Rich Flow Physics in Curved Arteries and the Vocal Tract

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Flow in the human body is primarily laminar and pulsatile. Turbulence or transitional flow plays a role in speech production and pathological flows in the circulatory system. Examples of pathological blood flow in which unsteadiness, separation and turbulence are important include regurgitant heart valves, stenoses or blockages, stents, and arterial branches and bifurcations. Speech production involves unsteady pulsatile flow and turbulent structures that affect the aeroacoustics and fluid-tissue interaction. Pulsatile, unsteady phenomena, coherent vortical structures and transitional flow or turbulence occurring at low Reynolds numbers are common to these biological flows. An overarching motivation for studying cardiovascular flow and speech is to facilitate surgical planning, i.e. to enable physicians to assess the outcomes of surgical procedures by using faithful computer simulations. Such simulations are on the horizon with the advent of increasingly more powerful high performance computing and cyberinfrastructure, but they still lack many of the necessary physical models.

Our cardiovascular flow studies are motivated by clinical evidence of arterial secondary flow structures, observed during patient diagnosis and associated with curved arteries and their pathophysiological conditions (Kilner *et al.* 1993, Sengupta *et al.*, 2008). Known as “spiral blood flow structures” in clinical terms, secondary flow structures are thought to play a protective role in preventing aortic arterial wall damage. The absence of these structures has been linked to carotid atheromatous disease, renal artery stenosis and rapid deterioration of renal function (Bulusu & Plesniak, 2013). Under physiological inflow conditions, complicated effects, such as asymmetry and spatio-temporal distributions arise. Several strategies were employed to characterize the multiplicity of secondary flow structures of various length scales in curved arteries with different strengths and morphologies. Continuous-wavelet-transform-derived vorticity fields were computed to characterize secondary flow structures quantitatively and objectively (Bulusu, Hussain & Plesniak, 2014). The richness in physics of these vortical structures and their loss in coherence during deceleration phases suggest several physiological and non-physiological implications related to the blood flow in diseased, stented and stent-fractured conditions.

Experiments were performed using multi-harmonic, physiological, carotid artery-based inflow conditions (Womersley number = 4.2). Magnetic resonance velocimetry (MRV) and PIV techniques were implemented independently, on a 180-degree curved artery test section to investigate spatio-temporal secondary flow structure morphologies.

The $\tilde{\omega}$-fields and $\lambda2$-parameter presented in Figure 1 are the result of an exhaustive pattern search for secondary flow structures and represent multi-scale vortical patterns. Phase-averaged, two-dimensional, PIV-data at the systolic peak ($t/T = 0.18$) at cross-sectional planes have been supplemented with 3D MRV-data to facilitate the characterization of large-scale, Dean-, Lyne- and Wall-type (D-L-W) vortices. The character of these large-scale structures represented in both PIV- and MRV-data is elucidated within spatio-temporal resolution limitations. The variation in strengths and scales and vorticity distributions is observed in three dimensions. Hence, generation of the complete time-varying, 3D geometry of the secondary flow structure is being explored within the MRV-data sets.

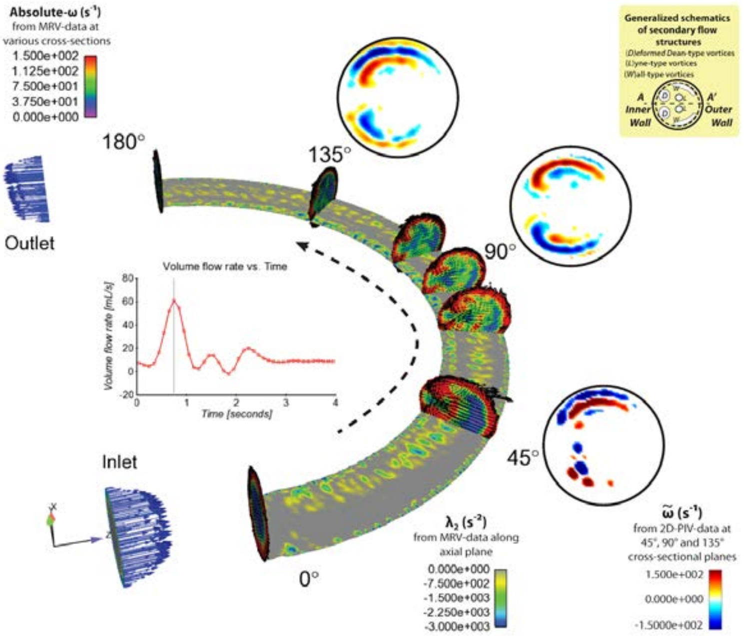

Figure 1. PIV and MRV-data Vortical structure identification ($\lambda2$) and wavelet-transformed vorticity fields ($\tilde{\omega}$).

ACKNOWLEDGEMENTS

This material is based in part upon work supported by the NSF (CBET-0828903), and GW Center for Biomimetics and Bioinspired Engineering (COBRE).

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