

科学研究費助成事業 研究成果報告書

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研究課題名(和文) Establishment of a verification and validation framework for the computational fluid dynamics simulations of intracranial aneurysm hemodynamics

研究課題名(英文) Establishment of a verification and validation framework for the computational fluid dynamics simulations of intracranial aneurysm hemodynamics

研究代表者

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研究成果の概要(和文)：本研究の目的は、脳動脈瘤内の数値血流解析の検証と妥当性の確認に対する技術基盤(V&Vフレームワーク)を確立することである。本基盤は、瘤の治療に使用されるステント、コイルやフローダイバータと呼ばれる医療機器の開発に役立つと考えられる。本V&Vフレームワークの提案の開発には、患者データから構築した理想形状と呼ばれる瘤形状を用いた。実験としては、DNSと呼ばれる直接数値シミュレーション技術を用いて行った瘤内の流れ(血行力学)について、粒子画像流体計測法(PIV)を用いた流れ計測結果と比較検討することで、妥当性の確認を行った。特に、粘性の効果、壁の力学的特性、および流れの特性について確認した。

研究成果の学術的意義や社会的意義

The verification and validation framework developed in this project is the first standard for the use of computational fluid dynamics simulations in the hemodynamic analysis of intracranial aneurysms. Available to the research community, it aims to improve the accuracy of CFD studies.

研究成果の概要(英文)：The purpose of this project was to establish a verification and validation (V&V) framework in order to standardize the CFD simulations of intracranial aneurysms (IA) which are essential to develop stents, coils and flow diverters used in IA management. The proposed V&V framework was developed using idealized and generalized models based on patient-specific populations. Direct Numerical Simulation (DNS) were performed and simulated hemodynamics were validated using Particle Image Velocimetry (PIV) experiments. Effects of viscosity, wall compliance and flow models on intra-aneurysmal hemodynamics were investigated. Results of this project will be made available as a database to the biofluid dynamics research community.

研究分野：Biomedical Engineering

キーワード：Intracranial Aneurysm V&V DNS PIV

様式 C - 19、F - 19 - 1、Z - 19 (共通)

1 . 研究開始当初の背景 – Background of the study

Computational fluid dynamics (CFD) has become the dominant research tool for investigating numerous aspects of intracranial aneurysm (IA) hemodynamics; most importantly growth and rupture mechanisms and their relation with vascular hemodynamics. CFD simulations are used to design, improve and examine new management methods including stents, coils and flow diverters. Nevertheless, despite the plethora of publications reporting CFD simulations of IA hemodynamics, there is no standard for using different CFD models in IA hemodynamics simulations. A recent review of IA hemodynamics literature conducted by our group revealed very interesting information about the trends of using different CFD models in IA simulations. As the main method of research, CFD simulations comprises 47% of the papers. By exploring this amount of papers, several controversies have been found. There is no consensus on the use of appropriate viscosity models. Classic and mainstream literature (90% of the papers) used Newtonian viscosity for the blood based on the assumption that shear rates in intracranial arteries are high enough to demolish the shear-thinning and viscoelastic properties of blood. On the other hand, there is a growing trend (10% of the papers) which asserts that neglecting the latter properties results in over-predictions of rupture risk measures such as wall shear stress (WSS). The use of steady models has been dominant (69% of the papers) along the past two decades. Recently (2005 onwards) it has been confirmed that steady models are insufficient to investigate rupture risk of IA. Moreover, the vast majority of CFD simulations assumes that blood flow is a laminar pulsatile flow (96% of the papers). Recent Direct Numerical Simulation (DNS) results showed that subcritical transition, with turbulent-like velocity fluctuations are likely to exist in IA.

2 . 研究の目的 – Research Purpose

The purpose of this project was to establish a verification and validation (V&V) framework for the computational fluid dynamics (CFD) simulations of intracranial aneurysm (IA) hemodynamics. For the past two decades, CFD simulations of IA hemodynamics have been the primary research tool in the field. However, the state-of-art practice lacks V&V framework. The United States Food and Drug Administration (FDA) has one framework only for CFD simulations of cardiac hemodynamics. However, there is no similar standard for intracranial hemodynamics simulations. The FDA V&V framework for cardiac hemodynamics simulations cannot be used for IA simulations because of the fundamental differences between blood in the cardiac and intracranial cycles. This project aimed to establish a V&V framework utilizing Direct Numerical Simulation (DNS) and laser measurements in order to standardize the CFD simulations of IA which are essential to develop stents, coils and flow diverters used in IA management. The proposed V&V framework was developed using generalized models based on patient-specific population and will be made available to the biofluid dynamics research community.

