebral Haemodynamics

Jia Liu
Laboratory for Engineering and Scientific Computing, Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, People's Republic of China

Cerebral autoregulation (CA) is defined as a control mechanism that maintains cerebral blood flow at a relatively constant level despite changes of arterial blood pressure within a wide range. Continuous assessment of CA may provide more insights of this physiological function during the course of cerebral vascular diseases. It may also allow for determining the 'optimal pressure' for the patient. In the last two decades, transfer function analysis or autoregulation index are the most commonly applied methods in assessing CA. However, these methods have not been accepted for individual assessment due to evident inter- and intra-subject variability. Two possible causes of the problems might be: (1) previous model assumes CA as a univariate process whereas it is more likely that multivariate processes are involved; and (2) previous methods considered CA as a time-invariant function whilst it may change over time. In the light of the above causes, a number of recent studies of mathematical models of CA have incorporated non-stationary and multivariate characteristics of this physiological function. In this presentation, I will introduce these new models as well as the possible clinical applications.

15

Preliminary Application of the Computational Fluid Dynamics Technique in Clinical Evaluation of Intracranial Atherosclerosis

Xinyi Leng
Division of Neurology, Department of Medicine and Therapeutics, The Chinese University of Hong Kong, Hong Kong

Intracranial atherosclerosis (ICAS) is of high prevalence in the Chinese population. As the leading cause for ischaemic stroke or transient ischaemic attack (TIA) in China, it accounts for around 30% to 50% of ischaemic stroke and over 50% of TIA. Ischaemic stroke or TIA patients with a symptomatic ICAS lesion are at particularly high risk of stroke recurrence. Traditional evaluation of ICAS is usually based on its severity of luminal stenosis, which has been identified as an independent predictor for recurrent stroke. However, the haemodynamic characteristics of symptomatic ICAS lesions may also play a role in risk stratification of these patients. Therefore, we applied the computational fluid dynamics (CFD) technique in simulating the haemodynamic environment in ICAS based on computed tomography angiography (CTA) images, and tried to explore its use in stratifying patients with symptomatic ICAS.

In a pilot study, we demonstrated the feasibility of CFD modelling of ICAS based on routinely obtained CTA source images. And then in another small study, we evaluated the relationships between haemodynamic characteristics of ICAS lesions revealed by the CFD models and the subsequent risk of stroke recurrence. According to the results, haemodynamic characteristics of ICAS evaluated via CFD models, including changes of pressure, shear strain rate and flow velocity across the lesion, may be correlated with the risk of recurrent ischaemic stroke in the territory of the target artery.

We therefore concluded that it was feasible to apply the CFD modelling technique in simulating blood flow in clinical scenarios of ICAS, based on routinely obtained CTA images. We inferred that this technique may yield potential values in risk stratification of ischaemic stroke or TIA patients with symptomatic ICAS, which needs to be further investigated in future studies.

16

Introduction to Computational Fluid Dynamics

David S Liebeskind
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Fluid dynamics is the science of fluid motion. Computational fluid dynamics (CFD) is the science-predicting fluid flow by solving the mathematical equations which govern these processes using numerical processes. With the advent of modern high-performance computing, CFD analysis complements practical testing and experimentation and reduces the hurdles required in carrying out estimation in real-life scenarios. Analysis begins with a mathematical model of a physical problem, eg the scenario of blood flowing through cerebral blood vessels. Conservation of matter, momentum, and energy must be satisfied throughout the region of interest. Fluid properties are modelled empirically. Simple assumptions are often made in order to make the problem feasible for analysis. There is a need for setting the appropriate initial and boundary conditions for the problem. CFD applies numerical methods to approximate the governing equations of fluid mechanics in the region of interest. The collection of cells is called a grid. The set of algebraic equations could be solved for the flow variables at each cell. The equations are solved simultaneously to provide solutions. The solution may be post-processed to extract quantities of interest, eg lift, drag, torque, heat transfer, separation, pressure loss, etc.

We have explored ways in which blood flow circulation in the brain is simulated with reconstruction of 3D models of intracerebral vessels from biplane angiography. The reconstructed vessel geometries are then used to perform calculations. A key component is incorporating user interaction to identify centerline of the vessels. The vessel profile is estimated automatically at each point along the centerlines and an optimisation procedure refined the 3D model using epipolar constraints. Finally the 3D model of the vessels is used as the domain where the wall shear stress, velocity vectors are estimated from a blood flow model that follows Navier-Stokes equations. Visualisation of haemodynamic parameters can then be illustrated.

