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BIOGRAPHICAL SKETCH

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NAME: C. Alberto Figueroa

POSITION TITLE: Edward B. Diethrich M.D. Professor of Surgery and Biomedical Engineering, University of Michigan

eRA COMMONS USER NAME: cafigueroa

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	COMPLETED (MM/YYYY)	FIELD OF STUDY
Universidade da Coruna, La Coruna, Spain	M.S.	1998	Civil Engineering
Stanford University, Stanford, CA	M.S.	2001	Mechanical Engineering
Stanford University, Stanford, CA	Ph.D.	2006	Mechanical Engineering
Stanford University, Stanford, CA	Research Assoc.	2011	Bioengineering

A. Personal Statement

I have a well-established record of research in the field of multi-physics and multi-scale computer modeling of hemodynamics. I have developed novel algorithms to perform fluid-structure interaction simulations of anatomically accurate cardiovascular models constructed from image data. My laboratory has focused on developing tools for non-invasive parameter estimation of material properties from medical image data, and on modeling cardiovascular auto-regulatory mechanisms such as the baro-reflex and local auto-regulations. The algorithms developed thus far in my academic career have made it possible to simulate blood flow and arterial dynamics in full-body scale arterial models, a feat that had not been accomplished before. These unique formulations for cardiovascular computer modeling have resulted into highly-cited journal papers and have been implemented in software tools that are now available to the academic and scientific community (e.g., www.simvascular.org, www.crimson.software). Recently, my basic science efforts in the field of cardiovascular disease research have been focused on the study of the biomechanical determinants of systemic and pulmonary hypertension, and on the mechanisms of blood coagulation using image-based modeling methods.

B. Positions & Honors

Positions & Employment

1998-1999 Acting Assistant Professor, Dept. of Applied Math. Universidade da Coruna, Spain.
2006-2011 Engineering Research Associate, Bioengineering Department, Stanford University, Stanford, CA
2011-2014 Associate Professor, Biomedical Engineering Department, King's College London, UK
2013-2014 Board of Directors, Virtual Physiological Human Institute
2014-2018 Associate Professor of Surgery & Biomedical Engineering, University of Michigan, Ann Arbor, MI
2014-2019 Honorary Senior Lecturer, Biomedical Engineering Department, King's College London, UK
2018- Professor of Surgery & Biomedical Engineering, University of Michigan, Ann Arbor, MI

Other Experience & Professional Memberships

Societies: International Society of Endovascular Specialists, Spanish Society of Numerical Methods in Engineering, MICCAI, ASME, SCMR, NASCI, AHA
Editorial Boards (3): Journal of Endovascular Therapy, Frontiers in Pediatric Cardiology, ASME – Journal of Biomechanical Engineering
Journal Reviewer: 33 different journals in the fields of Biomedical Engineering, Applied Mechanics, Life Sciences, Cardiovascular Imaging, and Vascular and Endovascular Surgery.
Grant Reviewer: National Institutes of Health (USA), Heart Research UK (United Kingdom), Technology Strategy Board/Medical Research Council (United Kingdom), Engineering and Physical Sciences Research Council – EPSRC (UK), Agence Nationale de la Recherche (France), Science Foundation Ireland (Republic of Ireland).

Honors & Awards

1998 "Dragados y Construcciones" Best Master Thesis in Civil Engineering Award. La Coruna, Spain.
1999-00 "Pedro Barrie de la Maza" Fellowship, fully funded M.S. program at Stanford University.