3 . 研究の方法 – Research Methods

[To be disclosed at a later date]

4 . 研究成果 – Research results

[To be disclosed at a later date]

5. 主な発表論文等

〔雑誌論文〕 計2件（うち査読付論文 2件／うち国際共著 2件／うちオープンアクセス 0件）

1. 著者名 Masami Matsuura, Simon Tupin and Makoto Ohta	4. 巻 3
2. 論文標題 Compliance Effect on the Flow Condition in Vascular In Vitro Experiments	5. 発行年 2018年
3. 雑誌名 ASME 2018 International Mechanical Engineering Congress and Exposition	6. 最初と最後の頁 V003T04A031
掲載論文のDOI（デジタルオブジェクト識別子） 10.1115/imece2018-87362	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1. 著者名 Tupin Simon, Saqr Khalid M., Ohta Makoto	4. 巻 61
2. 論文標題 Effects of wall compliance on multiharmonic pulsatile flow in idealized cerebral aneurysm models: comparative PIV experiments	5. 発行年 2020年
3. 雑誌名 Experiments in Fluids	6. 最初と最後の頁 164
掲載論文のDOI（デジタルオブジェクト識別子） 10.1007/s00348-020-02998-4	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

〔学会発表〕 計12件（うち招待講演 4件／うち国際学会 9件）

1. 発表者名 Simon Tupin, Kei Takase and Makoto Ohta
2. 発表標題 Experimental analysis of AAA treatment by multi-layer stent and fate of abdominal aortic branches
3. 学会等名 8th World Congress on Biomechanics (WCB2018)（国際学会）
4. 発表年 2018年

1. 発表者名 Simon Tupin, Shin-Ichiro Sugiyama, Kaihong Yu, Yasutomo Shimizu, Takanobu Yagi, Yoshihiro Okamoto, Yasushi Matsumoto and Makoto Ohta
2. 発表標題 Pre-operative FD deployment experiment using a PVA-H model
3. 学会等名 34th Annual Meeting of The Japanese Society for Neuroendovascular Therapy (JSNET)
4. 発表年 2018年

1. 発表者名 Kohei Mitsuzuka, Simon Tupin, Yujie Li, Toshio Nakayama and Makoto Ohta
2. 発表標題 Particle image velocimetry analysis of flush flow during intravascular endoscopy
3. 学会等名 The 30th JSME Conference on Frontiers in Bioengineering
4. 発表年 2019年

1. 発表者名 Simon Tupin and Khalid M. Saqr and Makoto Ohta
2. 発表標題 Transition to turbulence in side-wall intracranial aneurysm: a comparative PIV and LES study
3. 学会等名 The 19th International Symposium on Advanced Fluid Information (AFI2019) (国際学会)
4. 発表年 2019年

1. 発表者名 Simon Tupin, Hideki Ota and Makoto Ohta
2. 発表標題 Quantitative assessment of aortic tree geometry and flow in healthy adult
3. 学会等名 The 16th International Conference on Flow Dynamics (ICFD2019) (招待講演) (国際学会)
4. 発表年 2019年

1. 発表者名 Simon Tupin, Hideki Ota, Makoto Ito, Kei Takase and Makoto Ohta
2. 発表標題 Experimental flow investigations for medical device improvement and safety evaluation
3. 学会等名 The 10th annual LyonSE&N & ELYT & IARI Workshop 2020 (国際学会)
4. 発表年 2020年

〔図書〕 計0件

〔産業財産権〕

〔その他〕

Project introduction website:
https://simontupin.github.io/IA_hemo_database/

6. 研究組織

	氏名 (ローマ字氏名) (研究者番号)	所属研究機関・部局・職 (機関番号)	備考
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