COMPUTATIONAL HEMODYNAMIC IN CARDIOVASCULAR SYSTEM UNDER NORMAL AND PATHOLOGICAL CONDITIONS WITH PATIENT DATA

Thesis submitted in partial fulfillment for the Award of Degree

Doctor of Philosophy

By

Sumit Kumar

SCHOOL OF BIOMEDICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI-221005
INDIA

Roll No. 17021506 **Year 2023**

Chapter 7

Conclusion and future work

Chapter 7

7.1 Conclusions

The primary contribution of this thesis is that it provides greater insight into the types of blood flow dynamics that can occur in AAA, RIIAS, CAD and LV of human cardiovascular system under normal and pathological conditions using CFD modelling approach.

The aforementioned investigations resulted in the following conclusions:

- In case of multiple arterial problems like AAA and RIIAS both in the same patient, the blood flow behavior changes in terms of volumetric flow; near the AAA, enhanced blood flow recirculation tendency leading to increased swirling and reversed flow situation. Also, across RIIAS, because of sudden geometric contraction, there is a sudden increase in the maximum velocity. However, just after stenosis, there is waviness or vorticity formation and flow separation as depicted in the streamline plot. This causes a sudden reduction in blood volume in the diseased condition of the iliac artery. This reduced amount of blood flow to the lower extremities of the human body can cause numbness of the organs in that region.
- The D/ La of AAA and D/Ls of RIIAS play an essential role in deciding the diseased portion and its failure predictions. From the cpater-2 work it was noted that by varying the dilation and contraction percentage in the same artery, it may affect the mechanical property of the wall.
- From chapter 2 work on multiply afflicted arterial diseased it is noted that the secondary periodic fluctuations with rapid oscillations in flow, pressure, stress fields

towards the late systole, especially in the compounded diseased condition, have been consistently observed and seconded by the stream traces, localized adverse pressure gradients, vorticity degeneracy and vigorous swirling in the flow field. Such features put the blood components to additional stress, which can account for the growth in occlusion or generation of multiple occlusions at susceptible new sites downstream to RIIAS or can act as a catalyst for cell leakage that favors thrombus thickening in AAA in the following periods. This is a new insight into hemodynamics under compounded disease conditions.

- From Chapter 3 work on effect of rheological models in a multiply afflicted descending human aortic network it was noted that during peak of the systole, there is significant diversity in velocity curve response in all five models, although the cross model is closer to the Newtonian model in the context of trend line and behavior.
- The localized rheology-based variations, particularly in the RIIAS region, such as spatial lag in oscillatory peak WSS manifestation and downstream post-stenotic region oscillatory WSSs, can be attributed to flow complexities such as separation, vortex formation, swirling along the vessel curvature.
- While finding the suitability of rheological models in chapter 3 it is noted that WSSs corresponding to all the four non-Newtonian models depict a single space-time oscillatory behavior during the cardiac cycle, the WSSs corresponding the Newtonian fluid depict multiple space-time oscillatory behavior in WSS. Also, the Cross Model depicts a maximum variation in hemodynamics parameter results like WSS, WPs, centerline velocity and pressure.
- From the results of chapter 4 it is noted from the impact of AAA shape effect in terms of dilation, neck angle, common iliac bifurcation angle and aneurysms type

on the prediction of aneurysm that in all four-patient specific artofemoral models AAA, velocity distributions that the effect of aneurysm dilatation alters the flow velocity distribution, which may influence the lower extremities blood circulation.

- A large neck angle can result in severe asymmetric geometries, disrupted flow patterns, and proximal wall stress concentrations as seen from the morphology study of chapter 4.
- It has been noted from bifurcation angle perspective that bifurcation angle creates the critical hemodynamic conditions necessary for common iliac artery aneurysms (CIAA) progression and eventual rupture as noted from chapter 4 work.
- From new modelling methodology as discussed in chapter 5 for CAD patient it is noted that open loop modelling approach with lumped parameter-based physiologically and geometrically realistic outflow pressures will help cardiologists to analyze medically imaged coronary arteries and compute hemodynamic parameters to assess their patients' risk of coronary arterial disease (CAD).
- From Image based modelling approach for studying the patient specific LV hemodynamics it is noted that modelling approach using automated algorithm using deep-learning approach will help in analyzing the big real time data for investigation of pathophysiology and anatomical quantification of human heart chambers like (LV). Also noted from the results of chapter 6 that understanding of LV hemodynamic and have the potential to assist in the diagnosis, treatment, and management of cardiovascular diseases like left ventricular hypertrophy (LVH) and planning for treatment like left ventricular assist device (LVAD).

In conclusion, the results of this thesis provide a framework, modelling, and simulation approach for investigating hemodynamics parameters during important instant of cardiac cycle using patient data to further the understanding of pathophysiology of cardiovascular diseases such as (AAA, RIIAS, CADs, and LV dysfunction.

7.2 Future work

The research presented in this thesis has importance for future research. The work can be advance in the following ways:

- **Personalized Medicine**: Computational hemodynamics can contribute to the advancement of personalized medicine by providing patient-specific simulations. By incorporating individual patient data, such as detailed anatomical information and physiological measurements, computational models can be tailored to a specific patient's cardiovascular system. This could enable more accurate predictions of disease progression, optimal treatment planning, and improved patient outcomes.
- **Integration of Multi-omics Data:** With the advancement of technologies like genomics, proteomics, and metabolomics, there is an opportunity to integrate these multi-omics data with computational hemodynamics. By combining patient-specific genetic and molecular information with hemodynamic simulations, researchers and clinicians can gain a deeper understanding of the underlying mechanisms of cardiovascular diseases and identify potential targets for personalized therapies.
- **Real-Time Monitoring and Intervention:** Integrating computational hemodynamics with real-time monitoring systems can provide continuous assessment of cardiovascular function. By utilizing wearable sensors, implantable devices, or non-

invasive imaging techniques, it becomes possible to gather real-time data on blood flow, pressure, and other relevant parameters. These data can then be fed into computational models to provide instant feedback on the patient's hemodynamic status and assist in decision-making for intervention strategies.

- **Artificial Intelligence and Machine Learning:** The incorporation of artificial intelligence (AI) and machine learning (ML) techniques can enhance the capabilities of computational hemodynamics. AI and ML algorithms can aid in automating the process of data analysis, model generation, and interpretation of results. These techniques can help identify patterns, predict disease outcomes, and optimize treatment strategies based on large datasets, leading to more efficient and effective patient management.

- **Virtual Clinical Trials:** Computational hemodynamics can play a significant role in reducing the need for extensive and costly clinical trials by enabling virtual simulations of medical interventions and treatments. By creating virtual patient cohort’s representative of diverse populations, researchers can evaluate the efficacy and safety of new interventions before proceeding to human trials. This approach can potentially accelerate the development and approval of new therapies and medical devices.