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A Practical Introduction to ANSYS CFX

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ANSYS CFX is a general-purpose computational fluid dynamics (CFD) software that has been applied to solve a wide range of fluid-flow problems. It combines an advanced solver with powerful pre- and post-processing capabilities and its extensive capabilities have been widely employed to solve various industrial engineering questions with different physical models. This talk will focus on the general principles in CFX including setting up the physical models, running CFX-Solver, and visualising the results in CFD-Post. At the heart of ANSYS CFX is its advanced solver technology, the key to achieving reliable and accurate solutions quickly and robustly. The modern, highly parallelised solver is the foundation for an abundant choice of physical models to capture virtually any type of phenomena related to fluid flow. This would include biomedical applications including cardiovascular medicine. The solver and its many physical models are wrapped in a modern, intuitive, and flexible graphical user interface and user environment, with extensive capabilities for customisation and automation using session files, scripting, and a powerful expression language.

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Navier-Stokes Equations and Inverse Problems in Computational Fluid Dynamics

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Estimating the time-varying function in the physical system of governing questions is a daunting task when prior knowledge of the functional forms of the time-varying function of the source strength is not available. This is often referred to as an inverse problem. One of the ways for determining the solutions of inverse problems in computational fluid dynamics is to use the optimisation strategy. In my lecture to be presented in the workshop, I shall give a brief introduction of inverse problems in computational fluid dynamics, and discuss how the computational methodologies can be used for determining the time-varying heat source function through blood flows in any artery system.

Some Numerical Issues/Methods for Studying Blood Flows in the Human Arterial System

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Computational fluid dynamics is an important topic in applied mathematics. The main goal of computational fluid dynamics is to obtain numerical solution for the Navier-Stokes equations by means of any existing numerical techniques which describe fluid flows and pressure fields in some regions of interest. Due to the complexity of the mathematical equations, obtaining numerical solutions is perceived as a difficult task. In the lecture to be presented during the workshop, we shall give an overview of the field of applied mathematics in computational fluid dynamics and we shall discuss how the computational methodologies can be used for simulating blood flows in the human arterial system.

Clinical Applications of Computational Fluid Dynamics in Ischaemic Stroke

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Intracranial atherosclerosis accounts for nearly one third of cases of ischaemic stroke in Asia. For patients who have failed medical treatment for secondary stroke prophylaxis, intracranial angioplasty and stenting is considered to be a therapeutic option. However, since the publication of the first randomised controlled trial on Stenting versus Aggressive Medical Management for Preventing Recurrent stroke in Intracranial arterial Stenosis (SAMMPRIS), the benefit and safety of percutaneous transluminal angioplasty and stenting (PTAS) for preventing recurrent stroke has been questioned. The results concluded that aggressive medical therapy was superior to stenting in preventing recurrent stroke and there was an unacceptably high peri-procedural stroke risk and death. In SAMMPRIS, however, it was shown that blood flow was an important factor in predicting outcome or early recurrent stroke in the territory. For early recurrent stroke, when there was good collateral flow, the rate of recurrence was 0% in both medical and stenting arms. This is in accord with physics dictated by the Hagen-Poiseuille equation that it is not just the degree of maximal luminal reduction that matters but numerous other anatomical features such as the length of the lesion and the viscosity of the fluid as well as some other factors that may be important as they affect the pressure gradient across the lesion. All these specific anatomical variables may be difficult to study, yet advanced imaging techniques, such as computational fluid dynamics (CFD), may provide exquisite details about haemodynamics and the impact of a stenosis. Study also revealed that CFD analysis was feasible for demonstrating haemodynamic change such as Wall Shear Stress as well as flow velocity and wall pressure before and after intracranial stenting. This topic will cover some of the recent studies published in the field of CFD application in ischaemic stroke.

Clinical Case Sharing

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Patients having had an episode of or even recurrent ischaemic stroke with vascular investigations showing moderate–to–high grade intracranial stenosis are often offered endovascular intervention. In my presentation, cases related to the clinical application of computational fluid dynamics and intracranial atherosclerosis would be shared and exemplified.

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Information on the Division of Neurology, Department of Medicine and Therapeutics, The Chinese University of Hong Kong may be found in the following website:
http://www.mect.cuhk.edu.hk/neurology.html

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