2009 "International Society of Endovascular Specialists" Research Award for Innovation in Peripheral and Endovascular Research, Scottsdale, AZ
2011 "ICON2011" Endovascular Research Competition Award, Scottsdale, AZ
2013 "International Symposium on Endovascular Therapies" Research Competition, Barcelona, Spain
2015 Bronze Medal: American Association of Thoracic Surgeons Poster Competition. "Fluid Dynamics of the Thoracic Aorta – An Insight into Aneurysm Formation?" P. Youssefi, et al. Seattle, Washington.
2015 Walton Lillehei Young Investigator's Award: EACTS. Best paper award. "Effect of Aortic Valve Morphology on Fluid Dynamics of the Thoracic Aorta – Indication for a New Modality of Valve Assessment?" P. Youssefi, et al. Amsterdam, The Netherlands.
2016 BME Departmental Award, College of Engineering, University of Michigan. Award conferred for a high impact accomplishment in a meritorious area benefiting the Department and the College.
2018 First Place PhD student paper competition World Congress of Biomechanics. "FSI models of mice hemodynamics in Wild Type and Fbln5-/- populations". F. Cuomo, et al. Dublin, Ireland.
2019 Fellow, American Institute for Biomedical and Biological Engineering (AIMBE), Class of 2020.

C. Contributions to Science (selected from over 70 journal articles and 9 book chapters)

Fluid-Structure Interaction Methods for Large-Scale Image-based Blood Flow Modeling

Blood velocity and pressure fields in large arteries are greatly influenced by the deformability of the vessel. Modeling the interactions between blood flow and arterial dynamics is a computationally expensive task that typically results in simulations that consider either a rigid wall assumption for the vessel or significantly simplified or reduced geometries. In my doctoral work, I developed a new method (the Coupled-Momentum Method, cited below) that, inspired by Womersley's analytical solution for flow in a deformable vessel, enables the simulation of fluid-structure interactions in patient-specific, large-scale cardiovascular models with costs comparable to those of rigid wall simulations. The Coupled-Momentum Method has produced the first full-body scale simulation of hemodynamics in the human vasculature (cited below). The method has been expanded and enhanced through the years to include external tissue support (cited below) and anisotropic tissue properties (cited below).

Figueroa CA, Vignon-Clementel I, Jansen KE, et al. (2006) A Coupled Momentum Method for Modeling Blood Flow in Three-Dimensional Deformable Arteries. *Comp Meth Appl Mech Engr* 195: 5685-5706.

Xiao N, Humphrey JD, Figueroa CA (2013). Multi-Scale Computational Model of Three-Dimensional Hemodynamics within a Deformable Full-Body Arterial Network. *J Comp Phys* 244: 22-40. PMCID: PMC3667207.

Moireau P, Bertoglio C, Xiao N, Figueroa CA, et al. (2013). Sequential Identification of boundary support parameters in a fluid-structure vascular model using patient image data. *Biomed Model Mechanobiol* 12(3): 475-496.

Figueroa CA, Baek S, Taylor CA, Humphrey JD (2009) A computational framework for fluid-solid-growth [FSG] modeling in cardiovascular simulations. *Comp Meth Appl Mech Engr* 198: 3583-3602. PMCID PMC2770883.

Multi-scale Methods for Blood Flow Modeling

I have developed novel and robust (i.e. fully implicit) computational methods for the simulation of blood flow in complex networks. These methods have spanned formulations in 0D, 1D and 3D. Key developments in 0D have included fully-implicit Windkessel models (cited below) and an improved heart model (cited below); 1D efforts have been focused on parameter estimation (cited below). I have developed the first model of the baroreflex implemented in 3D (cited below), and also parameter estimator routines based on Kalman filtering techniques (cited below). These methods have contributed to the development of academic codes (cf. SimVascular) and continue to be deployed in the CRIMSON software framework (www.crimson.software)

Vignon-Clementel IE, Figueroa CA, Jansen KE, Taylor CA (2010) Outflow Boundary Conditions for Three-Dimensional Simulations of Non-Periodic Blood Flow and Pressure Fields in Deformable Arteries. *Comp Meth Biomech Biomed Eng* 13(5): 625-640.

Lau K, Figueroa CA (2015) Simulation of short-term pressure regulation during the tilt test in a coupled 3D-0D closed-loop model of the circulation. *Biomech Model Mechanobiol* 14(4): 915-29. PMCID PMC4490186.

