## S20: Flow Visualization of Cardiovascular Devices

### S20-1 Visualization of Cardiac Flows: In Vitro, In Vivo, and In Silico Studies

Immanuel David Madukauwa-David[a], Vrishank Raghav [b], Prem A. Midha [c], Vahid Sadri[d], Phillip Trusty[d], Zhenglun Wei[d], **Ajit Yoganathan**[d]

*[a]George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, USA*
*[b] Department of Aerospace Engineering, Auburn University, USA*
*[c] Biomedical Engineering Practice, Exponent Inc., USA*
*[d]Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology & Emory University, USA*

Cardiac fluid mechanics dictate much of how we understand the cardiovascular system, from diagnosis of valvular disease states to surgical strategy for complex congenital heart defects. In addition, fluid mechanics influence pathophysiological processes that could result in stroke, heart failure, malformations in the lungs and liver, or other complications. Hence, a comprehensive understanding of cardiac flow field characteristics is essential to effective patient care.
Flow visualization techniques are a critical step in the right direction as they enable the identification of regions of flow stasis, pathological shear, and other key flow characteristics. Over the past four decades, our group has dedicated resources towards a rigorous investigation of valvular and ventricular performance, as well as hemodynamics of congenital single ventricle circulation, using a wide range of techniques.
Particle flow visualization, laser Doppler velocimetry, and particle image velocimetry were applied to characterize prosthetic heart valves, the left ventricle, and the total cavopulmonary connection formed to palliate congenital single ventricle defects. Our in vivo work included the visualization of flows through heart valves and ventricles in patients and animal models using ultrasound and magnetic resonance imaging. We have also applied computational fluid dynamics methods to visualize prosthetic heart valve flow characteristics and hemodynamics through the total cavopulmonary connection, generating higher-resolution data than in vitro methods provide.
Taken together, these studies have yielded a better understanding of how design characteristics of valvular prostheses can interact with cardiac flows and how surgical design for congenital heart defects can impact patient outcomes.

### S20-2 On the effective visualization of aortic sinus flows: Eulerian vs Lagrangian schemes

Hoda Hatoum, Lakshmi Dasi

*The Ohio State University, USA*

The flow in the aortic sinuses of Valsalva after the implantation of prosthetic aortic valves such as surgical and transcatheter heart valves are complex and chaotic. With increased reports of blood flow related adverse complications such as leaflet thrombosis, deeper understanding and visualization of aortic sinus flows is critical to assess the effects of patient-specific anatomic and hemodynamic factors as well as valve positioning on sinus vortex patterns and stasis regions. High resolution time-resolved particle image velocimetry measurements were conducted in idealized as well as compliant and transparent 3D printed patient-specific models of stenotic bicuspid and tricuspid aortic valve roots. We introduce Lagrangian particle tracking analysis of sinus vortex flows to obtain probability distributions of residence time and blood damage indices. Specifically, we show that Lagrangian characteristics such as distributions of residence time are independent of Eulerian characteristics such as probability distributions of fluid shear stress. Further we illustrate how these Eulerian and Lagrangian characteristics paint a rich picture of aortic sinus flows in the context of the effects of patient specific parameters and valve type and positioning. This work provides new visualization and data reduction methods to better characterize the spatio-temporal aortic sinus vortex dynamics post heart valve replacement.

## S20-3 Leveraging Fluid Dynamic Measurements to Improve Cardiac Device Design

Keefe Manning

*The Pennsylvania State University, USA*

Experimental fluid mechanics is an art form and can impact our understanding of how flow negatively affects biological phenomena. While computational fluid dynamics has been able to extend our knowledge and challenge many paradigms related to cardiovascular fluid mechanics and design, we still need to validate computational simulations as we investigate more cellular behavior and systems. Newer experimental techniques are being developed but is the technology experiencing its swan song? At Penn State, we have been able to successfully use particle image velocimetry (PIV) to improve and influence the design of adult and pediatric pulsatile blood pumps. We will describe our approach to calculate the wall shear rates based on PIV and how to correlate these data to thrombus deposition from animal explants and then leverage into computational simulations and prediction.

## S20-4 Hemodynamics Assessment of New Transcatheter Bi-Caval Valves in the Interventional Treatment of Tricuspid Regurgitation

Munirah Binte Ismail, Foad Kabinejadian, Yen Ngoc Nguyen, Hwa Liang Leo

*National University of Singapore, Singapore*

Elderly patients with co-morbidities are usually denied the replacement tricuspid valve surgery, which may predispose them to a higher risk of surgical complications associated with open heart surgery. The advent of transcatheter technology provides these patients a new treatment alternative. Our team at the National University of Singapore has recently developed two percutaneous caval heart valves that are designed to deploy at the vena cava and atrium junction. Our previous studies showed that the Reynolds shear stress (RSS) values measured in the proximity of the percutaneous caval heart valves are higher than the threshold of platelet activation. In the present study, we have incorporated new design features in these percutaneous caval heart valves. The study objective is to provide insight on how these two new stented valves with compliant ends affects the surrounding blood flow patterns. To accomplish this, a physological flow loop was built and the two valves were deployed at the cavo-atrial junction. 3-D PIV measurements were conducted in the vena cava and right atrium in multiple planes. These caval stented valves comprise of nitinol stents, glutaraldehyde-treated porcine pericardial sleeve on the stent and glutaraldehyde-treated porcine pericardial tri-leaflets. Our findings revealed superior performance regarding the reduction of hemodynamic disturbances, particularly in the vicinity of the valves. Lower RSS values were recorded downstream of these valves when compared with previous valve designs. The maximum Reynolds shear stress values in the vicinity of the two valves were approximately 10 dynes/cm2. Our study demonstrated that the new bi-caval valves could be potentially considered as a minimally invasive option to treat tricuspid regurgitation.