Xiao N, Alastruey J, Figueroa CA (2014). A systematic comparison between 1-D and 3-D hemodynamics in compliant arterial models. *Int J Num Meth Biomed Engr* 30: 204-231. PMCID PMC4337249.

Moireau P, Bertoglio C, Xiao N, Figueroa CA, et al. (2013). Sequential Identification of boundary support parameters in a fluid-structure vascular model using patient image data. *Biomed Model Mechanobiol* 12(3): 475-496.

Computational Methods to Study Endograft Positional Stability

I developed novel strategies to investigate the forces exerted by blood flow on thoracic and abdominal endografts (cited below). Contrarily to what was previously believed, these studies have revealed that the most important determinants of these forces are curvature and pressure and not the shearing action of flow. Furthermore, I have developed the first computational framework to study the positional stability of the device by solving the two-way contact problem between vessel wall and the endograft, subjected to realistic hemodynamic loads. The framework reproduced well typical clinical findings regarding adverse anatomical factors such as short and tortuous aortic neck, the effect of over-sizing, etc. (cited below).

Figueroa CA, Taylor CA, Yeh V, et al. (2009) Effect of Curvature on Displacement Forces Acting on Aortic Endografts: a Three Dimensional Computational Analysis. *J Endovas Ther* 16: 284-294. PMCID: PMC2793567.

Figueroa CA, Taylor CA, Chiou AJ, et al. (2009) Magnitude and direction of pulsatile displacement forces acting on thoracic aortic endografts. *J Endovas Ther* 16: 350-358. PMCID: PMC2793566.

Figueroa CA, Taylor CA, Yeh V, et al. (2010) Preliminary 3D Computational Analysis of the Relationship between Aortic Displacement Force and Direction of Endograft Movement. *J Vasc Surg*. 51(6): 1488-1497. PMCID: PMC2874723.

Prasad A, To LK, Gorrepati ML, Zarins CK, Figueroa CA (2011) Computational Analysis of Stresses Acting on Intermodular Junctions in Thoracic Aortic Endografts. *J Endovas Ther* 18(4): 559-568. PMCID: PMC3163409.

Computational modeling of arterial stiffness and hemodynamics in hypertension

Central artery stiffening is a well-established initiator and indicator of cardiovascular disease; it arises in hypertension, aging, diabetes, obesity, connective tissue disorders such as Marfan syndrome, organ transplantation, and the treatment of AIDS patients. Such stiffening contributes to heart disease and end-stage kidney failure. Together with my collaborator Jay D. Humphrey, we have developed a combined experimental and computational modeling framework to study the hemodynamics and biomechanics of systemic hypertension using experimental data from different mouse models. The fluid-structure interaction computational model faithfully reproduces the experimental data and provides a high-resolution description of hemodynamics in locations where experimental acquisition is not feasible. The computational model also enables studying the sensitivity of different metrics of arterial stiffening. The overall goal is to identify metrics that are most sensitive to reflect the early stages of disease progression.

F. Cuomo, J. Ferruzzi, J.D. Humphrey, C.A. Figueroa (2015) An Experimental-Computational Study of Catheter-Induced Alterations in Pulse Wave Velocity in Anesthetized Mice. *Ann Biomed Eng* 43(7): 1555-1570. PMCID: PMC4497847.

J.D. Humphrey, D.G. Harrison, C.A. Figueroa, et al. (2016) Central Artery Stiffness in Hypertension and Aging: A Problem with Cause and Consequence. *Circ Res*. 118: 379-381. PMCID: PMC4745997.

F. Cuomo, J. Ferruzzi, P. Agarwal, et al. (2019) Sex-Dependent Differences in Central Artery Hemodynamics in Normal and Fibulin-5 Deficient Mice: Implications for Aging. *Proc Royal Soc A*. DOI: 10.1098/rspa.2018.0076.

Software tools for Image-based Blood Flow Modeling

I have contributed to the development of software tools for hemodynamics modeling, first during my time at Stanford University (SimVascular), and currently with the development of the hemodynamic software framework CRIMSON (www.crimson.software). The overarching goal of CRIMSON is to cater to an audience of researchers, including clinical fellows, providing a solution that is both intuitive to use for the non-technical expert and easy to expand for the advanced user.

R. Khlebnikov, C.A. Figueroa (2016) CRIMSON: Towards a Software Environment for Patient-Specific Blood Flow Simulation for Diagnosis and Treatment. *Clinical Image-Based Procedures. Translational Research in*

Medical Imaging. Ed: C Oyarzun Laura et al. 4th International Workshop, CLIP 2015, held in conjunction with MICCAI 2015 Springer, Munich, Germany.

C.J. Arthurs, C.A. Figueroa (2016): Integration of an Electrophysiologically-Driven Heart Model into Three-Dimensional Haemodynamics Simulation using the CRIMSON Control Systems Framework. *Computational Biomechanics for Medicine: Imaging, Modeling, and Computing*, Ed: G Joldes et al. Springer, Munich.

List of published work (My Bibliography):
http://www.ncbi.nlm.nih.gov/sites/myncbi/carlos.figueroa.1/bibliography/48304981/public/?sort=date&direction=ascending

D. Research Support

Active

NIH 2R01HL105297-05A1 Figueroa and Humphrey (MPIs) 04/16 – 3 /20
Agency: NIH/NHLBI
Title: ***Mechanisms Underlying the Progression of Large Artery Stiffness in Hypertension***
The goal of this study is to use a number of animal models and computational modeling tools to investigate the progression of arterial stiffening and its relationship to hypertension. Role: Contact MPI

U01HL135842 Figueroa, Dorfman, and Baek (MPIs) 03/17 – 02/21
Agency: NIH/NHLBI
Title: ***Image-based Multi-scale Modeling Framework of the Cardiopulmonary System: Longitudinal Calibration and Assessment of Therapies in Pediatric Pulmonary Hypertension***
The goal of this project is to develop and calibrate a multiscale model of the cardiopulmonary system that enables coupled high resolution simulations of the hemodynamics as well as cardiac and vascular mechanics. Role: Contact MPI

Pre-doctoral Fellowship Figueroa 8/18 – 07/20
Agency: American Heart Association
Title: ***Early Initiation of Venous Thrombosis Examined Through Photoacoustic Imaging and Image-Based Computational Models***
The goal of this study is to describe the kinetics of venous coagulation using animal models, photoacoustic imaging, and computational modeling. Role: PI

AHA AI and ML Research Grant Figueroa 07/19-06/21
Agency: American Heart Association
Title: ***A Cloud-computing Machine Learning and Computational Fluid Dynamics Framework for Assessment of Coronary Disease***
The goal of this project it to develop Neural Networks for automatic segmentation of coronary angiographic data and to reconstruct 3D computer models of coronary trees amenable for CFD analysis. Role: PI

Recently Completed Research Support

NSF-US: 15-PAF04428 Duraisamy 09/15 – 08/19
Agency: National Science Foundation
Title: ***Conflux: A Novel Platform for Data-Driven Computational Physics***
The goal of this study is to set up a hardware and software infrastructure to efficiently perform data-driven computations in several fields of engineering. Role: Co-PI

307532 ERC INTEG-CV-SIM Figueroa 12/12 – 11/18
Agency: European Research Council
Title: ***An Integrated Computer Modeling Framework for Subject-Specific Cardiovascular Simulation: Applications to Disease Research, Treatment Planning and Medical Device Design***
Goal: The goal of this study is twofold: to develop computer methods to extract boundary condition and material parameters from dynamic medical image data, and to implement dynamically adapting outflow and inflow boundary conditions to represent alterations in baseline physiology. Role: PI